THE SOCIO–ECONOMIC IMPACT ASSESSMENT OF THREE DECADES OF SOLAR ELECTRIFICATION IN ZIMBABWE

M C Mapako

Energy and Development Research Centre
University of Cape Town

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DECLARATION

I, Maxwell C. Mapako declare that this dissertation is my own original work. It is being submitted in partial fulfilment of the requirements for the degree of Master of Science (Applied Science) at the University of Cape Town. It has not been submitted before for any degree or examination in any other university.

M C Mapako

Dated at U.C.T this 2nd day of SEPTEMBER 2003.

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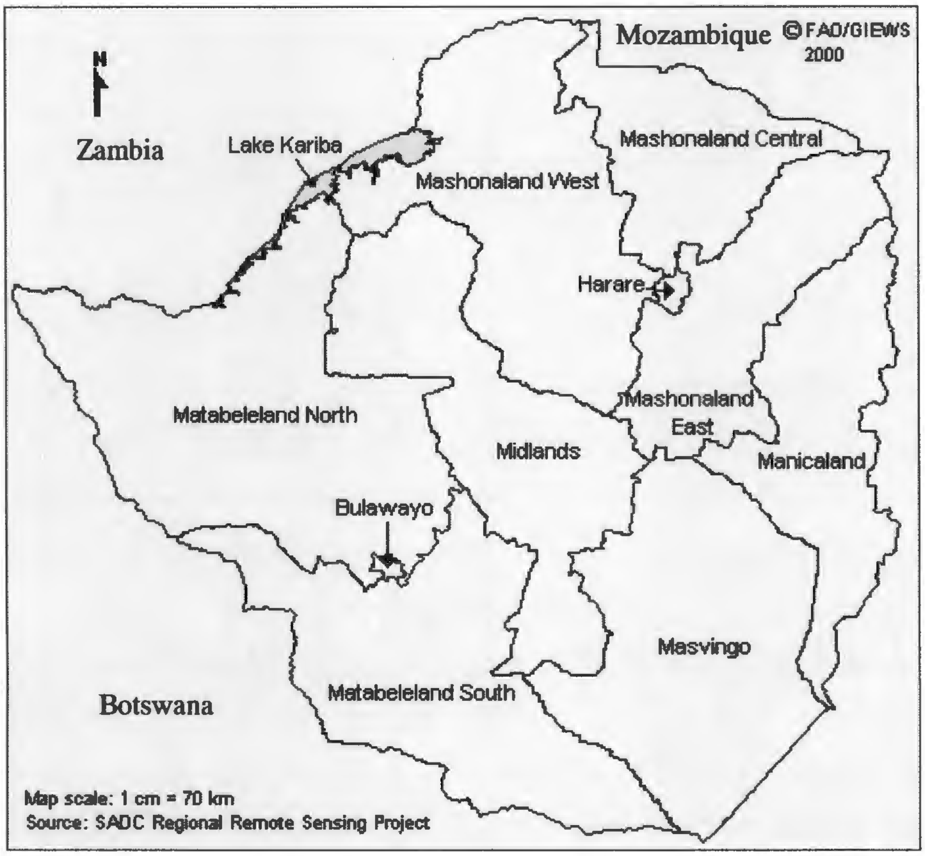
This work would not have been possible without the dedicated support of several persons. I am indebted to my supervisor, Yaw Afrane–Okese for his patience, even at times when he was extremely busy, and for wading through several drafts and offering incisive comments and encouragement.

In the early stages there was some despair because the survey work had to be postponed from the planned start in May 2002 due to election–related political tension in Zimbabwe's rural areas.

In the end, the data collection was completed in July 2002. I am indebted to Gleny Chirima for acting as the link between four enumerators in different districts of Zimbabwe and myself. The enumerators are Takura Dhliwayo, Innocent Jongororo, Johannes Mukuzunga and Hlupeki Phiri. I also wish to acknowledge the assistance of Doreen Ngwira for typing in the collected data. Because of this I was able to start analysis sooner than would have otherwise been the case.

The scholarship that enabled me to pursue this Masters degree was kindly provided by SIDA/SAREC (Sweden) through the African Energy Policy Research Network (AFREPREN). I am grateful for the opportunity provided by this generous support.

I dedicate this dissertation to my much loved four year old daughter, Manditawepi who I had to abandon for prolonged periods at a time in her life when it did not make sense where I was going, and why.



Provincial map of Zimbabwe

ABSTRACT

This study looks into the socio–economic impact solar home systems in Zimbabwe, given that they have been disseminated in various ways over the last three decades. The study first examines past solar photovoltaic projects across Zimbabwe and draws some lessons from them. It then focuses on three geographical areas with extensive solar home systems dissemination, and examines the impacts of the photovoltaic power systems compared to automotive batteries, grid electricity, and fuels used in non–electrified households. The necessary data was generated from mini surveys on households and public facilities in the three study areas. Survey findings, project reports and published literature contributed to the conclusions and recommendations.

Despite the three decades of dissemination of solar home systems in Zimbabwe, the impact remains negligible. Often, the donor–driven welfare dissemination of renewable energy technology leads to a top–down approach, marginalizing the role of the user. Privately acquired systems were often bought piecemeal or as do–it–yourself kits, a situation that led to poor component matching and poor installation.

Some solar home systems worked well and, in some cases contributed to income generation, particularly where affordable maintenance service was available. The major weaknesses of solar home systems dissemination were found to be inadequate project planning, high costs, low power, user ignorance, poor maintenance and unavailability of spares.

The study recommends that future dissemination of modern energy services should encompass several suitable alternatives and focus on income–generating activities to reduce poverty. Energy services that enhance agricultural productivity are most likely to have the most impact because agriculture was found to be the key income generating activity. Clarity of stakeholder roles should be attained early in projects, and users need to be better informed to improve their choice of components and that standardisation and labelling of components would simplify this task. Environmental impacts need to be assessed more candidly, and it is important to plan for maintenance by clustering installations and training local technicians.

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LIST OF ACRONYMS AND ABBREVIATIONS

ac	Alternating current
AFREPREN	African Energy Policy Research Network
BUN	Biomass Users Network
CIDA	Canadian International Development Agency
CPVC	Chinese Photovoltaic Cooperation Project
C$	Canadian dollar
dc	Direct current
DM	Deutsche mark (German mark)
DoE	Department of Energy of Zimbabwe
ENDA–Zimbabwe	Energy and Development Activities–Zimbabwe
ESMAP	Energy Sector Management Assistance Program
ESCO	Energy Service Company
GEF	Global Environment Facility
GTZ	German Technical Cooperation Agency
HVD	High voltage disconnect
IGA	Income–generating activity
ITDG	Intermediate Technology Development Group
JICA	Japan International Cooperation Agency
kg	kilogram
kW	kilowatt
kWh	kilowatt–hour
LPG	liquefied petroleum gas
LVD	Low voltage disconnect
MW	Megawatt
NGO	Non Governmental Organization
NRSE	New and Renewable Sources of Energy
PV	Photovoltaic
PVP	Photovoltaic pumping
R&D	Research and Development
RETA	Renewable Energy Trade Association
RETs	Renewable Energy Technologies
RIERF	Rural Institutions Electrification Revolving Fund
SEI	Stockholm Environment Institute
SEIAZ	Solar Energy Industry Association of Zimbabwe
SHS	Solar home system
SME(s)	Small to medium scale enterprise(s)

TV	Television
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organisation
US$	United States dollar
Wh	watt–hour
ZERO	Regional Environment Organization
ZESA	Zimbabwe Electricity Supply Authority
ZIMPREST	Zimbabwe Programme of Economic and Structural Transformation
ZPC	Zimbabwe Power Corporation

CHAPTER 1: INTRODUCTION TO RURAL ENERGY POLICY AND RURAL ELECTRIFICATION IN ZIMBABWE

1.1 Background on Zimbabwe

Situated in Southern Africa, Zimbabwe has an area of 390 757 square kilometres. According to the preliminary results of the 2002 census, Zimbabwe has a population of about 11.63 million persons (Central Statistical Office (CSO), 2003). The 1997 population was reported to be about 12.3 million (CSO, 1998a), which means the population has dropped by more than five percent. The latest preliminary census population figures sparked a debate in the media in early 2003, with suggestions that migration caused by the present economic difficulties, and AIDS, were to blame.

The average sex ratio in 1997 was of 93.8 males per 100 females (CSO, 1998a). The sex ratio varies considerably between the ten provinces. The average population density in 1997 was 30 persons per square kilometre, up from 27 at the time of the 1992 census. The average household size was 4.4 in 2002 (CSO, 2003).

Nearly 35 percent of the population is in urban areas because of gainful employment opportunities in industry, commerce and mining. Small and medium scale enterprises (SMEs) are pervasive, ranging from small household enterprises to cooperatives and small companies in both urban and rural areas.

Urban household electrification is relatively high, over 90% in Bulawayo, the second largest city, and over 80% in Harare, the capital city. About 5 percent of rural households are connected to the electricity grid, while small solar home systems (SHSs) and the use of car batteries are common in non–grid electrified areas. Paraffin is widely used for rural household illumination in simple wick lamps, and for cooking in some urban households. Wood is the universal cooking fuel for rural households. Crop residues are used seasonally.

1.2 Current status of rural energy in Zimbabwe

The Department of Energy in the Ministry of Energy and Power Development has overall responsibility for energy policy and planning. There is however a certain amount of fragmentation. The Ministry of Mines, Environment and Tourism is responsible for both coal (Mines department) and forests (Environment department). The rural electrification policy has been driven by the need to address the neglect of rural development during the pre–independence, minority rule era. Before independence in 1980, there was no separate ministry or department of energy. Instead, there was an *Energy Resources Advisor* in the prime minister's office in the 1970's.

The new Department of Energy (DoE) set up at independence in the Ministry of Industry and Energy was strongly technology–oriented with little provision for policy and planning as shown in Figure 1.1. In 1982 the Director of Energy had four assistant directors, each responsible for a section working on research and implementation of projects on solar, fuelwood and biogas, liquid fuels and coal respectively. There were also two under–secretaries with administrative responsibilities for parastatals dealing with liquid fuels and electricity, and liaison on coal and wood. The liaison was necessary because of the overlap with the ministries responsible for mines and for forests.

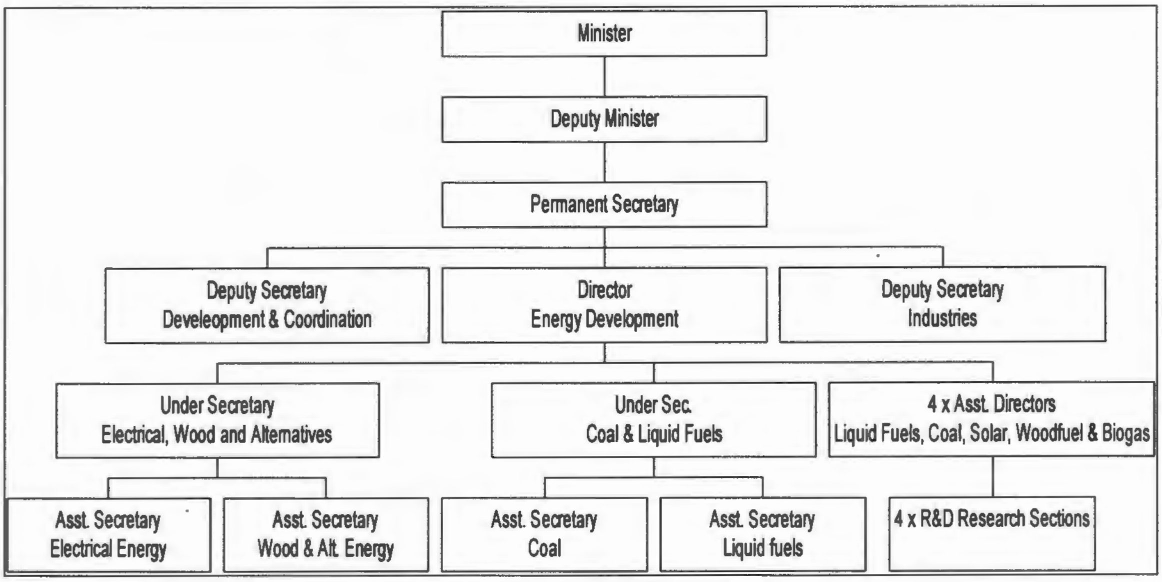

Figure 1.1 **Structure of the Department of Energy in The Ministry of Industry and Energy in 1982**

By 1997, the functions of the Department of Energy had evolved to explicitly encompass policy, planning and conservation as reflected in the structure in Figure 1.2. This structure has not changed significantly since then. The Department of Energy was upgraded to full Ministry status in late 2002, becoming the Ministry of Energy and Power Development. The new structure was not available at the time of writing of this Thesis.

The 1999 final energy supply chart for Zimbabwe in Figure 1.3 illustrates the importance of biomass in national energy supply.

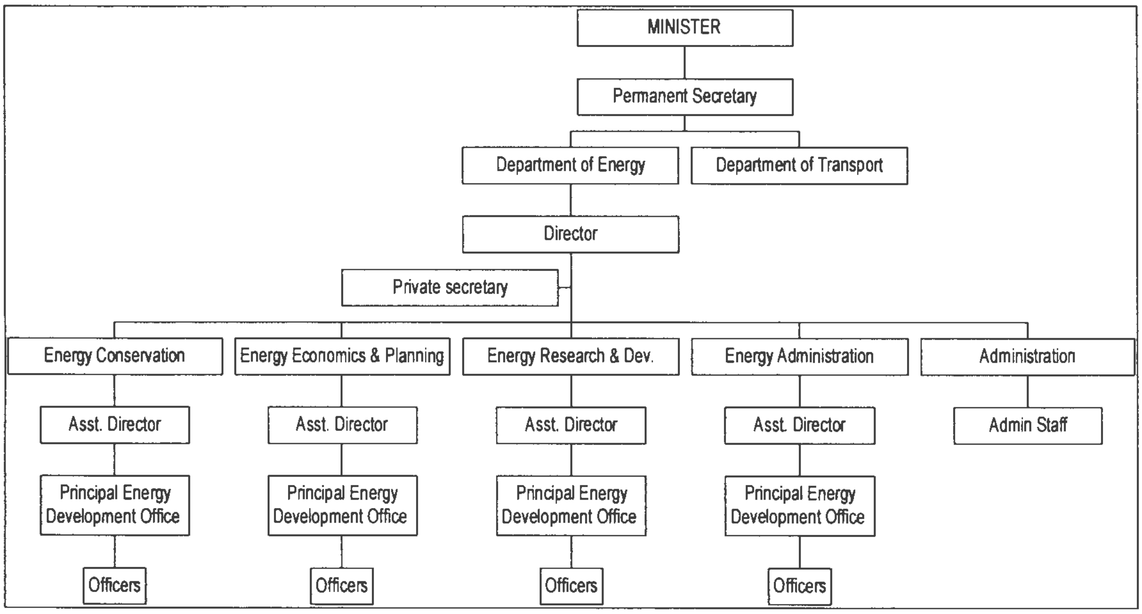

Figure 1.2 **Structure of the Department of Energy in the Ministry of Transport and Energy in 1997**

Biomass energy is especially important in the rural areas where households depend on fuelwood. The main policy objective for biomass energy in the draft National Energy Policy is to '*to achieve a sustainable level of fuelwood production and utilisation*'. Demand side management measures are advocated, in particular the development of appropriate appliances. Supply base widening through afforestation, and fuel switching strategies are also specified. A key strategy of the Energy Policy is to implement the findings of the national task force on the National Biomass Energy Strategy (NBES). The NBES task force has however not produced a definitive strategy to date, because it has not functioned continuously.

The Energy for Rural Development Strategy (DoE, 2001a) has recently been initiated to specifically address rural development needs. The strategy document is in its early draft form and still subject to internal discussion.

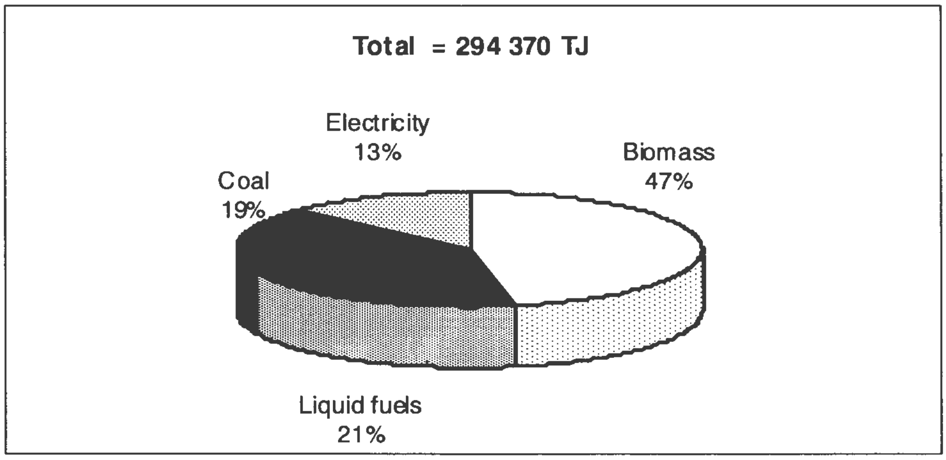

Figure1.3 Final energy supply by source for Zimbabwe, 1999
Source: DoE, 2002a

The most important element of the new strategy is to treat *rural development* as the overall goal. This will force integration with the efforts of other arms of government. This is in recognition of the poor delivery of services through the fragmented approaches of the past where DoE tended to pursue a narrow technology–led agenda in trying to address rural development needs.

1.3 Rural electrification through grid extension

Rural electrification through grid extension by the Zimbabwe Electricity Supply Authority (ZESA) in Zimbabwe has always focussed on rural service centres. Rural service centres (sometimes called *growth points* in Zimbabwe) are centres in rural areas where facilities such as clinics, police stations and retail and service businesses are congregated. The first phase of rural electrification by ZESA was up to 1984 when 23 rural service centres were electrified. By 1989 only an additional 13 rural service centres had been electrified. There was a suspension in the programme due to escalating costs and equipment shortages. It was noted that criteria for electrifying a given centre were not transparent, leading to electrification of both economically viable and unviable centres. An Electrification Masterplan Study was undertaken before the programme could resume. Upon resumption, the programme focussed on centres deemed viable according to economic and financial criteria. The rural electrification programme was financed through a 1% levy on ZESA sales revenue. In 1991 the number of centres electrified had risen to 134. The number of district and rural service centres identified for electrification between 1997 and 2010 is 415.

Clearly targeting rural entrepreneurs, a ZESA rural electrification brochure states:

> 'Electricity stimulates growth. Increase your productivity through the use of electricity in your shops, grinding mills and bottle stores. Electricity will enable you to venture into new business such as welding and manufacturing of farm implements for rural communities'.

The following schemes were put in place to enable communities help themselves to initiate grid electricity projects (Department of Energy, 2001c):

- **Rural Electrification Funds Matching Scheme** provides 50% of project funding requirements for rural communities who have identified their own projects and are able to raise the other 50% of total project costs. The loan is payable over five years at an annual interest rate of 35%. This approach has succeeded to the extent that more community–initiated projects have been completed than the Masterplan projects.
- **Rural Institutions Electrification Revolving Fund (RIERF)**, which was seeded with Z$1 million of GTZ funding. The revolving fund provides loans for wiring of rural clinics and schools, and in cases of shortfalls of connection fees that need to be paid to ZESA for grid connection. The revolving fund loan is repayable over two years at an annual interest rate of 17%.

1.4 Renewable energy initiatives in rural energy policy

There has been a mixed collection of players in the effort to disseminate Renewable Energy Technologies (RETs) in Zimbabwe's rural areas. The earliest organised efforts involving RETs were in the late 1970s when the office of the Energy Resources Advisor was established. A brief account of the growth of interest in solar energy in Zimbabwe is given in Appendix 1.4.

Initial efforts at implementing renewable energy projects included biogas, solar crop dryers, photovoltaics (PV), and vegetable oil fuel trials. Following independence in 1980 the government led the way with programmes to demonstrate improved woodstoves, biogas digesters, solar crop driers, solar PV systems, liquid fuel blend testing, and ethanol vehicles and appliances. Improved woodstoves and biogas digesters were subsequently widely disseminated through the governments own funding while solar PV systems were disseminated through donor funded projects and private sales.

A summary of selected renewable energy technologies disseminated since 1990 is shown in Table 1.

The total number of biogas digesters installed since the late 1970's is around 250. The total number of woodstoves since the late 1970's is more difficult to determine because many community builders became active after being trained, and records of their activities are not available.

It has become increasingly clear that despite the considerable efforts to disseminate renewable energy technologies, the impact is still insignificant. Most improved woodstoves and biogas digesters have been abandoned (DoE/GTZ, 1997).

Table 1 Renewable Energy Dissemination Numbers in Zimbabwe 1990–99

Category	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*Total*
Household Stoves	500	600	579	1277	1850	2051	1360	1290	1811	1965	9872
Biogas Digesters	3	28	10	9	4	4	5	3	3	3	72
SHS ESMAP Estimates	15 000 by 1993				85 000 estimated by 2000						

Source: DOE project files, and ESMAP (2000a)

The efforts continue but are unlikely to be more successful unless lessons are drawn from past failures to inform future efforts. Available information (ESMAP, 2000b) seems to point to the top–down approaches and heavy subsidies as some of the weaknesses of past initiatives. Some individual entrepreneurs have taken up renewable energy by themselves.

Evolution of solar electrification

The fact that households were not targeted in the grid extension efforts led to the implementation of solar electrification initiatives to bring electricity to remote households. Private sector sales and do–it–yourself (DIY) installations played a major role in dissemination of solar home systems (SHS). Donor–funded projects, especially the Global Environment Facility (GEF) / United Nations Development Programme (UNDP) / Government of Zimbabwe PV Solar Project[1], and the Japan International Cooperation Agency (JICA) Study on the promotion of photovoltaic rural electrification

[1] The GEF/UNDP/Government of Zimbabwe PV Solar Project will hereinafter be referred to as the *GEF Solar Project.*

in the Republic of Zimbabwe[2], have also played an important role in disseminating awareness of solar PV technology, and exploring different dissemination mechanisms. These projects are described in detail in Chapter Two.

Solar electrification is now in its third decade in Zimbabwe, having started in the late 1970's with isolated donor initiatives and individual enthusiasts. Following independence, the national electricity utility, the Zimbabwe Electricity Supply Authority (ZESA), was required by government to extend the grid to rural areas. Electrification was aimed at rural service centres, not households.

Despite the relatively strong emphasis on solar PV electrification, poor rural households have not been reached. The low power level of solar PV systems makes them unsuited for most income generating activities. The absence of maintenance infrastructure in most areas, and shortages of spares have also contributed to limiting the impact of solar PV electrification.

1.5 Objectives of the Study

From the above background information, the perceived problem under study in this Thesis is the *lack of clarity around the socio–economic impact of the three decades of solar PV electrification in Zimbabwe.* A number of projects, as well as private initiatives have led to the proliferation of solar PV systems[3]. There is therefore literature covering this activity. What is covered reasonably well in existing literature are the numerous dissemination efforts and the experiences from the implementation period and in some cases the immediate post–implementation period. What is not covered is the fate of the SHSs once projects ended and their support infrastructure was dismantled, yet this long–term understanding is crucial for the planning of future projects. Projects have not provided for follow up studies to provide this information. This situation is not peculiar to Zimbabwe. In a worldwide survey of solar PV systems, it was concluded that *not enough information was available on the performance of solar PV systems* (Niewenhout *et al*, 2000), and also that *there is as yet no sure recipe for the dissemination of solar PV systems* (ESMAP 2000b). To address this gap, this study

[2] The Japan International Cooperation Agency (JICA) Study on the Promotion of Photovoltaic Rural Electrification in the Republic of Zimbabwe will hereinafter be referred to as the *JICA Study Project.*

[3] The term '*solar PV systems*' is used in this Thesis to refer to solar PV systems *in general.* Solar PV systems at households are referred to as *solar home systems* (SHSs).

examines the impact of the three decades of dissemination of SHSs in Zimbabwe with the following objectives:

1. To document the progress made in solar electrification of households and public facilities in Zimbabwe. Lessons will be drawn from the outcomes of the different solar photovoltaic electrification dissemination modes.
2. To gain basic understanding of the socio–economic status and income–generating activities of the areas where solar home systems have been disseminated.
3. To determine the comparative impact of solar home systems on energy use, and expenditure on energy, in households. An understanding of existing energy use patterns and the preferences that the energy users have can be useful in identifying potential demand for specific energy services, and would be valuable guidance for policy.
4. To examine the overall effectiveness of solar photovoltaic systems by first comparing solar PV electrification with grid connection and paraffin, then comparing different SHS dissemination initiatives, and finally by examining user views and preferences.
5. To make recommendations to address the issues affecting existing solar photovoltaic systems, and for improving future dissemination of these systems.

1.6 Research Methodology

The research work can be divided into two parts. One was the review of literature covering the dissemination of solar PV systems in Zimbabwe, and the other was a survey to explore in greater depth the characteristics of selected areas where solar PV systems have been disseminated. Surveys were conducted in three areas of Zimbabwe. The areas were selected because they have had different projects disseminating solar PV systems, as well as private acquisition of solar PV systems. For comparison, a further three categories of households were also looked at. These are *grid electrified*, *unelectrified*, and households using only *automotive batteries* for their electricity in the selected areas.

Questionnaires were designed for each of the four categories of households. All questionnaires had a common section for background data, income generating activities and incomes, fuels used, fuel costs, and fuel preferences. Subsequent sections of the questionnaires were category–specific. The questionnaires are presented with the common background section first, followed by the category–specific sections, in Appendix 1.6.

The data analysis explored the socio–economic characteristics of the households in the three survey areas by first establishing the overall income trends and then dividing the households into three income groups, each comprising roughly the same number of households. The income groups were then analysed by geographic area, electrification category, and SHS dissemination mode. The analysis of income generating activities was preceded by a brief overview of national trends in medium and small and medium enterprises. The relevance of solar PV power was assessed on the basis of its ability to contribute to the prevalent income generating activities.

The *impact* of SHSs on household and public facilities was examined by looking at the major energy service requirements, and the energy sources used for them. The trends in the desire to switch to different energy sources gave an indication of the level of satisfaction with SHSs and other energy supply options. The energy burden on household incomes was assessed by comparing total household incomes against expenditure on energy.

The *effectiveness* of solar PV installations at private homes was assessed initially by comparing SHSs with the grid electricity and paraffin, using accessibility, service level, and environmental impacts as indicators. Different SHS dissemination modes were then compared on the basis of financial viability, maintenance provision, flexibility in service level provided, ownership and payment, battery and light replacement, subsidy requirement, design, theft risk, and impact on energy use. Finally, user views on maintenance, and their attitudes towards SHS were compared.

The analysis concludes with a summary of the main findings of chapters two, four, five, and six. Policy recommendations were formulated from these findings.

1.7 Chapter Outline and Scope

The first and second introductory chapters of the study are largely based on a literature survey, which establishes the background on solar electrification in Zimbabwe. Chapter One of the study provides background information on Zimbabwe, and its energy institutions and rural energy policy. The chapter also gives a brief overview of past renewable energy initiatives, indicating the place of solar electrification among the other options. It further outlines the objectives and structure of the Thesis.

work

Chapter Two provides an overview of the dissemination of solar photovoltaic systems in Zimbabwe, and briefly illustrates the dominant position accorded to solar PV electrification in comparison to the other rural electrification initiatives, which include small hydro schemes and grid extension. Chapter Three explains the survey methodology and sampling. It also explains how the data was analysed, and discusses data limitations and potential sources of error.

Chapter Four presents an analysis of the socio–economic status and income generating activities (IGAs) of households in the survey areas. Chapter Five provides a comparative assessment of the impact of SHSs on household energy use, level of satisfaction with current energy sources (*as indicated by the desire to switch from them to other fuels*), and expenditure on energy compared to household income. Chapter Six assesses the key issues related the effectiveness of SHSs at homes by comparing solar PV with grid and paraffin as energy sources, followed by comparison of the different photovoltaic systems dissemination modes and the views of users. Conclusions and recommendations are presented in Chapter Seven.

CHAPTER 2: PHOTOVOLTAIC ELECTRIFICATION INITIATIVES IN ZIMBABWE: OUTCOMES AND LESSONS

This chapter deals in more detail with the solar rural electrification initiatives in Zimbabwe, and demonstrates the emphasis that has been placed on solar photovoltaics. Zimbabwe has at this stage a relatively large number of installed SHSs, comparable to South Africa. This has resulted in SHSs having numerical dominance over other decentralised electrification energy options such as small hydro, wind, and grid extension. This dominance is despite the higher cost and greater technical complexity of solar PV systems. The discussion of SHSs is divided into project and non–project dissemination modes. Each of these two categories is discussed under various components of dissemination, namely ownership, financing, payment, quality control and maintenance. A brief summary of international experiences with the promotion of solar PV systems is presented to put the Zimbabwean experiences into context, before the chapter conclusions.

2.1 Non project dissemination of solar home systems

Of the total of around 85 000 SHSs in Zimbabwe (ESMAP, 2000a), the GEF Solar Project installed some 12 000 and the JICA Study 100 SHSs in two pilot *clusters* in Mashonaland West province, and over 400 in ongoing follow up activities in Matebeleland South province. The rest, about 72 000, were installed outside projects, through private sector sales on commercial terms including cash and credit. There are companies like Solarcomm and Battery World who offer special kits for DIY installation while also offering separate components. These companies are not purely solar companies; they have other business interests. Some DIY kits are sold through retail outlets like supermarkets and hardware dealers.

No project in Zimbabwe has actively promoted the dissemination of separate amorphous silicon modules[4]. These modules are however commonly found in households in many areas. They are often imported directly by the households or bought from private importers. Some batteries are also imported from neighbouring countries,

[4] The GEF Solar Project introduced a small number of solar lanterns with 12Wp amorphous modules around 1997–1998 for clients unable or unwilling to purchase the normal solar PV systems.

chiefly Botswana and South Africa. These are the countries most visited by informal traders to sell handicrafts and source goods for sale at home.

The above method of acquiring SHS components is generally gradual, with matching of components likely to be correct only by chance. Guidelines for system assembly and troubleshooting are generally not available since components are sourced individually and from informal sources that do not provide manuals, expert advice, or warranties.

2.1.1 Ownership

Ownership of SHSs acquired outside projects rests with the household. Where loans are taken out for the purchase of the solar home system, the lending agency usually retains ownership of the SHS until it is paid for, and can repossess the SHS if loan repayments are not paid as agreed.

2.1.2 Financing

The commonest financing arrangements outside projects are company schemes run by the companies selling the SHSs. These are standard hire–purchase arrangements with interest set at the prevailing commercial rate. Another common mechanism through which rural households can acquire SHSs is when a working relative in a city pays for the SHS. Often working children do this for their parents.

2.1.3 Payment

Payment for SHSs is often on a cash basis. Many rural farmers will time major purchases to coincide with the selling of agricultural produce. Formally employed buyers may opt for monthly payment of loans. Companies prefer this because stop orders can be arranged for automatic deductions from salary. Solar home system components acquired from outside the country are usually bought for cash though credit between individuals known to each other is possible.

2.1.4 Quality control

The quality of SHS components purchased as DIY kits from reputable companies is generally comparable to that of components provided in projects. A reasonable match between components can be expected. A major shortcoming in this case is likely to be sizing of the SHS for the intended load. It is left to the buyer to select the correct system size. There may also be limited choice of DIY kit sizes. The quality of installation is highly variable in this category. For DIY kits purchased in matched sets, the final product is likely to be good in most cases, since instructions are normally included with these kits. On the other hand, the gradual building up of a SHS through piecemeal acquisition of components is unlikely to result in a satisfactory system because of poor matching of components, and unavailability of instructions on how to connect and test the final installation. The owner, or local 'technicians' who may not be technically competent to do such work often do the installation. This can lead to shoddy workmanship, and improper cable sizing leading to high voltage drops for example.

2.1.5 Maintenance

The maintenance of non–project SHS installations is almost always up to the owner. It is not normal for companies selling DIY kits or individual SHS components to offer maintenance services except on an as–required basis, with the client meeting all transport, labour, and spares costs. The lack of training of owners on maintenance has led to some detrimental practices including adding of battery acid to batteries that had low electrolyte levels and needed pure water for top–up. The diagnosis of faults can easily be wrong when the user is not trained and does not possess any measuring instruments. The following example of a problem found at two public facilities described in Table 2.2 illustrates this point well:

<u>Battery running out of power after only a short period of use in the evening</u>:

Possible causes include:

- Battery coming to the end of its useful life.
- Solar module has faulty cell(s), or is partially shaded, and is not charging the battery well.
- Corroded or loose connections increasing resistance between module and battery.
- Charge/discharge controller malfunction.
- Water seepage causing short circuit across damaged wires going through a wall.

Similarly, *dim lights*, a problem reported to be common in some South African SHS projects (Hochmuth *et al*, 1999) can be a result of improper cable sizing causing voltage drops, despite the battery being healthy and fully charged. In cases such as those just cited, the owner may proceed to replace the battery or light, which are the components showing the *symptoms*. This may not solve the problems and shows that unverified reports of component faults from users, should not automatically be taken as an accurate reflection of component failure trends.

2.2 Solar PV systems dissemination through funded projects

This category encompasses government and donor–funded initiatives. Donor activity was particularly pronounced in the early 1980's, the immediate post–independence period. A number of donated solar PV systems were installed at public facilities.

2.2.1 Solar PV systems at public facilities

Table 2.1 gives information on the site, size, date and application of some *early solar PV installations at public facilities*. Some of the details on these old installations, including donor, and fate of the equipment could not be located at the time of writing. At that time, many of the components supplied were prototypes on test, particularly high power inverters, which were necessary because standard ac appliances were being used at the public facilities where the solar PV systems were installed.

Table 2.1 Early photovoltaic installations at public facilities in Zimbabwe

Site	*Date*	*Power rating*	*Application*
Chihota rural hospital	February 1983	0.264kW	Medical refrigeration
Mahusekwa rural service centre	February 1983	no data	Entertainment, lighting
Chikwaka rural clinic	May 1983	1.8kW	Medical refrigeration, lighting, sterilisation
Marymount Mission (Donated by French Government)	November 1982	no data	Medical and domestic refrigeration, lighting, water pumping, X–rays, sterilisation
Shutu, Chiweshe communal area (Donated by French Government)	June 1982	1.3kW	Water pumping

Source: DoE, 1995

Most donated systems were found to be poorly cared for. A study carried out by DoE in 1993 had the following observations and recommendations about the donated institutional solar PV systems (Mzezewa, 1995):

- Institutional systems should be designed taking cognisance of the subsequent maintenance requirements. At schools, charge controllers and batteries should be inaccessible to pupils, and other unauthorised personnel.
- Where institutions had management problems, poor maintenance of solar PV systems was also observed.

- Maintenance duties should be allocated to specific trained individuals, who can be held accountable.
- Small installations in institutions work better than large ones.
- System sizing was not being done properly. In some instances, lighting systems were undersized for the requirements, resulting in poorly lit classrooms.
- DC power available for science experiments was not being used despite its value to pupils.
- System maintenance in clinics was generally better than schools, but the major reason for this was the maintenance back up provided to clinics.

In some cases the solar PV installations at public facilities became redundant when the grid reached the areas and the public facilities got grid–electrified. This is known to have happened a few years after the installation of the solar PV system at Chikwaka rural clinic for example.

Installations by JICA at clinics and schools

In 1998 BUN visited 11 of the 12 public facilities that had been PV–electrified through the JICA Study project. The purpose of the visit was to check on the status of the PV systems *within one year of installation,* and to explore the possibility of the public facilities raising funds to allow maintenance cover to be extended to them. Table 2.2 summarises the public facilities visited. It would have been instructive to revisit the same institutions at the time of the Thesis surveys, but the long distances between the survey areas and the scattered public facilities could not be covered within the limited survey budget.

From the descriptions of the problems that had been experienced by the public facilities at the time, it is clear that four (*shaded in table 2.2*) of the 11 PV systems had developed problems serious enough to warrant the attention of a qualified maintenance technician. These four PV systems were practically providing no service to the public facilities where they were installed. In one case the battery had been changed within a year of installation. Another three PV systems had minor problems that could be repaired without expert help (shown in *grey text in Table 2.2*). Four PV systems had not given trouble at the time of the visit. Though forbidden by the project, charging of non–system batteries was discovered in three of the 11 systems (*italicised in Comments column in table 2.2*) during earlier unannounced visits.

Table 2.2 Summary of public facilities with PV systems checked by BUN in 1998

Name	Date	Owner & Staff No.	System Size	Problems Experienced to Date	Comments
Kadoma District					
Benhura Secondary **School.** Kadoma district	05/11/98	Private 16 Staff	4 x 83Wp modules 33 lights	Light blew. 1 switch rectified by JICA Team. Lockable battery boxes needed.	School committee prepared to pay up to Z$6000 for service fee next year.
St Charles Secondary **School**. Kadoma district	15/5/98	Council ? staff	4 x 83Wp modules 24 lights	2 of 4 batteries working. All controllers dead. 1 battery missing	Battery boxes broken.
Jondale Bumbe Clinic. Kadoma district	05/11/98	Government 3 Staff	2 x 83Wp modules 17 lights	Lights go out soon after sunset. Candle used in emergencies. Lockable battery boxes needed.	Replaced 9W tubes with 11W to improve lighting levels.
Turf Clinic. Kadoma district	05/12/98	Council 4 Staff	2 x 83Wp modules 14 lights	None. Lockable battery boxes needed.	Field technician once *found foreign battery being charged.*
Nyabango Clinic. Kadoma district	15/5/98	Government 3 Staff	2 x 83Wp modules 12 lights	One light fixture not working.	Very well maintained system
Nyamatani Clinic. Kadoma district	16/5/98	Council 4 Staff	2 x 83Wp modules 17 lights	None	Panel dusty.
Gokwe District					
Gawa Clinic. Gokwe district	13/5/98	Council 5 Staff	2 x 83Wp modules 11 lights	Lights last <15 minutes. Problem began after battery change. Lockable battery boxes needed.	Installing company (Jotpav) reported finding *foreign battery being charged on system.*
Chitave Clinic. Gokwe district	13/5/98	Council 3 Staff	2 x 83Wp modules 9 lights	None. Lockable battery boxes needed.	Alarms fitted to two systems.
Msita Clinic. Gokwe district	14/5/98	Council 3 Staff	1 Module 7 lights	None	Panel very dusty. *Batteries connected together in series in delivery block*
Chemahororo Clinic. Gokwe district	14/5/98	Council 4 Staff	2 x 83Wp modules 21 lights	Unable to use lights since battery change by installing company on 14/01/98. 1switch faulty.	
Tongwe Clinic. Gokwe district	15/5/98	Council 10 Staff	3 x 83Wp modules 18 lights	1 double switch dead, 1 socket broken.	*At 07.25hrs TV was on.* Battery post next to Police post used for charging other batteries

Source: Compiled from BUN ESCO Project files

The misuse of the PV systems by charging foreign batteries included two systems that did not yet have serious problems. These systems are likely to experience problems before long because their batteries are probably not always getting full charge.

St Charles secondary school was visited again in the Thesis surveys. This school PV system was installed in August 1997, and was in serious disrepair by the time of the first round of visits in May 1998, only 9 months after installation.

With the exception of the one privately owned school (Benhura secondary school) it was not possible for the public facilities to undertake to set aside budgets for maintenance. This was because the schools and clinics are owned by either the government, or the local district councils. The public facilities' budgets are decided at their respective head offices. The Ministry of Education, and the Kadoma and Gokwe Rural District Councils all declined to promise to allocate solar PV maintenance budgets. This was because they had not been formally approached with the plans to install solar PV systems at the various public facilities under them, and had never planned for the added financial obligations. The result is that all these public facilities do not have maintenance support.

Project–installed solar home systems

The best–known solar PV project undertaken in Zimbabwe to date is the **GEF Solar Project**, which was implemented between 1993 and early1999. The majority of solar PV systems in Zimbabwe were in fact installed outside this project (ESMAP, 2000a). The number of systems installed by the GEF Solar Project may vary depending on how the systems are counted. The GEF project was using the *45Wp equivalent system* as the unit for counting installed systems. On this basis the number of equivalent systems was put at 12 000. This does not directly translate to number of physical installations since, for example, a single 90Wp installation would be counted as two *equivalent systems*.

The JICA Study Project installed one hundred physical systems between 1997 and 1998. In 1998 the Chinese government donated 110 home systems and a water pumping system to the government of Zimbabwe. All the Chinese–donated systems were installed around Nzvimbo rural service centre, in Mazowe district. A summary of the major features of the different project installations is given in Table 2.3.

A survey of 183 SHSs, conducted jointly at the end of 2002 by JICA, Biomass Users Network (BUN) and DoE covering all SHSs delivery modes in six districts of Zimbabwe had the following major findings:

- Significant company activity has continued after the end of the GEF solar project because some companies survived.
- Sixteen percent of all systems were completely dead.
- Fifty one percent of all systems had experienced technical faults.
- The major problem components according to users were the battery (33%), followed by lights (23%) and charge/discharge controllers (12%).

Table 2.3 Summary of the major features of different solar PV dissemination methods

Parameter	*GEF Solar Project*	*JICA Study*	*Chinese donation*	*Private/DIY*
Duration	1993–1999	1997–ongoing	1998–1999	No official start or end
Typical system configuration	Module, controller, automotive or deep cycle battery. Wiring in conduit.	Module, controller, deep cycle battery. Wiring in conduit.	Module, controller, deep cycle battery. Wiring in conduit.	Module, automotive battery. Some wiring in conduit.
Module size (Wp)	25Wp to 83Wp	25Wp and 56Wp	70Wp	5Wp to 83Wp
Battery size (Ah)	40Ah to 110Ah	60Ah and 110Ah	105Ah	7Ah to 100Ah
Battery type	Initially mostly automotive, later deep cycle	Deep cycle	Deep cycle	Predominantly automotive
Light wattage	7W, 9W	7W, 9W and 11W	No data	7W, 9W
Incandescent bulbs used	Some systems	Not used	Not used	Common
Power socket	Present	Present, optional	Present	Not common
Payment scheme	Cash or terms	Service fee only	Free	Cash or terms
TV/Radio load	Often both	Often both	Often both	Radio alone more common

Source: Compiled from Thesis survey and Biomass Users Network/JICA/DoE (2003).

The operational status of systems is summarised in Table 2.4. The high level of system functionality among the JICA systems was attributed to the higher level of technical support availed to owners in this group.

Table 2.4 Operational status of systems covered in the BUN/JICA/DoE Survey

Parameter	*GEF Solar Project*	*JICA Study*	*Chinese donation*[5]	*Private/DIY*
Present system status	63% of systems not fully operational	Most systems working well	Most systems working well	80% of systems partly operational. Wiring poor.
Component failure trends	48% battery 18% lights 12% controller	43% lights 14% battery 10% battery	All charge controllers and some batteries replaced	50% battery 25% lights 10% controller
Major failures	Mostly battery failures	Mostly light failures	Charge controllers and batteries	Mostly battery failures
User satisfaction level	Fair. Complaints against some companies	Generally satisfied	Generally satisfied *(repairs have been under warranty)*	Generally dissatisfied

Source: Based on BUN/JICA/DoE (2003) and Thesis survey (for Chinese donated systems).

The highest failure of non–battery components, coupled with low battery failure, was found in the JICA project clusters, while the highest battery failures were in the GEF

[5] The Chinese donated SHSs had an initial design fault in having undersized 5amp charge/discharge controllers. These were all replaced with 10amp units by the project, along with batteries that had been affected.

and DIY systems (48% and 50% respectively). This pattern was explained by the general lack of charge/discharge controllers, especially among the DIY systems, and poor system condition.

Because the JICA systems are generally in good working condition, and in constant use, the higher fault rate among the lights is understandable; these components face heavier usage in operational systems.

It was also noted that the use of incandescent flashlight and automotive bulbs among DIY systems was significant. These are cheaper, and readily available, and are far simpler than the fluorescent solar lights, which have electronic ballasts. Failure of the incandescent bulbs is of less concern to the owners, because of the relatively insignificant replacement cost and ready availability.

2.2.2 GEF Solar Project

The GEF Solar Project was disseminated countrywide. Figure 2.1 summarises the overall GEF Solar Project approach. The structure of the GEF Solar Project clearly shows the limited emphasis on maintenance when compared to the JICA Study Project Energy Service Company (ESCO) approach, described in sub–section 2.2.2. The project did not impose a specific size of system on customers. The range of solar module sizes available in the project was 25Wp to 83Wp.

The three delivery modes used by the GEF Solar Project were:

- Through the national electricity utility, the Zimbabwe Electricity Supply Authority (ZESA), which was allocated a quota of 500 equivalent systems.
- Non–governmental organisations (NGOs), allocated a total quota of 600 equivalent systems.
- Private companies registered with the project, whose allocation was not fixed, but had to be at least 7 900 equivalent systems in order to meet the project installation objective.

None of the above delivery modes was confined to a specific geographical area, because there was no deliberate attempt at clustering of installations in the GEF Solar Project.

Two key indicators of the GEF Solar Project success were number of equivalent systems installed, about 12 000, and the number of new companies formed, around 50 by 1997 according to the GEF Solar Project Annual Report for 1997 (GEF PMU, 1998). The number of *physical* SHSs installed by the GEF Solar Project has been estimated in this Thesis to be about 6600, and up to 800 public facilities, giving an overall total of up to 7 400. The details of how these figures were estimated are provided in Appendix 2.2.1.

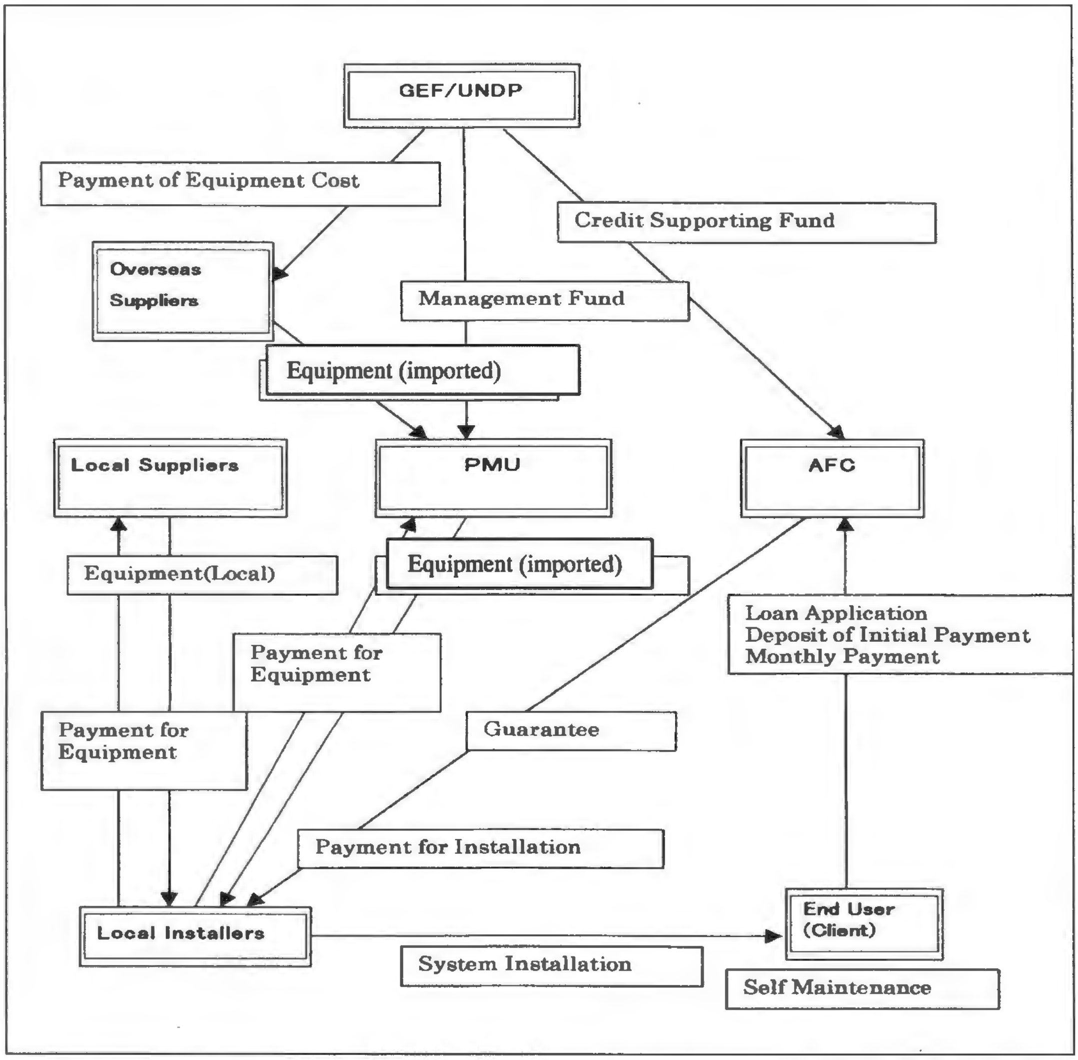

Figure 2.1 Schematic diagram of the structure of the commercial mode of the GEF Solar Project
Source: JICA 1999

By 1998, the number of companies active in the solar PV industry was estimated at 73 (ESMAP 2000a), an increase of almost 50% over the 1977 figure. These companies were not set up by the project. They were independently registered and then applied to the Project Management Unit to qualify to participate in the project. When the project formally ended in February 1999, most of the companies that had been formed collapsed (SEIAZ, 2001b) leaving many of their clients without maintenance backup. This situation is potentially damaging to the image of SHSs in the eyes of the public. In addition, the impact of one of the project outputs, the setting up of more solar companies, seems to be largely negated by this development.

The major reason for the collapse of the solar companies was that their revenues were principally from the installation of systems (Ndlovu, 1998), and in a few cases, fabrication of balance of system components. Besides an obligation to provide warranty service for one year on their installations, and to visit each installation at least three times in the first two years following installation, solar companies were not obliged under the project to provide further maintenance services. Indeed the way the project was run provided a strong incentive for companies to install as many systems as possible to maximise earnings. Since clients owed nothing to the companies after installation, there was no incentive for client care after sales were concluded.

The project provided customers with solar systems, the majority in the range of 40Wp to 60Wp capacity. These were normally used to power typically four to five lights, a radio and small monochrome television. The annual equivalent system installation figures for the GEF Solar Project are given in Table 2.5. It will be noted that the figures reported by GEF PMU and SEIAZ in some cases differ. The more recent SEIAZ figures are likely to be more reliable because there has been time to verify figures between the PMU and participating companies.

Table 2.5 GEF Solar project installation progress and average system cost to client

Year	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	***Total***
Equivalent systems (SEIAZ figures)	8	624	1 075	2 565	5 828	1 144	533	**11 777**
Equivalent systems (GEF PMU figures)	8	799	1 704	2 765	3 266			
Cost of equivalent system to end user (Z$)	9 033	10 244	11 026	13 137	14 236			
Cost per Wp (Z$)	200	228	245	292	316			

Source: SEIAZ (2001b) and GEF PMU (1998)

For 1997, the GEF PMU figures were only for part of the year since the report from which the figures were taken was written in mid–project.

Another project output was the development of standards in collaboration with the Standards Association of Zimbabwe (SAZ). Three standards documents were developed, covering design and installation, charge controllers, and batteries and lights.

Rationale

The GEF Solar Project in Zimbabwe was intended to address the issue of global warming and greenhouse gas emission by providing a sustainable model of solar electricity dissemination in Zimbabwe's rural areas in order to supplement grid electricity extension where it is not economically possible (GEF PMU, 1998). The main thrust was therefore not so much rural development as it was environmental.

Ownership

The GEF SHSs were bought for cash or under a loan scheme administered by the Agricultural Finance Corporation (AFC, now called Agribank), a parastatal agricultural bank. Those systems bought for cash immediately became the property of the purchasers while SHSs purchased under credit remained the property of the Agribank until the loan was paid off in the two to three years allowed by the project.

Financing

Zimbabwe was awarded a US$7 million solar PV project, which was intended to install more than 9 000 45Wp equivalent SHSs. The purpose was mainly to establish a revolving fund to be administered by the Agribank. Intended beneficiaries were rural households, small rural businesses, community establishments (churches, schools, clinics, cooperatives, district councils etc) and commercial farms (workers housing units). Five thousand one hundred and fifty solar system loans with a total value of Z$52.85million were disbursed by the Agribank by February 1999 (SEIAZ, 2001a). This is roughly US$4.5 million at 1997 exchange rates, the period around which most of the solar PV systems were installed.

It is clear that the number of household equivalent systems was roughly equal to the number of institutional equivalent systems (schools and clinics) in 1997 as shown in Figure 2.2. The number of *physical* installations is much less for public facilities because each institutional solar system, which could be 250Wp for a school, was much bigger than the average SHS of 40Wp to 60Wp.

Figure 2.3 provides the key steps in the process by which customers obtained their loans and solar systems, and the sequencing of payments in the main commercial delivery mode of the GEF Solar Project.

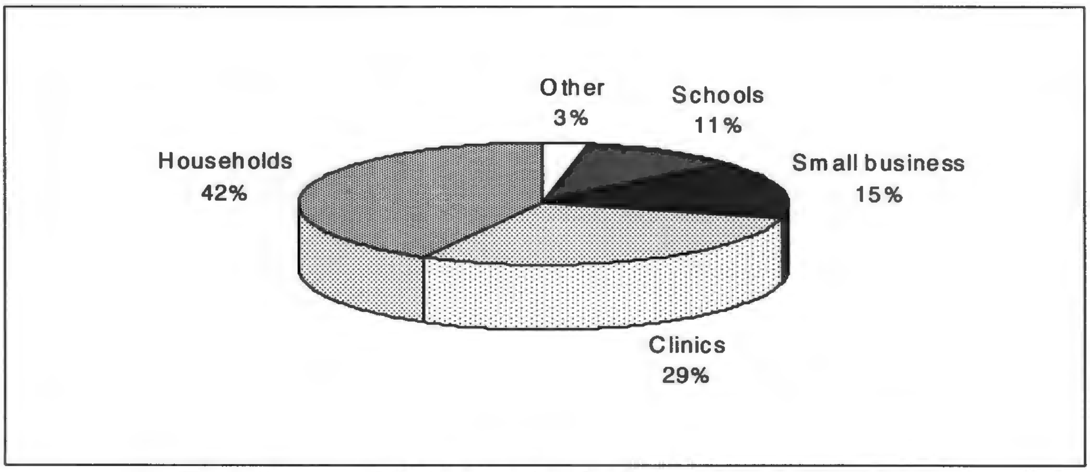

Figure 2.2 GEF Solar Project installation breakdown, 1997

Source: GEF PMU, 1998

Payment

The format of the BUN client quotation form, which shows both component costs and assumed charge utilisation is given in Appendix 2.2.1a. This form is similar to those used throughout the GEF Solar Project.

The full list of GEF Solar Project clients has not been published. The client list for one of the participating NGO's, BUN is available, and shows at the start of the year 2003, of the Z$2.25 million cost of installed systems, Z$1.82 million had been repaid (BUN, 2003a). This represents about 81% payback. Project loans were for two to three years, and the newest installations on the list were at the end of 1998, two months before the end of the project. These clients would be paying back up to the end of 2001, depending on the loan option they took. Reasons for some clients not fully paying back include death, and cases where clients could not be traced after they moved.

If a client had a problem with their systems and decided to withhold repayments in order to enforce maintenance support, the Agribank would enforce collection of the due amount. This is because Agribank was not part of the guarantee arrangement whereby the installing company was required to provide a one–year guarantee on the installation, and visit the installation three times in the first two years. This situation forced clients to pay off loans regardless of how badly their SHSs were performing, or when installing companies ignored requests for maintenance support under guarantee.

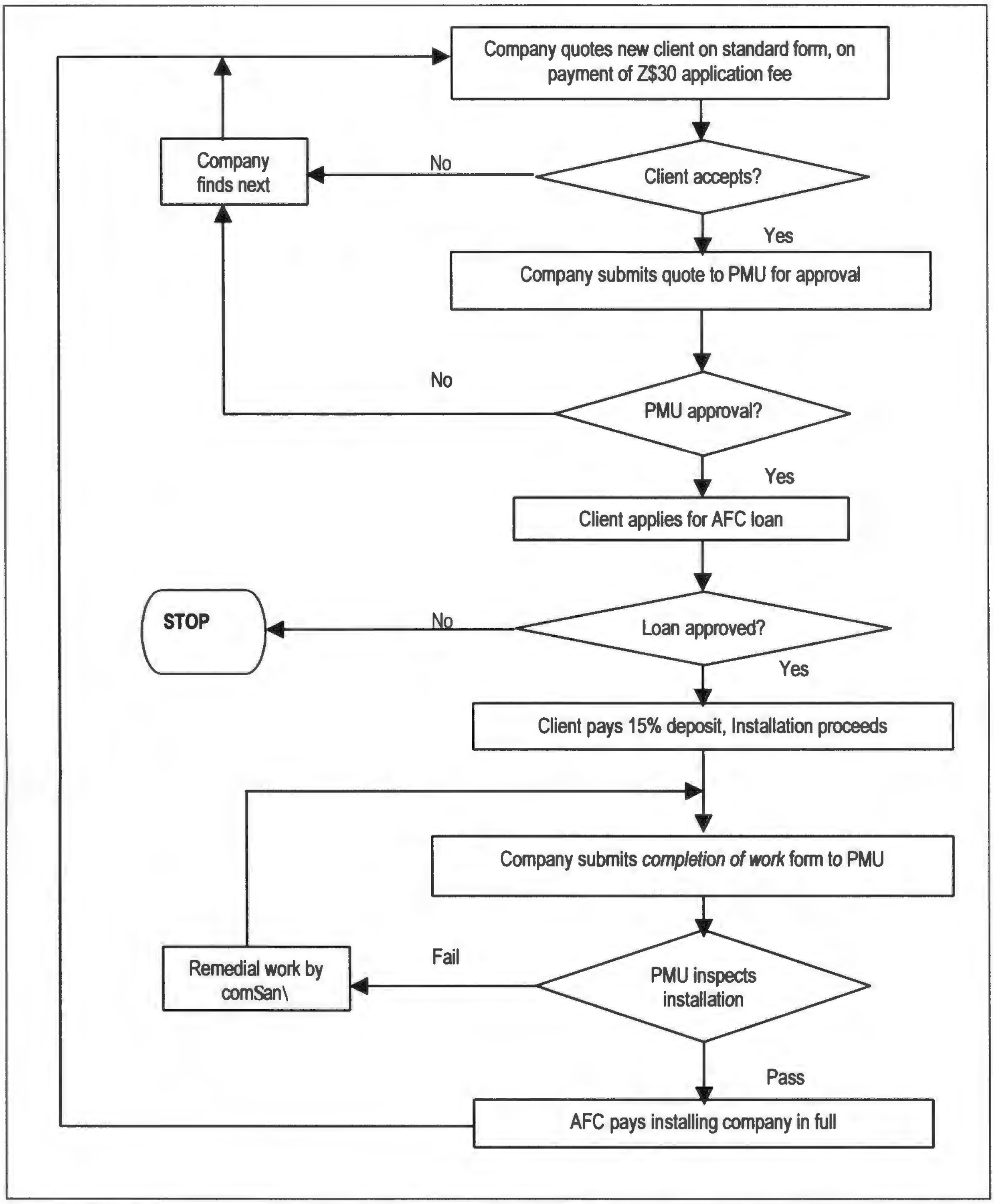

Figure 2.3 Flowchart showing the GEF Solar Project process from initial application to final payment to installing company by AFC

The NGO delivery mode was different in that the Agribank was not part of the loan arrangement. The loan was advanced by the NGO, which was also responsible for maintenance. In this arrangement clients had effective means of demanding maintenance by withholding instalments when their SHSs were faulty and maintenance support was not forthcoming.

Each client paid a non–refundable application fee of Z$30 (US$2.50 in 1997) to cover administrative costs associated with handling the application by the company. Concessions were in the form of government duty and surtax waiver on imported components, and a low interest rate of 15% per annum on Agribank loans (compared to about 23% prime rate at the time) for clients purchasing systems under the project.

All these special provision to reduce cost of solar PV systems fell away at the end of the project. Since the project was intended to establish a sustainable model for solar PV dissemination, it is difficult to see how the post–project situation could benefit when full duty was re–imposed, and no concessionary lending was available.

Quality control

Quality control was exercised at several stages. The qualification of companies to participate in the GEF Solar Project was an initial step to regulate the quality of the participating companies. After installation, the PMU inspected the work. The Agribank paid the installing company only after a positive inspection report. With the growing rate of installations, the PMU adopted a sample inspection regime in order to cope. This meant that installing companies got paid for all installations based on some samples. The companies could afford to take chances once they knew that inspections were only on a sample basis, and that the PMU was short staffed, a problem pointed out as early as 1994 (Mwandosya *et al*, 1994).

The development of standards was an important step in ensuring quality of both components and standard of work. One of the key functions of SEIAZ, the solar industry association, was to encourage high standards of service delivery by member companies, and to provide aggrieved clients with assistance in cases where a member company was unable to resolve a problem, for example due to liquidation.

The PMU convened technical review meetings with all stakeholders twice a year to review progress, to attend to problems and to plan future activities.

Maintenance

The key provision for maintenance in the GEF Solar Project was the requirement that all installing companies provide a one–year warranty on their installations. Beyond that, companies had no other binding obligations towards their clients. Even with the warranty requirement, only 20% of faults were attended to within one month of being reported. The majority of faults, 50%, were attended to *after one to three months* of being reported (GEF PMU, 1998). Another 20% of faults were attended to between three to six months after being reported, and the remaining ten percent over six months after faults were reported.

Automotive and deep cycle batteries left in a discharged state for months would lose much of their capacity, or become useless through self–discharge and subsequent sulphation, yet 80% of all fault reports were attended to after one month. Findings on component faults when maintenance did arrive could distort analysis of systems faults by showing a disproportionately large number of battery failures when, at the time many faults were reported, the batteries may have been healthy, and perhaps loose connections were to blame. A major cause of this unsatisfactory maintenance situation was the system adopted for paying installing companies, which encouraged them to prioritise identifying new clients and installing as many SHSs as possible to maximise their profits. There were no effective penalties for not attending to faults after the companies had been paid in full for installation work. At the time, this emphasis on installations assisted in the realisation of the key project goal of installing the nine thousand 45Wp equivalent systems.

Facilitators

NGOs participating in the GEF Solar Project identified local agents, called ***facilitators*** from areas where SHSs were being disseminated in significant clusters. The facilitators were trained by the GEF PMU and worked together with the NGOs, but were *not contracted* to the NGOs. The details of the facilitator/NGO relationship described here are specific to the Biomass Users Network (BUN), one of the participating NGOs. The initial role of the facilitators was to give out marketing literature and answer queries from potential and existing clients. The facilitators were also trained to maintain and repair SHSs, and they collected loan repayments on behalf of the NGOs from those clients who did not have easy access to banks. The facilitators joined NGO technicians in local SHS installation work in order to reinforce their technical understanding of the SHSs which they would subsequently have to service. This involvement in installation work was considered part of training; therefore no remuneration was paid to the facilitators. To streamline repairs of components, facilitators bring faulty components to BUN. BUN arranges, verifies and pays for repairs, and the facilitators collect the repaired components from BUN. Clients pay the repair costs to the facilitator for banking into the BUN account, thereby reimbursing BUN the amounts paid for repairs.

The facilitator approach has the following advantages:

- There are minimal administrative overheads on the installing company or NGO, because the facilitator is not on contract.
- Clients do not to pay a regular maintenance fee, which they may feel is not necessary if their systems are not failing. Payment is only necessary when the client calls the technician.
- The problem of system ownership does not arise since the clients own their systems.

The disadvantages of the *facilitator* approach are:

- Quality control is more difficult to ensure since facilitator is freelance.
- A good relationship is necessary between the facilitator and NGO to ensure backup support such as that provided by BUN (*facilitation of repairs and spares acquisition*). If this relationship breaks down, the approach will become less effective.
- Facilitators need to have diverse income sources because calls for assistance may be erratic; the amount of work, and therefore income, partly depends on the number of clients in the facilitators operating area.

The facilitators earned income in two ways; by getting a *commission* from the NGOs on instalments collected and banked, and from *client payments for repair work* on SHSs in their areas. Since there was no competition for the facilitators' services, BUN negotiated a schedule of charges with its facilitators to avoid profiteering.

The future of the GEF Solar Project

There is a balance of about Z$50million in the project revolving fund held by the Agribank. DoE is planning to implement a successor project to the GEF Solar Project (DoE, 2001b). This will focus on the rehabilitation of faulty GEF Solar Project SHSs. A decentralised approach where rural district councils will have powers to licence technicians to carry out the rehabilitation is envisaged. Details of the proposed approach are still under development. The plan to focus on rehabilitation indicates awareness that performance of the installed SHSs is not satisfactory at Ministry level.

2.2.3 JICA Study Project

The JICA Study Project is a bilateral project between the governments of Japan and Zimbabwe, housed in the Department of Energy (DoE) in Zimbabwe. The project began with a study phase that was intended to test the proposed approach, based on the *Energy*

Service Company (ESCO) concept as an input into the Electrification Masterplan for Zimbabwe. In this concept, an ESCO installs and maintains the SHSs for a service fee paid regularly by the client. This approach is similar to the *facilitator* approach used in the GEF Solar Project described in sub–section 2.2.1 in that both approaches require *clustering of SHS installations*, and build maintenance capacity within the SHS cluster. The following advantages are common to both the *ESCO* and *facilitator* approaches:

- Easier collection of payments from clients through the technician or facilitator.
- More reliable fault identification and repair by the trained facilitator or technician.
- Higher probability of local shops stocking solar SHS spares for the *clustered* local market.
- SHS user group meetings for training and consultation are easier to convene in cluster areas. This makes it easier to integrate community participation in project activities. Sensitive issues like disconnections for non–payment or abuse of project equipment are best handled with community participation to minimise damage to relations between projects and the communities in which they are active.
- The major disadvantage of the clustering requirement is that it can be slow to establish because the ability and willingness of clients to acquire SHSs at any one time will vary in any settlement. The slow build–up of clients prolonged the start–up of the JICA Study Project and also forced acceptance of clients from further than would have been considered ideal for easiest access. Installation started in mid 1997 and continued well into 1998. Figure 2.4 illustrates the overall structure of the JICA Study Project. Unlike the GEF Solar Project, maintenance is one of the key components of the project. The end user is able to effectively demand service backup from the ESCO by being able to withhold service fee payments.

By limiting ESCO replacement liability to the major components, that is the module, battery and charge/discharge controller, the ESCO strategy adopted in Zimbabwe reduces the costs of ESCO support. This leaves the user responsible for replacement costs of all smaller components. For this arrangement to work, users must have local access to the required spares, at affordable cost.

After extensive consultation with stakeholders, two clusters of 50 households each were selected at ***Sanyati and Turf***, in Kadoma District, Mashonaland West province, for the study (see map on page iv and Figure 3.1). Turf and Sanyati are about 160km apart by road. Three local companies, ***Munyati Solar, Enercare, and Jotpav*** were hired by the JICA project team to install the systems.

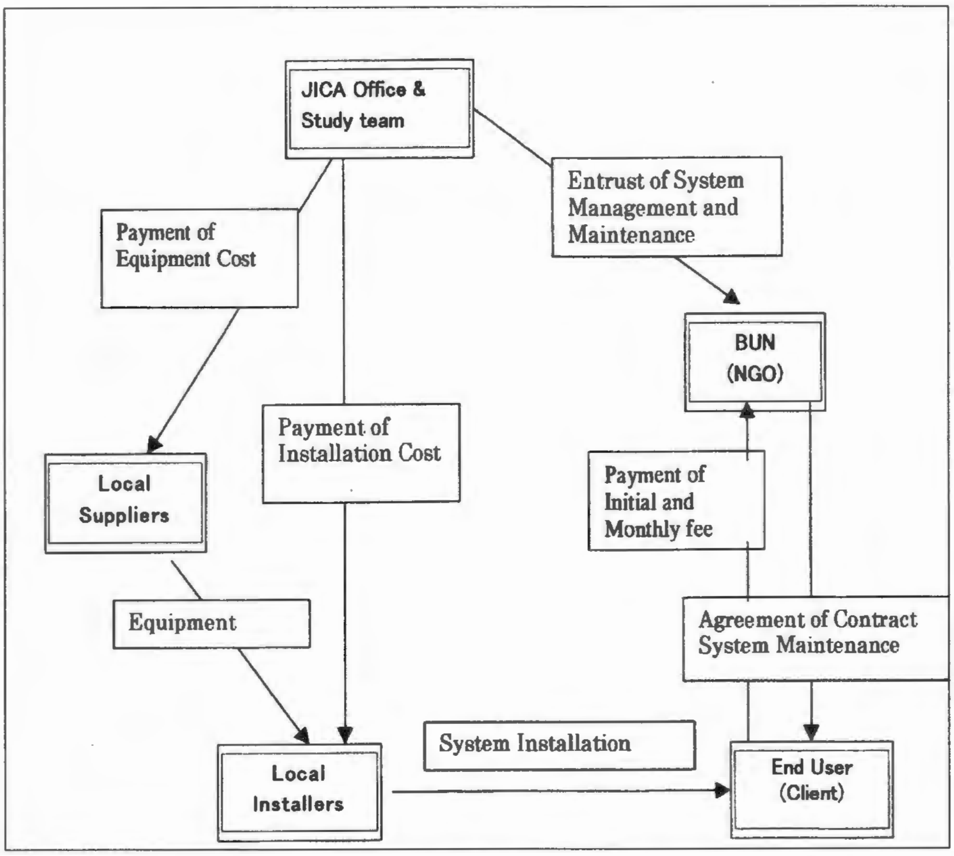

Figure 2.4 Schematic diagram of the overall structure of the JICA Study Project.
Source: JICA, 1999

A total of 101 SHSs were eventually installed, 51 in Turf and 50 in Sanyati. The Turf systems were not covered in the surveys for this study.

Ten rural clinics and two rural schools were also electrified with solar PV systems. Of these 12 institutional installations, two clinics and one school are in Mhondoro–Ngezi district, three clinics and one school are around Sanyati in Kadoma district, and five clinics are in Gokwe South district.

Following the installation of the systems, a local NGO, the Biomass Users Network (BUN) was contracted to act as the energy service company (ESCO) and maintain the SHSs. This maintenance arrangement excluded the installations at schools and clinics.

Ninety–nine of the 101 clients in this project are households. There are two general dealer shops where the solar systems are used for extending opening hours. The benefits of having solar PV power in these cases are better light and power for radios and televisions to entertain clients. The sizes of the installations at the general dealer shops were the same standard size as the household installations.

System size

All SHSs installed initially consisted of a 25Wp module, and either two lights, or one light and one power point, intended for a radio. This size limit was a project condition, which could not be negotiated by households intending to participate. The small size was meant to keep costs down, to ensure that poorer households would not be left out. A contradiction arose in that the JICA Study Project sought to install systems in an area with identifiable sources of income (i.e. not a poor area) and yet sought to unilaterally limit the systems on offer to one very small size, equal to the smallest module size offered in the GEF Solar Project. By this time it was already known from the GEF Solar Project experiences that the most popular range of modules was the 40Wp to 60Wp range (GEF PMU, 1998).

Clients raised bitter complaints over the inadequacy of the small systems during public meetings that the JICA Study Project held with clients. The project was forced to relent, and introduced a 56Wp expansion option with increased maintenance fees. By December 1998, 34 of the 101 x 25Wp systems had been expanded to 56Wp modules. A year later, about half of all the clients had opted for expanded systems. The situation in 1999 is shown in Table 2.6. The list of clients shows that more households had radio cassettes and televisions, than had plain radios. These larger loads further justify larger SHSs.

Table 2.6 Expansion status and appliance ownership among JICA Study Project clients in 1999.

Parameter	*Turf cluster*	*Sanyati cluster*
Unexpanded. still 25Wp	24	31
Expanded to 56Wp	27	20
Have radio without cassette deck	11	15
Have radio with cassette deck	32	31
Have TV	30	27
Have both radio and TV	6	5
Have both radio cassette and TV	22	21

Source: Compiled from BUN project files

Ownership

The ESCO acts as the owner of the solar PV equipment during the project. In practice, the client is responsible for the minor components including lights and tubes, wires, switches, battery box, and fuses. After the end of the project, all equipment will become the property of DoE because it was provided under a bilateral agreement between the governments of Zimbabwe and Japan. Clients can gain ownership of the equipment installed at their households by paying off agreed amounts through the ESCO under terms still to be defined by DoE. This provision for eventual ownership of the SHSs led to persistent questions about ownership conditions, and to the maintenance fees being sometimes seen as instalments towards purchase of the SHSs.

It was envisaged that during full–scale implementation ZESA would procure all necessary equipment in bulk and install it in clusters, and provide maintenance as the ESCO. In this case, the equipment would never become the property of the client. As indicated in later in this section, full–scale implementation is unlikely to occur.

Financing

JICA provided the hardware for the ESCO study project and paid the local installation companies. The study was therefore not intended to simulate a commercial trial, but rather to identify operational problems during execution. The cost of maintaining the installed systems was met from fees paid to the ESCO by the clients. By providing the hardware free to DoE for the ESCO study, the project does not convincingly simulate commercial ESCO dissemination. The lack of a more realistic pilot trial may be one reason why ZESA has so far declined to become the first ESCO for full–scale SHSs dissemination in Zimbabwe.

Payment

Each client paid an initial deposit of Z$750 (equivalent to US$65 in 1997) to join the project, starting in mid 1997. The initial payment was intended to cover the cost of labour and balance of systems components (wiring, switches, sockets), which would be left in place if the systems had to be removed. The monthly maintenance fee payable to the ESCO was Z$75, (US$6.50 in 1997), to cover the cost of system maintenance. Part of the maintenance fee was a contribution to a fund that would enable replacement of key system components when they failed, particularly the batteries, and less frequently, charge/discharge controllers.

The project has been running for almost five years, with most clients, who are peasant farmers, paying their maintenance fees annually after harvesting and selling their produce, cotton in most cases. Monthly payments are not practical with such clients, given their income patterns.

A major risk factor with annual payments is the variation in agricultural yields, which depend on the weather. Farmers can fall into arrears due to poor rainfall, and if this happens successively, then catching up with payments becomes difficult. The major advantage of this approach is that clients are assured of a high level of system maintenance due to the close proximity of the technician, and the dependence of the ESCO on client payments, which will not be forthcoming if systems are not working.

The most serious problem has been the rapid depreciation of the Zimbabwe dollar against the major currencies. It has not been possible to keep up the Zimbabwe dollar instalments at a rate equivalent to US$6.50, which in 2002 would have had to be some one hundred times the amount paid in mid–1997. Payments at the end of 2002 were equivalent to almost US$3 at official exchange rates (***around US$0.10 at 2002 parallel exchange rates***). This necessitated cost saving measures, and technician visits were reduced to one every three months, with reduced remuneration to the technicians. This is acceptable to the project because the initial monthly visits were primarily for intensive data collection, and to cope with more initial problems due to unknown equipment and ill–informed users. Technicians are still available for emergency repairs in–between the regular visits.

An unintended consequence of reduced frequency of technician visits with the attendant reduction of remuneration was that technicians sought to supplement their incomes by utilising their spare time for gold panning. This can be lucrative, and leads to neglect of the monitoring of SHSs and slow response to client calls for assistance. The Sanyati resident technician, who had served for over three years, had to be replaced in 2003 following client complaints over his neglect of their systems. The replacement technician had also attended the Kwekwe Technical College solar training course, but this change is a loss of experienced staff to the project.

Quality control

Three local companies, Munyati Solar, Enercare, and Jotpav, carried out installations in the two clusters. The JICA study team carried out post–installation inspections. The project established a laboratory to test components, and actively liaises with local companies supplying balance of system components where problems have been identified. Because of its small size, the project has not had a pronounced impact on the fortunes of local solar companies.

A JICA technical expert worked with local solar component manufacturing companies to improve the quality of locally manufactured balance of system components, particularly lights and charge/discharge controllers. This was clearly necessary because local batteries and charge/discharge controllers had had to be replaced early in the project when reliability and performance shortcomings were experienced.

Maintenance

Most installations were completed in 1998. Selection of maintenance technician trainees was competitive, and was undertaken together with the local rural district council. Four selected candidate maintenance technicians were trained at Kwekwe Technical College where JICA provided Z$200 000 (about US$17 000 in mid–1997) for the establishment of a solar PV training course. Nine instructors were trained at Kwekwe Technical College. The first technicians' training course attracted 17 technicians from solar companies all over Zimbabwe. Two candidate technicians with the best results from this training course were contracted as maintenance technicians by BUN. One of these two technicians was female.

Each technician was provided with a bicycle and a toolbox. These items were provided on an ownership scheme, with the costs deducted from the technicians' salaries over a period of six months. This ownership arrangement was meant to improve care of the bicycles and tools by the technicians after it was noted that when these items were provided as project assets, they were often abused and damaged, then presented for replacement within a short time. Once the costs of the bicycles and toolboxes had been paid up, the project hired the bicycles each month by paying a fixed sum to each technician to help them maintain the bicycles. Each technician was required to visit every installation monthly to complete data sheets and attend to any problems. The clients can call the technicians in–between the regular visits in case of system problems. Random visits by a senior BUN officer are undertaken (without prior notice to the technicians) to some households to check on the technicians' activities. The two technicians also had 83Wp systems installed at their households free of charge as an added incentive, and to continually expose the technicians to a SHS at close range. A condition was that these free systems would be recovered in case of termination of employment of the technicians, and this has been enforced so far. The technicians'

SHSs have worked well to date, helping to instil confidence in clients served by the technicians.

Precautions taken against clients tampering with their systems include placing each battery and charge/discharge controller in a box that is locked, the keys being kept by the technician who visits clients regularly or when a fault is reported between such visits. The battery boxes were initially wooden, but severe termite damage was experienced, resulting in total replacement with galvanized iron boxes.

All the padlocks in each area are *keyed–alike*, which means the technician only needs to have one key when visiting clients. Despite these anti tamper precautions, there have been cases of clients tampering with battery boxes to gain access to the battery to use it for other purposes, or to disconnect it in order to charge a car battery for example.

The future of the JICA Study Project

The ESCO support to clients is expected to continue until mid 2003. At that point, DoE will decide in consultation with clients and the ESCO on how to proceed. Some of the options available are to allow clients to take over their systems on payment of an agreed terminal lump sum to the ESCO, to continue with a modified maintenance arrangement still to be worked out, or to continue with the present arrangements, assuming all parties are still interested.

Two offshoots of this JICA Study Project have been implemented and are described below. These bring the total number of ESCO–type SHSs to at least 550, possibly close to 600, by early 2003 since one of the initiatives is still actively installing systems.

1. In 2000, JICA started up another (ongoing) initiative with the Organisation of Rural Associations for Progress (ORAP) in Matebeleland North and South provinces. Over 400 systems have been installed, but it was found out in late 2002 that due to misunderstandings, the approach taken by ORAP was not as an ESCO, which is what JICA had intended. Discussions were underway between ORAP and JICA at the start of 2003 to find a way forward. It is not clear how clustered the ORAP installations are. No detailed report has yet been published on this initiative.
2. In 2000 BUN started up another cluster of 52 SHSs at Chitora, 110km northeast of Harare, between Murewa and Mutoko in Mashonaland East province. The Embassy of Japan in Zimbabwe funded the initiative. The distance between the clusters of the JICA ESCO in Kadoma district and the BUN office in Harare is about 250km. This long distance was seen by BUN as one of the major factors contributing to the cost of providing support to clients in Sanyati.

Unlike the JICA Study Project ESCO, the Chitora cluster had no possibility of eventual ownership by clients. The size of module offered in Chitora was 56Wp, because these were the modules available to BUN, and the Zimbabwe dollar cost of importing modules had become prohibitive due to the fall of the Zimbabwe dollar. This size of module was also felt to be a good compromise in view of the fact that no clamour for larger sizes was noted among households whose systems had been expanded to 56Wp in Sanyati, and that the size is within the most popular range of 40 to 60Wp sold under the GEF Solar Project.

Negotiations between the Zimbabwe Electricity Supply Authority (ZESA), JICA and the Government for ZESA to replicate the ESCO model on a large scale have not succeeded. The major obstacle is that ZESA is undergoing reform and is under pressure from government to operate profitably. ZESA seems unconvinced that the proposed large–scale solar PV electrification will be profitable.

2.2.4 Chinese Donated Systems

The Chinese government donated solar equipment to the Zimbabwe government in 1998. Kawanzaruwa village at *Nzvimbo* rural service centre in Mazowe district was selected to receive the solar equipment. Nzvimbo rural service centre is situated some 100 km northwest of Harare. Kawanzaruwa village is about 4 km from Nzvimbo rural service centre. It is a planned resettlement village. The total number of households in the village is about 200.

The budget for the project is not known, and DoE is still incurring some support costs in its efforts to address the maintenance needs of the beneficiaries. No criteria could be found for the selection of the target site for the donated equipment, nor for which specific households deserved the free SHSs and televisions.

ZESA undertook the installation work with local technicians and Chinese experts. The equipment installed at each selected household in 1998 comprised:

- 1 x 70Wp polycrystalline Chinese solar module.
- 4 x fluorescent lights.
- 1 x 12 inch monochrome TV.
- 1 x 105Ah Chinese made sealed battery.
- 1 x 5A charge controller.
- 1 x user manual.

The 110 systems installed included two shops, namely a bottle store and a general dealer. In 1999, the Chinese donors replaced all the 5A charge/discharge controllers with 10A charge/discharge controllers after the 5A controllers were found to be prone to failure. The reason is almost certainly that the controllers were undersized for the loads, given that, in addition to the free televisions that came with the SHSs, most households in Zimbabwe have radios or radio–cassette players. If the television were rated at about 30W, the four lights at 9W each, and the radio cassette at 15W, the total load at a recipient household would be 81W. At 12volts, the current drawn would be almost 7A, and would certainly blow a 5A controller.

Community facility

A communal water pump was also installed, and consisted of 21 x 51Wp polycrystalline solar modules, one submersible pump and one corrugated galvanised iron storage tank fitted with a tap and overflow. The pumped water was available to the community free of charge via the tap on the tank. A garden was set up to utilise any water that might overflow, or be spilled. The pump site was not fenced.

All the 21 water pump modules were stolen early in 1999. The stolen modules were replaced by the Ministry of Transport and Energy that same year. The pump site was fenced in 2000 and an alarm system was fitted. Some of the stolen modules were recovered between 1999 and 2001. The number of modules recovered could not be established.

The water pumping system failed in mid 1999, soon after the stolen modules had been replaced. Submersible pump failure was suspected, and the Chinese donors supplied a replacement pump. When the old pump was taken out, it was found to be operational. The Department of Energy consulted the Zimbabwe National Water Authority, who indicated that the well may have collapsed and may need extensive repairs. The quotation for this work was more than the Department of Energy was willing to consider. The result is that as of May 2002 there was still no water being pumped.

Ownership

All the SHSs were given to the villagers, as was the solar water pump. The motive seems to have been to gain political mileage, and the process seems to have been hurried. As a result, no administrative structures were set up in advance to handle common issues related to the donated SHSs, nor the communally owned solar PV water pump.

Financing

The Chinese government procured and delivered all the equipment. The Zimbabwe government provided in kind inputs in the form of skilled manpower time for project coordination, and logistics for locally transporting and distributing the solar equipment. Post–installation efforts to arrange maintenance have also been handled by the Zimbabwe government through DoE.

Payment

Beneficiaries were not charged anything, and no pre–installation negotiations to cover future maintenance costs were held. When technical problems started to surface, the need for maintenance backup was realised. DoE initiated negotiations with the villagers to pay a fee to enable ZESA to maintain their SHSs. This has so far not been successful because the villagers objected to the issue of fees being raised long after they had been unconditionally given free systems, which they assumed would be looked after by the donor. The maintenance fee would not be freely negotiable since there is a minimum cost that ZESA would incur in providing maintenance support.

Quality control

Chinese technical experts participated in the installation of the SHSs, together with ZESA and DoE staff. The technical level of this manpower is well above that of the solar companies that participated in the private and GEF Solar Project installations. The level of quality control during installation would seem to be beyond reproach. The post–installation phase where local volunteer technicians are now carrying out basic maintenance, and calling on DoE at their own discretion, is much more worrying. This is because the volunteer technicians were not given formal training, and have already requested payment for their services. The funds to ensure that they can be paid are not in place.

Maintenance

There is a stalemate over who should meet the cost of maintenance as already indicated above. The position at the end of 2002 was that five local technicians were trained by DoE to do basic preventive maintenance, and refer any complicated problems to DoE. Since the issue of maintenance fees remained unresolved, the local technicians are working voluntarily, but have now requested remuneration. The five volunteer technicians are too many for 110 SHSs if maintenance fees are to be introduced. In the

JICA ESCO Study, the ratio is one technician to 50 systems. In this case, it is one technician to 22 systems.

The stolen modules that were recovered have been sold, and the money banked by the community. There are 60 replacement batteries in stock. These will be used to replace failing batteries for a fee. The community will also bank the battery replacement fees. The banked money has been dubbed a *revolving fund.* The DoE has suggested that this 'revolving fund' could be used to pay for maintenance subject to the concurrence of the community. How the 'revolving fund' will be replenished is not clear. The present situation means that the above funds may be used to pay for maintenance for a time, but will be exhausted and the community will be back to the same situation. The usability of the stored batteries critically depends on their being kept fully charged through frequent charging at the storage site. If this is not done (which is probably the case) the batteries may become unusable due to self–discharge and subsequent sulphation. Should this happen, the expected revenue from the sale of the batteries will not be available to help cover maintenance costs.

DoE is unlikely to provide long–term, responsive maintenance backup because of the distance between Harare, where DoE is based, and Nzvimbo. The cost of spares and failed components, as well as transport, subsistence and staff–time costs are an additional burden with which DoE is saddled. These costs are not budgeted for within the DoE budget. This implies that only very limited support can be provided, and that this will not be available in the long–term.

2.3 Other off–grid electrification initiatives

Other off–grid initiatives include small (micro and mini) hydro schemes (ESMAP 2000b). Although there was considerable micro hydro activity in the country after 1930, this came to a stand still around 1965. This was probably because of the developing independence war situation, as micro hydro activities are associated with remote areas that are off grid. The majority of the small hydro schemes are clearly for income generation and were installed several decades ago. It is interesting to note that the problems of controlling client behaviour in order to protect installations are similar in a community small hydro scheme and an ESCO type SHS scheme. For example, the 20kW Nyafaru hydro power station described in this section supplies a community with power. To avoid overloading the generator, it has been necessary to limit the sizes of appliances that connected consumers may use. This is difficult to police. Important changes and decisions are also taken in collaboration with the community. This prolongs and complicates issues such as setting economic tariffs and revising them.

All the small hydro schemes except for that at Kuenda (in Mashonaland Central province) are situated in Manicaland province, which is more mountainous than the rest of the country and enjoys good rainfall, a situation that favours hydro schemes. In contrast to the distribution of small hydro potential, solar insolation levels are more evenly spread around the country. The capacity of the small hydro schemes ranges from 20kW to 750kW, which enables a wide range of income generating activities to be powered. SHSs typically are around 40Wp, which precludes all of the activities mentioned under small hydro schemes, except limited lighting.

The main small hydro schemes in Zimbabwe are:

- *Claremont* hydro plant is in Manicaland Province, at Claremont Orchards. Capacity 250 kW used for electricity generation.
- *Mutsikira* hydro plant is also in the Manicaland Province, near Nyabadza Business Centre off the Rusape–Nyanga road. The capacity is 3kW. It is used to drive a hammer mill, pump irrigation water, drive a timber sawmill, and to power a grinder for sharpening tools.
- *Kuenda* Cooperative Farm in the Mashonaland Central Province near Mt Darwin. The power plant is on the Ruya River and has a capacity of 74kW. The equipment has not worked since about 1986.
- *Aberfoyle* hydro plant is in the Manicaland Province on the Aberfoyle tea estate in the Honde Valley. It is located on the Nyakombe River, a tributary of the Pungwe River. Its capacity is 25kW and it provides electricity for the farm's clubhouse complex, which includes guesthouses.
- *Svinurai* Cooperative Scheme, located at Cashel on a tributary of Umvumvumvu River. It has a capacity of 10kW. It drives a hammer mill and a 20kW DC generator, but not at the same time.
- *Rusitu* hydro power station at the confluence of the Rusitu and the Nyahode rivers. The Rusitu Power Corporation, a joint venture between the NGO Energy and Development Activities–Zimbabwe (ENDA–Zimbabwe) and the Zimbabwe Power Corporation, a small–scale power subsidiary of ZESA, own it. The generation station has a rating of 750kW, and was installed in 1997.
- *Nyafaru* hydro power station, completed by ITDG in 1996, is on the Nyafaru River, also in the Eastern Highlands. Capacity is 20kW. This supplies a community with electricity and has administrative complications often associated with community projects, including abuse of administrative power, use of unauthorised appliances, and disagreements over tariffs.

2.4 The emphasis on solar PV

Compared to the 85 000 SHSs in Zimbabwe, the other electrification initiatives are far fewer. It is not just this numerical dominance of SHSs that indicates greater emphasis on solar PV. The level of funding provided for solar PV is also much larger, as are the number of sponsors. The small hydro schemes have relied on local private sector initiatives, and the rural electrification by grid extension relies on a levy raised by ZESA. Donor funding has been poured into photovoltaics, despite the much more limited service level that is provided to the end user. This apparent obsession with solar PV has been the subject of some critical comment (for example Leach, 2001). Table 2.7 illustrates the involvement of sponsors in the different electrification initiatives and shows the greater involvement of sponsors in solar PV electrification initiatives. Furthermore, an Italian solar PV initiative to electrify public facilities on a budget of Z$400 million has been under discussion since about 2001. It is not clear if it will be implemented because many bilateral donor initiatives have been cancelled because of political differences between the Zimbabwe government and the donors.

Table 2.7 Comparison of sponsor involvement in electrification initiatives

Sponsor	*Rural grid electrification*	*PV pumping*	*SHS*	*Wind*	*Small hydro*
GEF/UNDP			US$7m		
GTZ	Z$1m seed	DM9m			
JICA			US$10m		
Government	1% ZESA bill levy				
China Govt		*[6]	*		
ITDG					*
Private			*	*	*
CIDA					C$5m

2.5 Overview of international lessons

International observations and recommendations (ESMAP, 2000b, Niewenhout *et al*, 2000, and Asian Institute of Technology (AIT), 2002) show that the issues arising in Zimbabwe are not unique. The administrative problems found in all the projects implemented in Zimbabwe underscore the *complexity* of implementing large–scale solar PV programmes. The problems surrounding implementation of *subsidies* can be seen to be common, as are the issues surrounding *maintenance*, for example local technical capacity, availability of spares, and the financial viability of ESCOs. The issues of *customer centred sizing* of systems, and the role of *local participation* in improving

[6] Denotes donor involvement where the budget figure is not known

security and payment, raised by AIT also have their parallels in Zimbabwe in the JICA Study Project systems expansion, and the theft and recovery of modules in the JICA and Chinese donation projects.

2.6 Chapter conclusions

Ownership is a relatively simple issue where SHSs are sold or donated. Credit and cash sales used in the GEF and DIY dissemination of SHSs are the same as for many other household durables, and most buyers are familiar with the conditions. The screening of potential buyers by commercial lending agencies for loan collateral and ability to pay monthly generally leads to the exclusion of the poor. The JICA Study Project has experienced persistent equipment ownership queries from the ESCO clients because it provided for this eventuality from the outset. The newer cluster established by BUN in Chitora made it clear clients would *never* own the equipment. With this clarity given *at the outset*, clients have not been clamouring for ownership. This suggests that some clients in the JICA Study Project probably joined that project as a way to gain ownership of SHSs.

Financing in the private dissemination of SHSs is less problematic and more sustainable compared to the subsidies and concessions granted to project SHSs. The granting of concessions such as import duty waiver on GEF Solar Project hardware, which also benefited the JICA Study Project, did not help dissemination after these projects ended, resulting in the concessions being suddenly withdrawn. By providing cheaper PV components through the GEF Solar Project warehouse, the project stifled commercial competition, only to end abruptly itself. The ESCO approach has failed to cover operating costs from the fees collected, thereby failing to demonstrate economic viability. Furthermore, a realistic trial where the ESCO invests the necessary funds to procure SHS hardware has not been tested in Zimbabwe. The SHSs in the Chinese donation project need a way to finance maintenance. Taking the ability to afford regular maintenance fees as a condition for receiving donated SHSs in future is likely to result in disqualification of the poor. This underlines the difficulty in providing SHSs to the poor in a sustainable manner, and raises the question of whether SHSs are a practical option for the poorer rural households.

Payment in private dissemination of SHSs is through conventional methods such as cash and various forms of credit. The GEF Solar Project involved a relatively complex scheme that shielded installing companies from the instalment collection process, thereby allowing laxity in maintenance, along with the collection of instalments from clients regardless of the state of their SHSs. In the JICA ESCO, the payment scheme is simpler and payment terms are more flexible to suit the rural income patterns. By relying on rural farmers, the ESCO is exposed to erratic payment of fees in drought years. This may cause collapse of the ESCO unless it has a diversified income base. Maintenance fees have not kept pace with the equivalent foreign currency equivalent needed to build up a battery replacement fund by the ESCO. This has been exacerbated by the rapid deterioration of the Zimbabwean economy. The difficulty in collecting sufficient fees to cover operating costs applies to most ESCOs as found in a global survey of PV projects (Niewenhout *et al*, 1999). The Chinese donation project did not have agreed maintenance payment arrangements at the time of writing, nor was there an organised effort to sensitise the SHSs recipients on the need to save for battery replacement.

Measures for ***quality control*** of ***workmanship and components*** generally existed in the project–disseminated SHSs, partly because they were all of a pilot nature and the sponsors were on hand cope with initial problems. The problems include the hardware failures experienced in the early stages of both the Chinese donation and JICA Study projects. The private dissemination of SHSs is exposed to more variable quality control, ranging from company–supplied and installed components, to DIY systems built piecemeal by the owner.

Maintenance support was found to be generally reasonable in the Thesis survey areas. In Sanyati, the presence of the ESCO project meant that a generally positive impression was recorded. One problem with the ESCO approach was the difficulty in retaining good technicians while attempting to cut the cost of providing service to clients. In Nzvimbo, the fact that recipients of the Chinese donated SHSs had not yet faced maintenance bills also led to a positive attitude among SHS owners. In Makosa, the facilitator attended to any systems when summoned, again leading to a generally positive attitude among SHS owners. This situation contrasts with the findings of the wider BUN/JICA/DoE survey, which found that owners of DIY–installed SHSs were generally unhappy, with 80% of SHS in that category having limited functionality.

The positive situations in Nzvimbo and Sanyati will change because the ESCO service will end with the handover of SHSs to clients in Sanyati in the second half of 2003, and there is no maintenance plan for the donated systems in Nzvimbo. Competent local maintenance support along the lines of the *Facilitator* approach used in Makosa is perhaps the most effective way to cope with the future maintenance needs of the SHS–owning households in these areas. Facilitators can also provide maintenance to public facilities in their areas.

The main issues that complicate the maintenance of *solar PV systems at public facilities* revolve around failure by the project sponsors to consult adequately at the time of installation. This is largely a result of the prevalence of donations, which are a top down approach.

The two common outcomes of this in Zimbabwe have been:

1. Failure to allocate a maintenance budget by the parent body, which may not have been consulted prior to installation, or may not have been aware of this long–term obligation. This applies to the majority of solar PV systems at public facilities owned by local district councils or by government. This is the situation at the JICA–donated solar PV systems, except for Benhura secondary school, the only privately–owned school (see Table 2.2) on the list.
2. Unwillingness or inability of the community to contribute to the maintenance fund for their public facilities. Often this is because the community was not fully aware of the existence, or scale of such an obligation at the time of installation. This situation is exemplified by the Nzvimbo communal water pump, which is out of operation due to lack of funds to meet the repair costs quoted by the Zimbabwe National Water Authority. Issues of equity in access to benefits from the public facility also affect willingness to pay[7], particularly where the size of household contributions towards a public facility is not commensurate with the benefits derived from the public facility.

Staff at public facilities owned by local councils and government are subject to transfer to other council or government schools. This often causes loss of staff trained to look after solar PV systems. The decision to transfer is usually made at head office, and issues such as maintenance of solar PV systems are not considered in redeployment of staff.

[7] This problem is not peculiar to solar PV projects. In Botswana, village biogas plants for water pumping failed partly because villagers were expected to bring cow dung for the biogas digesters when they came to fetch water. However, those not bringing dung could also fetch water, i.e. some 'paid' for water with dung, others got free water (Mapako 1993).

The ***strong emphasis on solar PV systems*** is shown by the greater donor funding that has been provided for solar PV dissemination compared to other renewable energy options. This has been illustrated in Table 2.7. This emphasis is in spite of the greater levels of power that alternative options like grid extension or mini hydro can provide. The preference that donors have for solar PV dissemination is in part due to the business that it generates for their own industries in the supply of key solar PV systems components, particularly the modules, charge/discharge controllers and deep cycle batteries.

International experiences with Solar PV systems show many parallels to the Zimbabwean experiences on the key issues of programme implementation, subsidies, maintenance, and local participation.

Small hydro schemes are the other significant decentralised electrification option found in some parts of Zimbabwe, with power outputs ranging from 20kW to 750kW. This power range is much more suited to the demands of income–generating activities when compared to solar PV systems which are typically in the range 40Wp to 60Wp. Due to their dependence on flowing water and gradient, the feasibility of hydro schemes is subject to the local topology and rainfall patterns. In Zimbabwe the high–rainfall and mountainous eastern highlands are most suited to small hydro schemes. Where communities are provided with power from small hydro schemes, rationing of power use may become necessary to avoid overloading the generator. This causes frustration of users, but allows the use of much more power than with solar PV systems.

CHAPTER 3: SURVEY METHODOLOGY AND DATA ANALYSIS

This chapter explains the survey methodology and sampling employed for the surveys undertaken to generate most of the data used for this Thesis. The locations selected, and the criteria for selection are explained. The analysis of data is described next. The chapter concludes with a discussion of possible data shortcomings and sources of error and the measures taken to minimise the impact of the identified shortcomings where possible.

3.1 Surveyed areas

The areas surveyed have different and important characteristics and they were chosen for the following reasons:

- They all have solar PV installations.
- The electricity grid passes through all the areas, and it is possible to find some grid–electrified households and public facilities for comparative samples.
- Reasonable geographic coverage of the country is achieved within the constraints imposed by the budget.
- All modes of dissemination of SHSs are covered by examples in the selected areas.
- The areas give contrasting types of income generating activities

Most of the data used in the analysis is derived from mini surveys in three areas of Zimbabwe, namely Makosa in Mutoko District, Nzvimbo in Chiweshe communal land, Mazowe District, and Sanyati, in Kadoma district. A fourth area covering Kezi and Matopos in Matobo district, in Matabeleland South province was initially included, but data collection proved difficult due to local suspicion that data gathered may be used to prejudice respondents in the ongoing food relief exercise if they were perceived to have incomes. Matebeleland South is possibly the worst–hit by the current drought and resultant famine among Zimbabwe's provinces, and most households are depending on food aid. All the above areas are pointed out on the map of Zimbabwe in Figure 3.1. More detailed local maps are included in Appendices 3.1a (Sanyati), 3.1b (Nzvimbo), and 3.1c (Makosa).

Four categories of households were targeted. These are:

- Grid–electrified, which refers to houses connected to the national electricity grid.
- Solar home system electrified, which refers to households having SHSs. The term 'system' is used loosely to include DIY installations that may only have a small module and battery.
- Battery–only households are those with only an automotive battery, without any means of charging the battery at the household, and;
- Non–electrified households, where none of the above options are installed.

Sanyati, in Kadoma district, is in the *cotton belt* of Zimbabwe, and most small–scale farmers are engaged in growing this export cash crop. This has encouraged the setting up of cotton buying depots and ginneries by major cotton companies, the Cotton Company of Zimbabwe and Cargill (a multinational company). Sanyati centre is a thriving grid–electrified service centre with modern shops, restaurants and commercial banks. The town of Kadoma is 90 kilometres from Sanyati. A tarred road links Sanyati to Kadoma, which is 140km southwest of Harare.

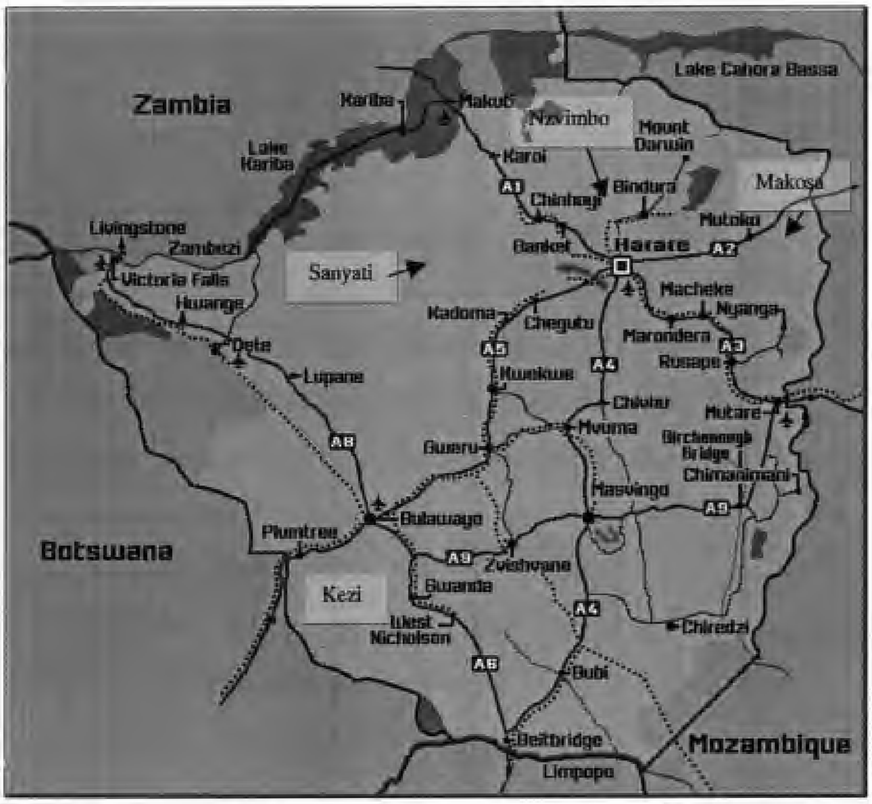

Figure3. Map of Zimbabwe

Solar companies are active in Sanyati and have ensured a high level of exposure to photovoltaic technology in the area, particularly during the GEF Solar Project. Two important solar projects, the GEF Solar Project and the JICA Study disseminated SHSs in the area. As with all the other areas, privately acquired SHSs are common.

Makosa is a small, grid–electrified rural service centre in Mutoko district. It was grid–electrified fairly recently, around 1996. The town of Mutoko is 35 kilometres from Makosa. The road between Mutoko and Makosa is gravel and access is sometimes interrupted when the streams crossing the road get flooded. Makosa is known for the production of vegetables, including tomatoes, cabbages and onions. The area is an important supplier to the urban markets in Harare, some 150 km to the southwest. It is common to see crates of vegetables being transported by road to Harare every night for sale the next day.

There are no local solar companies operating in Makosa, and exposure to photovoltaic technology was more limited compared to Sanyati. Some privately installed and GEF project SHS installations exist in the area.

Nzvimbo is a small rural service centre in Mazowe district north of Harare. Though gardening and small–scale farming are carried out in the area, there is no dominant and commercially important crop to compare with cotton in Sanyati and vegetables in Makosa. Nzvimbo is accessible by tarred road, some 100 kilometres from Harare. Nzvimbo rural service centre is grid–electrified, though the year of electrification could not be established at the time of writing.

There are no solar companies in Nzvimbo and prior exposure to photovoltaic technology was more limited compared to the other two areas. Comparatively, fewer privately–installed and GEF project SHS installations exist in the Nzvimbo area compared to the other two areas. Nzvimbo has the only clustered donation SHS project in Zimbabwe, which was donated by the Chinese government (refer to section 2.2.3). The other donated PV installations are found only at public facilities, particularly clinics and schools.

Table 3.1 presents a summary of selected features of the survey areas. It can be seen that the rural service centre at Sanyati is larger than the other two areas, and has almost grown to small town status. It has some branches of the major national chain stores and depots of competing cotton companies who purchase cotton locally, and usually pay cash on the spot.

There are cotton ginneries and textile industries around Kadoma. Banks have established branches to serve the needs of the cotton farmers, who periodically handle sizeable cash and cheque payments when they sell cotton.

In contrast, Makosa and Nzvimbo are both small rural service centres without major shops or banks. One reason for this difference is that Makosa and Nzvimbo have not attracted major investment because they both lack important commercial crops. The mountainous terrain around Makosa results in many streams.

Table 3.1 Summary of selected features of the survey areas

	Sanyati	*Makosa*	*Nzvimbo*
Geographical Position	Communal Area in the cotton belt. Flat terrain.	Communal area. Mountainous rocky terrain.	Communal Area with resettlement villages. Flat terrain.
Size of rural service centre	Large with banks, shops, cotton depots.	Small, with few shops, no banks	Small, with few shops, no banks.
Main income–generating activities	Cotton farming.	Vegetable farming, especially tomatoes and green leaf vegetables.	No dominant commercial crop. Gardening and small–scale farming.
Electrification status	Grid–electrified rural service centre. Many households grid–electrified.	Grid–electrified rural service centre. Few households grid–electrified.	Grid–electrified rural service centre. Few households grid–electrified.
Solar Electrification	JICA ESCO, GEF Solar Project, Private installations.	GEF Solar Project and private installations.	GEF Solar Project, private installations, and Chinese–donated systems.
Accessibility	Tarred road link to district capital town of Kadoma, about 90km away.	Reasonable dust road link to tarred main road 30km away. Can be cut off by flooding of small bridges. Many streams due to mountainous terrain.	Tarred road link to district capital town, Mazowe, about 60km away.

The streams provide water for canal irrigation, which facilitates the cultivation of vegetables all year round, assuring the farmers of steady incomes. Daily delivery of vegetables to Harare is common, which provides many farmers with daily, weekly and monthly incomes. These income frequencies are not typical for most Zimbabwean rural farmers who generally rely on rain–fed agriculture, with an annual harvest that imposes an annual income frequency. These differences in income patterns have a bearing on what project payment options will be feasible in each area.

3.2 The survey sample

The sample distribution for the survey has been shown in Table 3.2. A total of 135 households were surveyed, whilst the number of public facilities surveyed was 13.

Since SHSs were the focus of the surveys, almost half (60 out of 135) of the households sampled were SHS electrified. In each of the three areas, 20 SHS electrified households were interviewed, and ten each of battery–only and unelectrified households, and five grid–electrified households. The thirteen public facilities surveyed comprised four clinics and nine schools. The total number of SHSs in the survey areas is not known since no census of these systems has been undertaken.

Different, though broadly similar questionnaires were used for the different categories of households and public facilities. Selection of households to be interviewed varied from area to area. For the Chinese–donated SHSs in Nzvimbo, a complete list of beneficiary households is available. Households were thus selected at random by generating a list of random numbers corresponding to the household list numbers.

In the other two areas, there is a mixture of SHSs installed by the different approaches and thus details of the numbers of each category of installation were not known in advance. Sample selection was by first limiting the area to be surveyed to within 10km of the local rural service centre, and then visiting every third house that had a SHS. In practice, since the enumerators were local residents, they had a good idea which households had SHSs.

It was necessary to limit distances because of transport budget constraints, and to limit enumerator fatigue, because much of the movement would be on foot. Any battery–only and unelectrified households encountered in between the SHS electrified households were interviewed until the quota of ten of each of these categories was satisfied.

Households with grid electricity are usually owned by prominent families and are well known. Power lines also make it easy to identify houses that are grid–electrified.

Because of the relative scarcity of public facilities and grid–electrified households in rural areas, any public facilities and grid–electrified households that were accessible were interviewed with the aim of filling the quota of five grid–electrified households and six public facilities.

Table 3.2 Survey sample distribution

	Category	Sanyati	Makosa	Nzvimbo	Total
Households	SHS	20	20	20	60
	Car battery only	10	10	10	30
	Non–electrified	10	10	10	30
	Grid–electrified	5	5	5	15
	Total	***45***	***45***	***45***	***135***
Public Facilities	PV–electrified clinic	1			1
	Grid–electrified clinics	1			1
	Non–electrified clinics	1		1	2
	PV–electrified schools	1		2	3
	Grid–electrified schools	1	2		3
	Non–electrified schools	1	2		3
	Total	***6***	***4***	***3***	***13***

Only 13 public institutions out of the required 18 were located, but all 15 grid–electrified households were located. The representation of the different SHS projects and private initiatives in the survey sample is shown in Table 3.3.

Table 3.3 Representation of projects in the survey SHS sample

Project or Initiative	*Sanyati*	*Makosa*	*Nzvimbo*	*Total*
GEF Solar Project	6	6	–	12
JICA Study	9	–	–	9
Chinese donation	–	–	20	20
Private	5	14	–	19
Total	20	20	20	60

A deliberate effort was made to exclusively target the donated systems in Nzvimbo; therefore no SHS installed by other projects were surveyed in Nzvimbo. No quotas were set for the different projects or initiatives in the sampling, thus the numbers presented for Sanyati and Makosa are what enumerators encountered in the field. The inclusion of areas with JICA Study Project clusters in Sanyati boosted representation of these ESCO systems in the sample. This was not seen as a problem because useful lessons could be learnt from the ESCO approach, which is new to Zimbabwe. Thus, even though selection of households in each area was random, selection of the areas was not.

The twenty SHS for each area are spread among the different projects as follows:

- In Sanyati, six GEF Solar Project, nine JICA Study Project, and five privately installed SHSs.

- In Makosa, six GEF Solar Project and 14 privately installed SHSs.
- In Nzvimbo, all 20 SHS were Chinese donated SHSs.

The totals for each dissemination mode are 20 for the Chinese donation, 19 for the privately installed SHSs, 12 for the GEF Solar Project, and nine for the JICA Study Project.

3.3 Data analysis

The *unit of analysis* was the household, and comparisons were generally made across different income groups and geographical areas. Grid electrified households were left out of the discussion of energy burden because they generally could not give figures on energy expenditure. This was likely to be a result of their bills being paid by urban based relatives, in which case the billing address used by the electricity utility would be the address of the payee.

3.3.1 Income data

Analysis was based on reported household income in the different electrification modes across the different survey areas. Impact analysis of solar PV electrification was largely based on (1) income groups, (2) means of access to electricity, (3) survey area, and (4) mode of solar PV dissemination. The analysis explored the relationships between income level and category of electrification, family characteristics, and income generating activities. Comparison across areas was also used extensively to establish patterns. This was necessary because analysis based on cash incomes alone may not give a complete picture in rural areas, given the importance of the non–cash subsistence part of the rural economy.

Since respondents specified their incomes according to the frequencies with which they received it, all incomes were converted to the equivalent monthly amounts. For example, annual incomes were divided by 12 and weekly incomes were multiplied by 4. To convert daily amounts, 20 working days were assumed per month. This is because most people go to church on Sundays, and there is usually one other day in the week, called *chisi,* when people do not go to the fields. The specific day of the week on which *chisi* falls varies from region to region.

Statistical analysis was performed using *Analyse–It software*[8], a commercial statistical extension to *Microsoft Excel*. This was suitable for the relatively small sample size.

3.3.2 Income generating activity (IGA) data

Identification of the key income–generating activities (IGAs) in Sanyati, Nzvimbo and Makosa was accomplished by calculating the percentages of households involved in each IGA. The prevalence of income generating activities results were compared to published national findings. Only the main IGAs were used for more detailed analysis. The percentages of households involved in each of the key IGAs were also compared on the basis of income group, survey area, electrification category and SHS dissemination mode. The purpose of this was to check where SHSs contributed to the energy needs of IGAs found in the survey areas. The roles of different family members were analysed to highlight gender roles and parent/child contributions to income generation.

The contribution of SHSs to income generating activities was examined by first compiling all activities that were powered by SHSs, batteries and grid electricity. A comparison of the income–generating activities between grid–electrified, SHS–electrified and non grid–electrified households was used as a way to highlight the contribution of SHSs.

The number of public facilities was very small at 13. Missing data for some of these few public facilities made it inadvisable to attempt statistical analysis on this small sample. Data from project files, particularly reports on visits to institutions when problems were recorded was used to supplement survey information on installations at public facilities. The discussion of public facilities is therefore largely confined to sub section 2.2.1 of Chapter Two.

3.3.3 Energy sources and end use data

Analysis of energy source data looked at grid–electrified, SHSs, battery only and unelectrified categories of households. The links between electrification category and appliance ownership were explored. The switching preferences of users were used as an indicator of the level of satisfaction with existing energy sources. The proportion of total household income spent on energy was compared across high, medium and low income households to show the size of the energy burden on these different groups.

[8] See http://www.analyse–it.com

3.4 Data difficulties and possible sources of error

The size of the surveys on which the study is based was limited by the budget of US$890, which the scholarship provided for all Thesis–related expenses. Sampling was therefore restricted, and representation of public facilities and grid–electrified rural households was particularly limited because the relatively more sparse geographical distribution of these samples requires more travel.

At the time of the surveys in early 2002, the whole Southern Africa region was facing serious food shortages and relief food was being provided by donor agencies. Enumerators came across reluctance on the part of respondents to discuss issues related to incomes. This was due to fears that either eligibility for food relief, or the assessment of the deserved amount of relief could be prejudiced by information given, if it suggested that respondents were relatively wealthy. Respondents were not sure that the data collected would not be available to agencies responsible for screening for food relief, or that the survey was not meant to find out such information for those agencies. It is therefore possible that some respondents under–reported their incomes. Illicit income–generating activities such as brewing potable spirits and gold panning are also unlikely to be reported by many respondents.

The surveys had to be postponed due to raised political tensions in Zimbabwe. The tensions were raised by elections that were held in early April 2002. The contested results led to prolonged tension as the political opposition challenged poll results in some constituencies in court, resulting in some results being set aside. Surveys in two areas, Sanyati and Makosa were done satisfactorily while those in Nzvimbo and Kezi (Matebeleland South province) took longer. Kezi is more arid and poorer than the other areas, and greater resistance was encountered in the area. Thus, the results from Kezi are not included in this Thesis, reducing the overall sample size and leaving out insights from possibly the poorest of the intended survey areas.

Accurate data was not available from respondents in certain instances. Rural households do not keep written records of the history of their SHSs. They therefore rely on memory, or second–hand information to answer questions on fault dates, costs, replacement of components, or even who installed the SHS, and on what payment terms. This was complicated by the fact that the respondent who provided information was not necessarily familiar with the SHS or battery history. Accuracy, or honesty, could not be guaranteed when the respondent had to provide the income figures of several family members.

The surveys focussed on cash incomes; therefore, the substantial subsistence component of rural economies was not captured. One consequence of this is that the contribution of women tends to be less visible in the results. Whereas fathers and sons, and to a lesser extent mothers often engage in activities to raise income, daughters are expected to perform household chores like fetching firewood and water, cleaning the homestead, cooking, and looking after small children. Mothers take up some of these tasks to varying extents depending on the numbers and ages of daughters in the household.

Urban relatives often sponsor electrification of rural households, particularly for their parents. In such cases the reported income level of the recipient rural households may sometimes fail to agree with the expected trends in electrification mode and ownership of appliances. In the case of grid electrification, rural parents may also have their bills paid by their urban based children.

The survey focus on areas that have SHSs means that there is a bias towards the affluent rural households. The results cannot therefore be taken to be representative of the average rural situation in Zimbabwe. They are more applicable to the more affluent rural households.

CHAPTER 4: SOCIO ECONOMIC STATUS AND INCOME GENERATING ACTIVITIES OF HOUSEHOLDS IN THE SURVEY AREAS

This chapter looks at the socio–economic status and income–generating activities (IGAs) of households in the survey areas. It provides an overview of all the households in the survey areas and explores the links between household income levels and mode of electrification, mode of dissemination of small solar home systems (SHSs), and survey area. The aim of this is to explore the links between SHSs and household socio–economic status and to compare such links with those identified in other electrification categories.

The chapter next examines the IGAs in the survey areas in the context of national patterns of IGAs. Patterns between IGAs and income, geographical area, electrification category and SHS dissemination modes are identified and explained. The nature and scale of the contributions of SHSs to IGAs are examined. The chapter concludes with a summary of the main socio–economic and IGA trends observed, paying particular attention to SHS–related aspects.

4.1 Socio economic status of households in the survey areas

4.1.1 Income grouping and general sample distribution

All households provided income figures except one, which means 134 out of a possible 135 household incomes were recorded. Of these, three had extreme values and were excluded as outliers from all analysis related to household income. All reported incomes were converted from their daily, weekly, monthly, bi–annual, and annual frequencies to their corresponding monthly equivalents prior to analysis.

The distribution of monthly household incomes for households in all survey areas is given in Figure 4.1. It should be remembered that the total sample of 135 households is not equally distributed among the different electrification modes. In this sample, 15 households are grid–electrified, 60 are SHS–electrified, 30 are battery–only, and 30 are unelectrified

Figure 4.1 shows that the income distribution is negatively skewed, a fact confirmed by the gap between the sample mean of Z$13 492, and median value of Z$8 200.

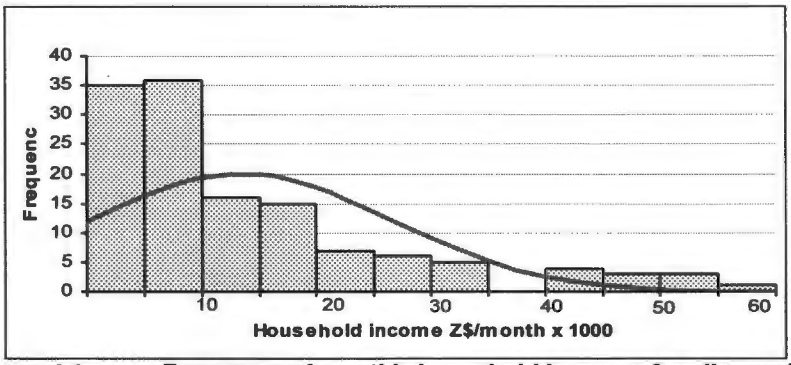

Figure 4.1 Frequency of monthly household incomes for all samples

The households were subdivided into three income groups to allow subsequent analysis to examine trends across the income groups. The income groups are shown in Table 4.1.

Table 4.1 Ranges of income groups

Income group	*Range (Z$)*	*Mean monthly household income (Z$)*	*Number of households*[9]
Low	Up to Z$5 000	3 385	45
Medium	Z$5001–15 000	9 285	45
High	Over Z$15 000	29 202	41

Figure 4.2 illustrates the income patterns for all households (sorted in ascending order) and also shows the preponderance of the lower income households. It can be seen that over 80% of all households earn not more than Z$20 000 per month.

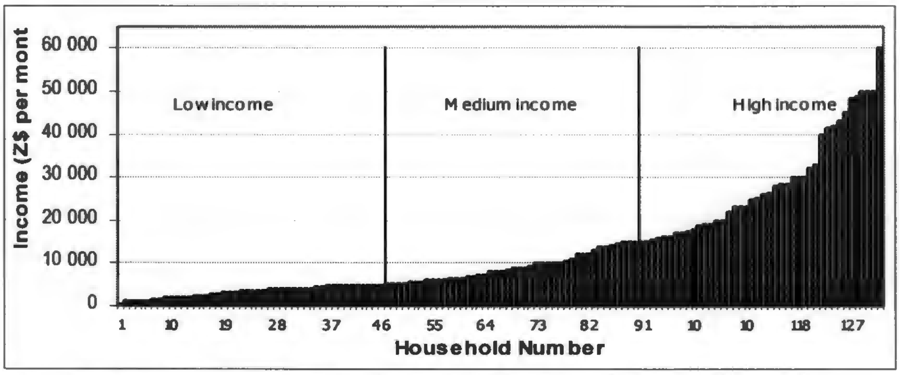

Figure 4.2 Monthly household incomes in ascending order

This is an indication of widespread poverty in rural Zimbabwe given that the survey areas are among the wealthiest rural areas to which solar PV dissemination is attracted.

[9] The total here is 131. Four households, one with no data, and three with extreme values (one low and two high) were excluded from the sample total of 135.

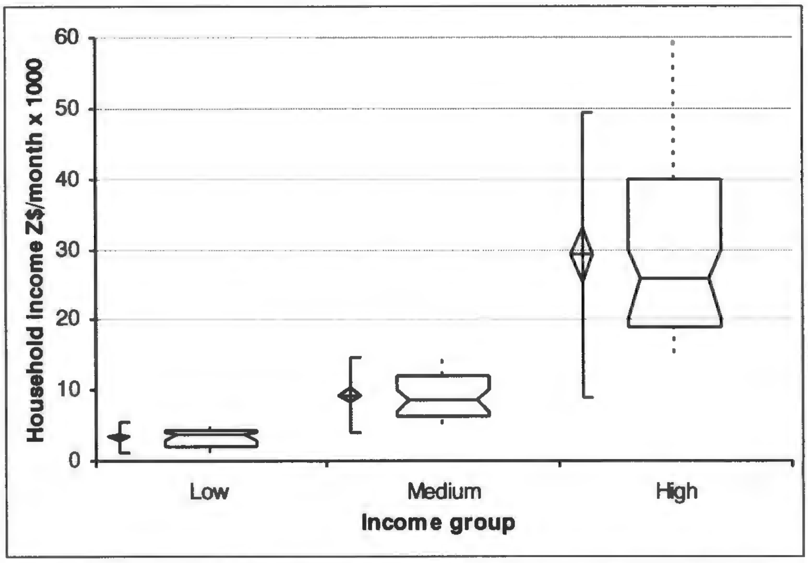

Figure 4.3 Box plots showing mean and median values of monthly incomes in the three income groups

Explanation of box plot.

The vertical lines with diamonds show the mean value across the centre of the diamond, with the confidence interval (95%) shown by the vertical spread of the diamond.

The boxes show the median value as the middle horizontal line, with the angled portion showing the confidence interval. Box height shows the inter–quartile range (IQR) (upper, lower).

Outliers are plotted as ---- up to 1.5 IQR from the median, +++ from 1.5 to 3 IQRs from median, and oooo if further than 3 IQRs from the median.

Figure 4.3 is a box plot showing all three income groups, and their mean (*diamond plot*) and median (*box plot*) values. Because of the much wider spread of incomes in the high–income group (Z$15 001 to Z$60 000), the inter–quartile range (represented by box height) is greatest in this group.

4.1.2 Comparison of household incomes in all survey areas

Figure 4.4 shows that the three survey areas have distinct income profiles, with Sanyati having the highest overall incomes. Nzvimbo has the lowest incomes and Makosa is generally in between the other two areas.

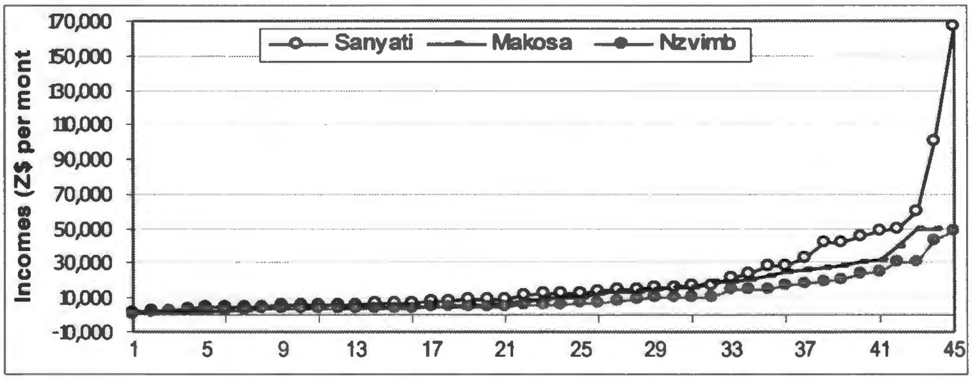

Figure 4.4 Comparison of household incomes in ascending order for the three survey areas

Cotton farming is the major reason for the relatively high incomes in Sanyati, while availability of streams with water for small–scale irrigation of gardens provides income–generating opportunities in Makosa. The general area characteristics and occupations in the three survey areas have been outlined in Section 3.1 of Chapter 3.

The two extremely high incomes in Sanyati (Z$100 000 and Z$160 000 per month) were excluded from the income grouping analysis. The income group patterns for the three survey areas are explored in Figure 4.5

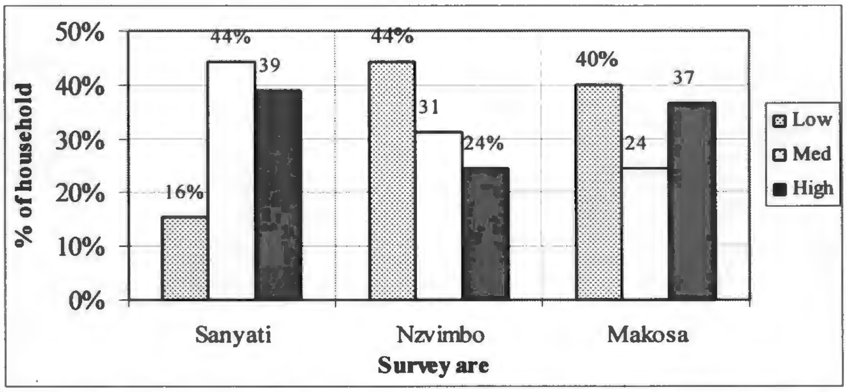

Figure 4.5 **Percentage of households in each income group by survey area**

In Figure 4.5, Sanyati shows the lowest proportion of low–income households, coupled with the largest medium/high–income groups. Nzvimbo has the highest proportion of low–income households, coupled with the lowest proportion of high–income households in a trend that is roughly the opposite of the situation in Sanyati. Makosa falls in between the other two areas in respect of the high and low–income groups while having the smallest medium–income group, slightly smaller than that in Nzvimbo. Figure 4.6 is a box plot depicting the statistical characteristics of incomes in the survey areas. The pattern of mean and median values shows Nzvimbo to have the lowest incomes. Note the presence of outliers, which point to income disparities in the survey areas.

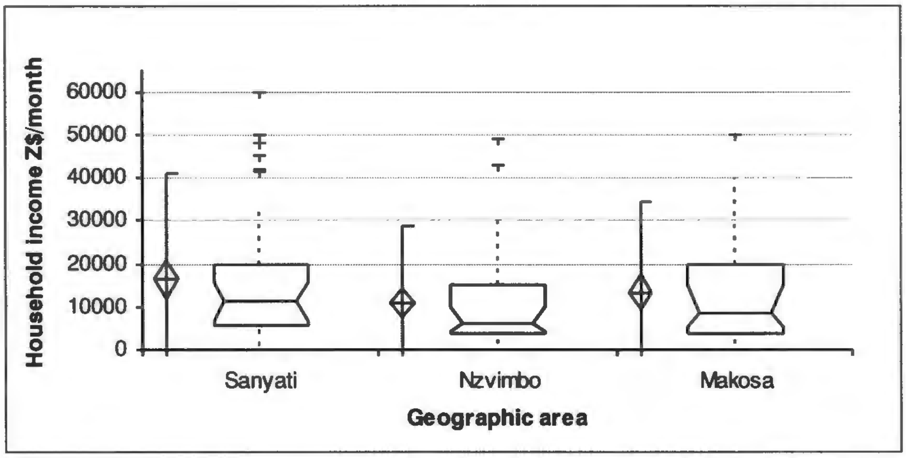

Figure 4.6 **Box plots of the three survey areas illustrating relationships between mean and median values**

The actual mean and median values illustrated graphically in Figure 4.6 are given in Table 4.2 below.

Table 4.2 **Summary of income data for the three survey areas**

Area	*Mean*	*Median*	*n*
Sanyati	16 277	11 167	43
Nzvimbo	10 873	6 250	44
Makosa	13 389	8 400	44

Figure 4.7 is a bubble plot which gives an overview of SHS–electrified households, showing households grouped into survey areas, plotted against photovoltaics (PV) module size. The income value at each point plotted is used to modulate the size of that point into a bubble.

The income is proportional to the ***area*** of each bubble. Some income values have not been inserted to avoid excessive clutter. Nzvimbo has the largest module sizes (y–*axis value*), but these do not correlate with the highest incomes (*income is proportional to **bubble area***) as may be expected, because the SHSs were all donated.

Sanyati has a wide range of module sizes, with the smallest modules in that area generally associated with lower incomes (smaller bubbles at the 25Wp level on the Y–axis). Most large bubbles (higher incomes) are associated with larger module sizes (higher position on Y–axis). All the unexpanded Japan International Cooperation Agency (JICA) SHSs of 25Wp are associated with lower incomes that are below the median income of the area, though not in the low–income *group* of the total sample.

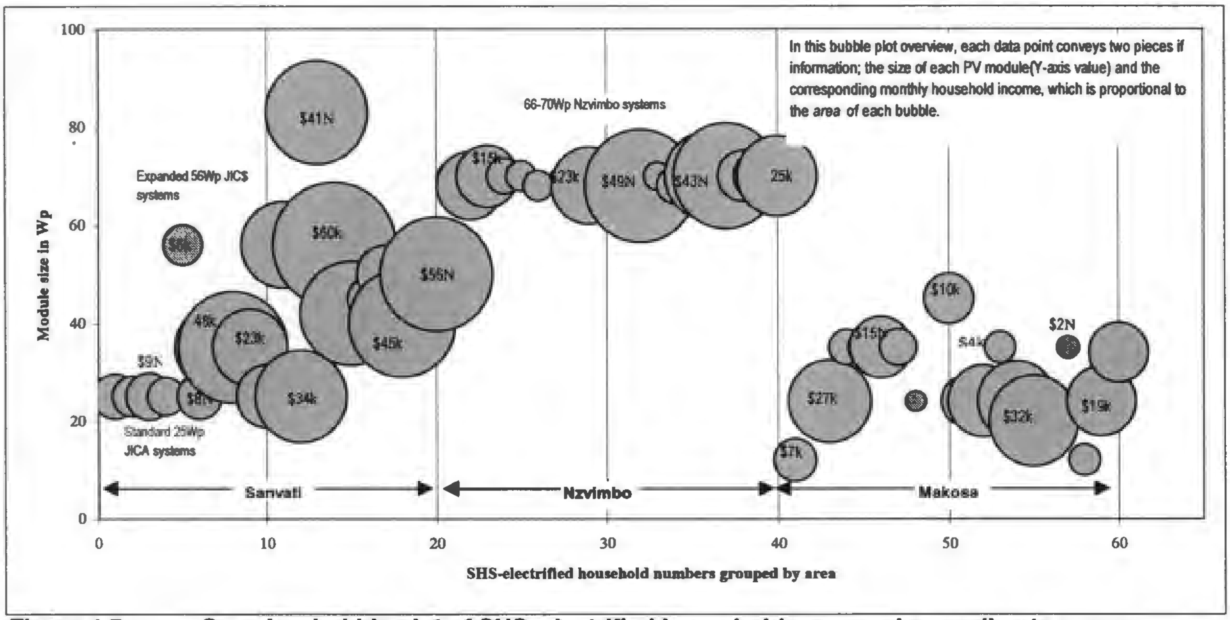

Figure 4.7 Overview bubble plot of SHS–electrified households grouped according to survey areas, showing the relationship between household income and module size.

Of the three expanded JICA SHSs (at 56Wp on the Y–axis), only one is associated with a comparatively small income, which is about half of the area's median income, shown in Table 4.2.

Makosa does not show a clear pattern between income level and module sizes. It is however clear that there are some households with incomes well below the median value for the area (Z$8 400) with SHSs. This may be partly explained by the fact that the area has the *smallest module sizes overall*, including the only amorphous 12Wp modules encountered in the survey. The fact that other SHS projects besides the GEF Solar project have not come to Makosa may also be responsible for lower exposure to SHSs, and reduced availability of SHS components.

There is now a general shortage of solar modules in Zimbabwe because of the prevailing economic crisis and shortage of foreign currency. This affects all areas, but it means Makosa cannot catch up with the other areas despite its relatively good incomes.

4.1.3 Incomes by electrification category

Figure 4.8 is a box plot showing monthly household incomes across the different electrification categories. The monthly household income means for battery–only and unelectrified categories are quite similar. Though the means for the grid and SHS categories are well above the battery–only/unelectrified category means, the median values show that the means for the SHS and unelectrified categories are strongly exaggerated by outliers.

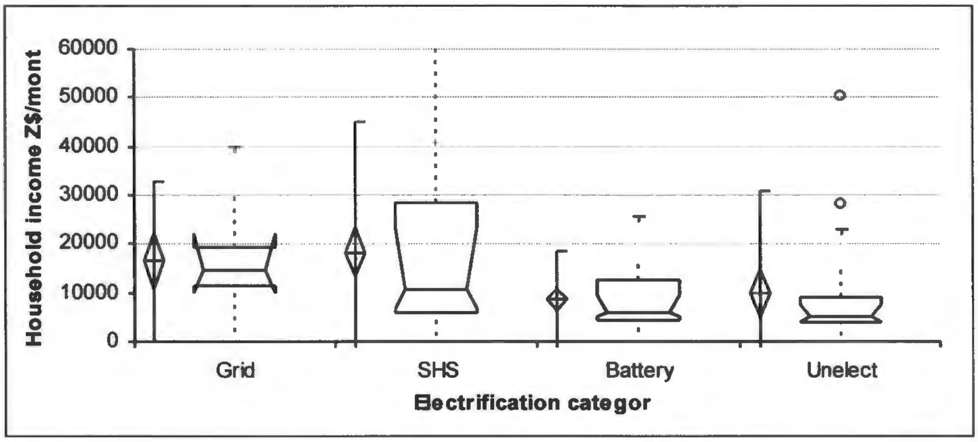

Figure 4.8 **Box plot of household income against electrification category, showing relationship between mean and median values**

The same applies to the other categories to a lesser extent. The mean values still convey the divide between the grid and SHS–electrified groups which are largely on the higher income side, and the battery–only and unelectrified groups, mostly on the lower income end. This income related pairing up of the *grid/SHS* and the *battery–only/unelectrified* households can also be seen in the high–income group in particular in Figure 4.9, and the mean income values in Figure 4.10.

Within the low–income group, there is strong dominance by the unelectrified households (57%), falling sharply as the electrification options become more costly, to only 14% grid–electrified households. The opposite trend is observed among the high–income households, with grid and SHS–electrified households dominating. The medium–income group has the highest percentage of battery–only households while the percentage of SHS–electrified households predictably falls in between the low and high income groups. This is a reversal of the trend seen in the high–income group where the battery–only percentage is much lower than the SHS–electrified percentage.

The prevalence of battery–only households in the medium–income group may be due to the ability to afford this option, but not SHSs. The percentages for grid–electrified and unelectrified households are similar to the high–income group.

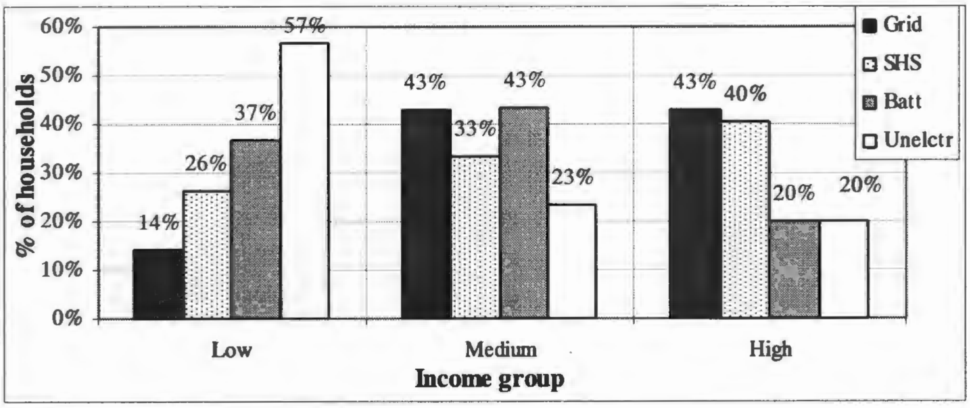

Figure 4.9 **Percentage of households in each income group, grouped by electrification category**

The trends observed above suggest that lower income households are largely excluded from grid and SHS options by their low incomes, and that many medium–income households are unable to acquire SHS and have to rely on batteries.

The mean monthly household incomes of *grid and SHS–electrified* category households in all survey areas generally exceed the respective overall survey area mean incomes, shown in Table 4.2.

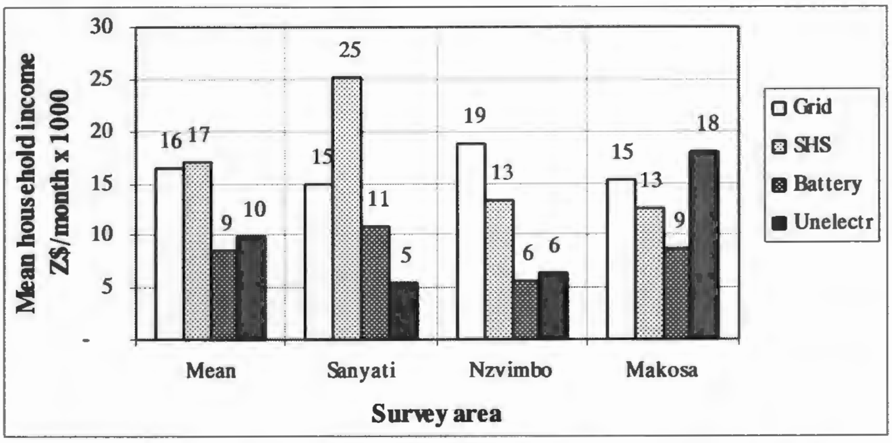

Figure 4.10 **Mean household monthly income by survey area and electrification category**

With the exception of the unelectrified households in Makosa, the *battery–only and unelectrified* household mean incomes in all survey areas are well below the area mean incomes. This pattern is well captured in the overall means shown in the leftmost cluster on Figure 4.10. The overall sample mean is Z$13 492, which is less than the *grid/SHS* category mean incomes, but more than the *battery–only/unelectrified* category mean incomes.

The overall mean incomes once again highlight the divide between grid/SHS–electrified categories and battery–only/unelectrified categories, alluded to in the discussion of Figure 4.8.

Grid and SHS category mean incomes are generally highest across all areas except Makosa where the unelectrified mean is the highest. The anomaly in Makosa may be due to more limited access to the grid, because of the small size of the service centre, which means that most households are located away from the centre, which the grid reached in 1996, later than the other rural service centres covered in the survey.

The observation from Figure 4.10 that the mean monthly income for SHS electrified households in Nzvimbo is higher than that for the battery–only and unelectrified households again points to the poor having been marginalized in the distribution of the Chinese–donated SHSs in the area.

4.1.4 Income group by SHS dissemination mode

Figure 4.11 shows the percentage of households in the high, medium and low income groups in each SHS dissemination mode. In Chinese donation project the medium and high–income group total exceeds the low–income percentage, which means more medium–to–high income group households (68%) got the free Chinese–donated SHSs than low–income group households (42%).

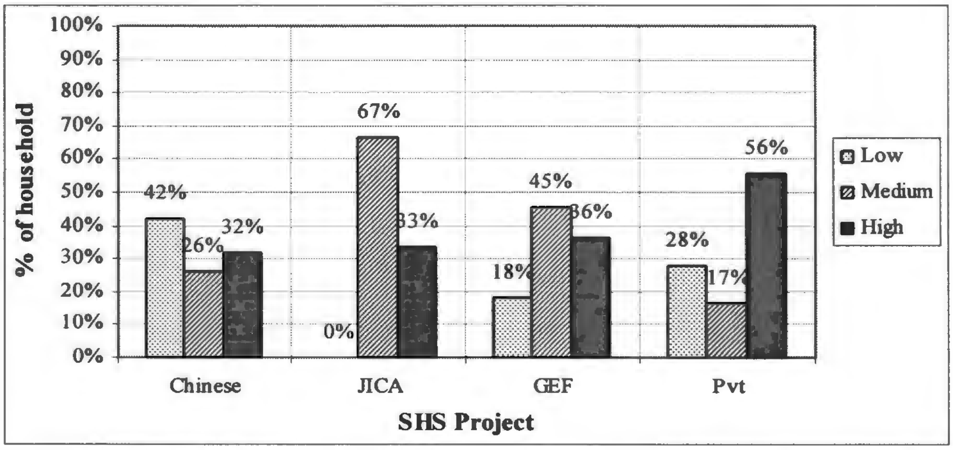

Figure 4.11 **Percentage of households in each SHS dissemination mode, grouped by income group**

The medium–income group is strongly represented in the project–subsidised JICA and GEF projects. In the JICA case, the percentage of medium–income households is greater than any other single SHS dissemination group. In fact, no low–income group households are found in the JICA project. This may be related to the location of the project in Sanyati, which has the best incomes of all three areas surveyed. It may also be that the project was unattractive to low–income households due to the very limited service level (25Wp) compared to the high service fee (discussed in Chapter 2, Section 2.2.2).

The GEF project is heavily dominated by the medium–to–high income households because of the requirement for monthly loan instalment repayment, and the fact that the majority of the clients of that project were rural–based civil servants.

The privately acquired SHS category is strongly dominated by the high–income group. High–income households show a clear rising trend from the Chinese donation systems to the private mode of SHS acquisition. This is due to the level of inherent subsidies in the project systems, like the Chinese donation, JICA ESCO and GEF Solar Project. Costs, especially capital payment, can be expected to rise along the same trend, being highest for the private buyer, who is without the benefit of project subsidies and concessions.

Ignoring the Chinese project, medium–income households show the opposite trend, gravitating to the subsidized projects (JICA and GEF). Low–income households are not as consistent.

4.2 Income–generating activities (IGAs)

This section presents the income–generating activities (IGAs) in the survey areas. These are presented after a brief introduction of the national patterns of IGAs. The IGAs found benefiting from SHSs in the survey areas are compared to the prevalent IGAs in the survey areas to bring out the significance of the SHS contribution.

4.2.1 Brief overview of national trends

In 1998, Zimbabwe had some 1.3 million small and medium enterprises (SMEs) employing some 3.85 million people (McPherson, 1998). This means over 30% of Zimbabwe's population depend on or benefit from informal sector IGAs. The national breakdown of the SMEs is shown in Table 4.3. Manufacturing, commercial and service SMEs were found to be more profitable than agricultural and mining SMEs.

Table 4.3 Breakdown of Small and medium enterprises in Zimbabwe

Type of enterprise	*Number*	*Number of employees*
Manufacturing, commercial and service	860 000	1 650 000
Agricultural and mining	442 000	2 200 000
Total	**1 302 000**	**3 850 000**

Source: McPherson, 1998

The most common farming category activities were maize growers, poultry farmers and multiple crop growers. A correlation between gross domestic product (GDP) growth and the birth and death of SMEs was indicated in the McPherson survey of 1998. A one percent drop in GDP was found to correlate with a 0.68% increase in the birth of new SMEs, meaning that a net increase in the number of new SMEs occurs in times of economic adversity, when the formal sector generally tends to shrink.

Because of the deteriorating economic climate in Zimbabwe, the level of female ownership of SMEs had declined from 75% in 1991 to 58% in 1998. The SME sector was found to act as a safety net for those with no other economic options, and to have both economic and poverty alleviation components (McPherson, 1998; Helmsing, 1992). Poorer households tend to extend household activities to a commercial level to earn income when opportunities for formal employment are limited (Dunnet, 2001). This role of the SME sector partly explains the tendency for more new SMEs to be formed during adverse economic circumstances, and suggests that this sector is particularly important under the prevailing economic crisis in Zimbabwe.

4.2.2 General pattern of IGAs in the survey areas

Figure 4.12 shows the percentages of all households involved in the different IGAs mentioned during the Thesis surveys. The pattern of IGAs in which all households are involved shows overwhelming dominance by farming and employment[10].

[10] *Employment* here refers to both the formal and informal sectors. It can be regular (e.g. civil servants like teachers and nurses, vegetable graders, packers, and transporters), or irregular/seasonal (e.g. cotton gin workers, cotton pickers and packers).

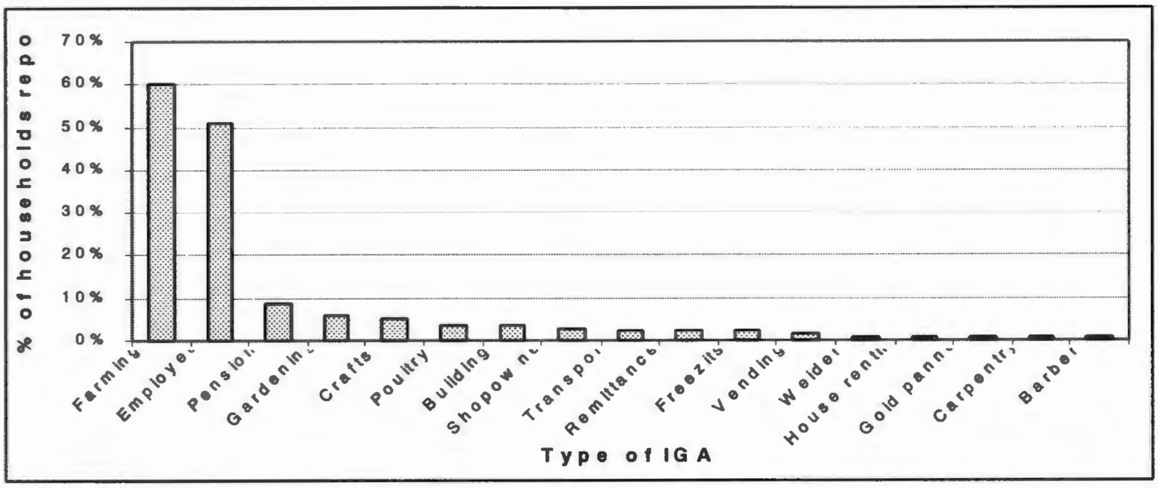

Figure 4.12 **Percentage of households and the IGAs in which they are involved in all survey areas and all electrification categories**

Since the rest of the IGAs are far less prevalent, detailed analysis of trends will be carried out only on the two main IGAs, farming and employment. As noted in Chapter 3 (section 3.4), illicit IGAs like gold panning and illegal brewing of potable spirits may be under–reported. The mean incomes from farming and employment, the major IGAs encountered in the survey areas, are compared in Figure 4.13. Category '*Both*' refers to households who reported involvement in both farming and employment, and category '*Other*' refers to households who are involved in neither farming nor employment, but in other IGAs.

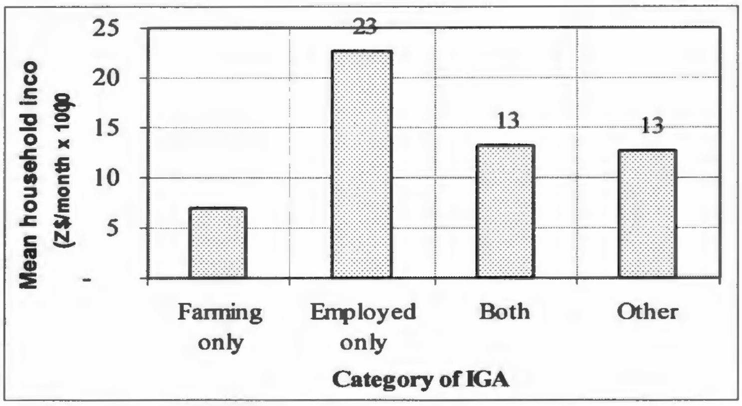

Figure 4.13 **Mean household income from key IGAs**

Employment provides the highest income on average, and dependence on farming alone the lowest. Incomes for households combining both activities fall in–between these two extremes. The mean income values for categories '*Both*' and '*Other*' are not identical, the values shown in Figure 4.13 are rounded from Z$13 281 and Z$12 269 respectively.

The lower relative profitability of agriculture is in line with the findings of the national survey of SMEs presented in the overview presented at the beginning of this section on IGAs.

4.2.3 Nature of contribution of SHS to IGAs

Table 4.4 summarises SHS–related IGAs encountered in the Thesis survey, and also in an earlier survey conducted by the author in April 2002. Service and handicraft type IGAs seem to benefit more from SHS that farming related IGAs. Many household–level IGAs can be operated without SHSs, batteries or grid power. The majority of the IGAs can be carried out using manual tools and traditional energy sources such as wood (see for example Tedd *et al*, 2001). A few IGAs are intrinsically dependent on electricity, for example soldering, welding, and battery charging. These latter activities are normally found at rural service centres where grid power is often available.

Solar home systems generally play a supplementary or secondary role in IGAs by enabling an extension of the time for which an activity can be carried out. This is through the provision of good quality lighting in the evening at home or in shops and bottle stores. In shops and bottle stores, music and television can be added to entertain clients, perhaps providing some competitive advantage over neighbouring shops without these facilities. The limited role of SHSs in IGAs has also been observed elsewhere, for example by Djamin et al (2001), and also AIT (2002).

Whether SHSs allow significant extension of operating hours for shops needs to be verified because, in the absence of SHSs, rural shops still remain open after dark, relying on paraffin lamps and candles. Some shops use high–pressure paraffin mantle lamps, with light output of the order of 1400 lumens. These easily outshine SHS lights whose output is in the range 150 to 500 lumens, depending on wattage (ESD, 2003). Automotive batteries can provide the same functions as SHSs, but with the added cost and inconvenience of frequent trips for charging. In practice, the use of batteries for lighting is rare, as will be shown in Chapter 5.

Table 4.4 Summary of income–generating activities benefiting from SHSs in survey areas

Category	*Details of income generating activity*	*Nature of SHS contribution*
Handicrafts	Husband makes artificial flowers (for sale) in evenings. Is a teacher during the day.	Quality light makes production of handicrafts in evening possible.
	Wife takes school orders for jerseys. Knits by hand in the evenings.	Producing quality garments for sale is easier with good lighting
	Wife sews garments in the evenings. These are for sale or being mended for a fee.	Producing quality garments for sale is easier with good lighting
	Wife sews and knits baby sets for local sale. She works in the fields during the day.	Producing quality garments for sale is easier with good lighting
Services	Manual peanut butter production. Clients leave peanuts packets, which are labelled by children throughout the day. Father grinds peanuts on manual machine at night; clients collect peanut butter next day.	Father works peanut butter–making machine under SHS light. Free for other work during the day.
	Repair of radios and SHS charge/discharge controllers with electric soldering iron.	Soldering iron powered by SHS or battery via inverter. Workshop light powered by SHS or battery.
	Barber, using electric hair clipper.	Hair clipper powered by SHS or battery via inverter.
	Wife bakes scones and other confectionery for sale to primary school children. Day/night baking shifts.	Night baking shift requires good light, which SHS provides. Quality control easier if product is clearly visible.
	Shop/ Bottle store lighting and radio.	Powering lights and entertainment from SHS.
	Husband is a teacher who gives supplementary lessons in the evening and charges for them.	Teaching at night would not be possible without good light. Teaching at night would not be possible without good light.
Farming related	Two wives involved in gardening. Grading and packing of tomatoes, and bundling of green leaf vegetables carried out at night.	Grading and packing for sale next day facilitated by good quality light.
	Raising poultry for sale.	Solar home system powered light at night allows poultry to continue feeding and grow faster

The more frequently a battery is used, the more frequent the charging trips, and the sooner the battery will come to the end of its useful life (which is rated in *number of charge/discharge cycles*).

4.2.4 IGA by income group

Figure 4.14 shows the percentages of households involved in farming and employment in the low, medium and high–income groups. Farming is dominated by the low, and to a lesser extent, medium–income groups, while employment is strongly dominated by the high–income group.

The trend in the high–income group shows the highest dominance by employment, contrasting strongly with an equally strong dominance of farming in the low–income group. The high–income group also has the highest representation in the '*Both*' category, in which a clear trend can be seen, with the low–income group having the least representation. Since employment has already been shown to have a better rate of remuneration than farming (see Figure 4.13), it is understandably strongly dominated by high–income households.

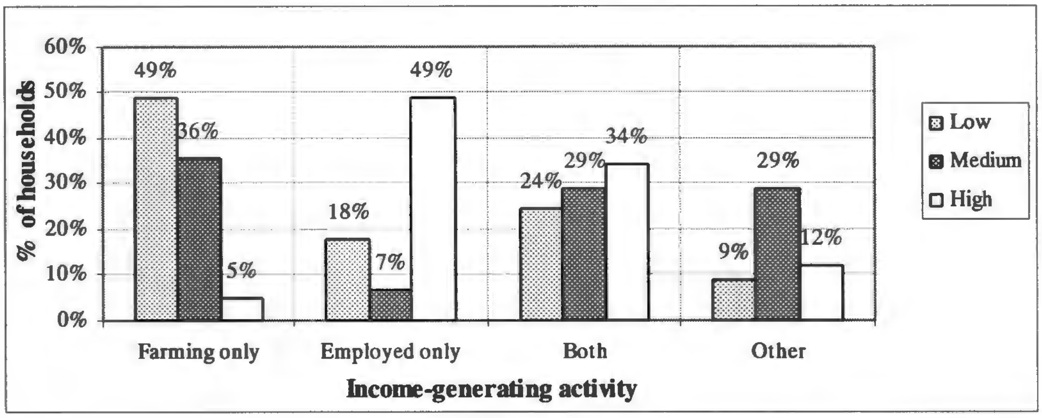

Figure 4.14 **Percentage of households involved in farming and employment across income groups**

All income groups are involved in both farming and employment at comparable levels, though the trend rises towards the high–income group. Medium income households are much more involved in other IGAs besides farming and employment.

4.2.5 Income–generating activities by survey area

Figure 4.15 shows the percentages of households involved in farming and employment in the three survey areas. Sanyati is dominated by farming, and both farming and employment.

Most people in Makosa are either employed, or undertake farming in addition to their employment. Nzvimbo has the highest percentage of households involved in farming, a pattern that ties in with the low–income group characteristic found in Figure 4.14, and the low–income status of Nzvimbo.

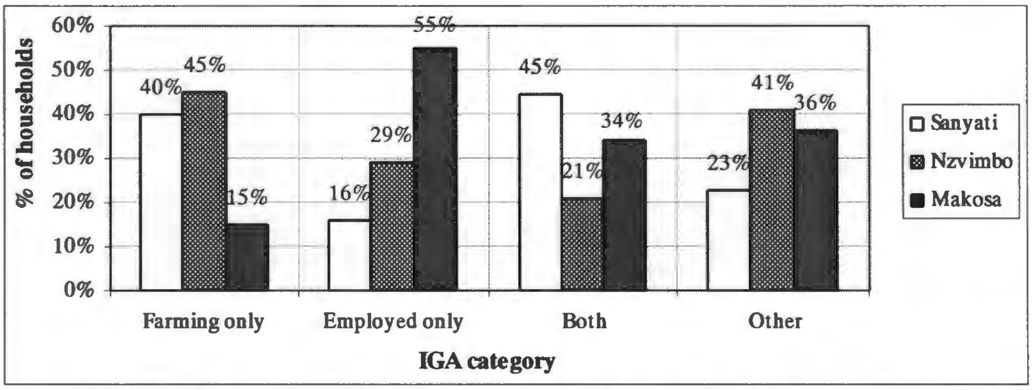

Figure 4.15 **Percentage of households involved in farming and employment across survey areas**

The farmers in Sanyati are generally not involved in subsistence farming, but in producing cotton, a lucrative export crop. This explains the prevalence of farming in this comparatively high–income area. Makosa shows high levels of employment, as well as farming and employment.

4.2.6 Contribution of family members to IGAs

Figure 4.16 shows the percentage of households with family members involved in IGAs in all survey areas. SHS–electrified households show dominance by husbands in income generating activities, like all the other categories.

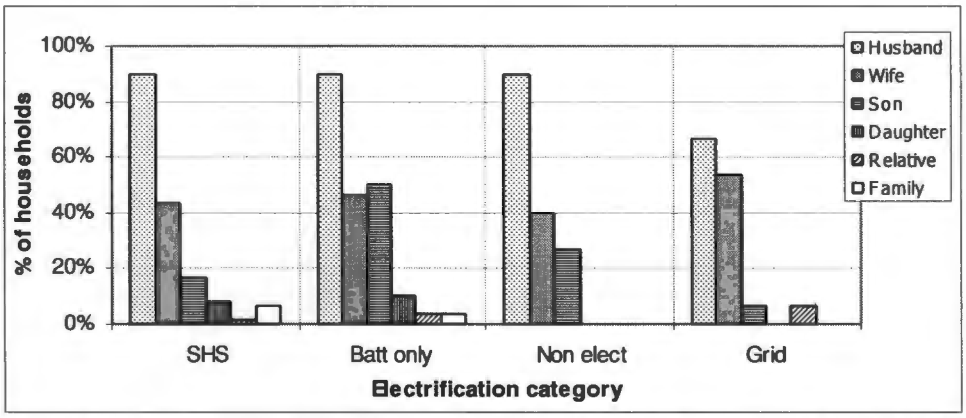

Figure 4.16 Participation of family members to income–generating activities by electrification category

When the participation of other family members is compared, SHS–electrified households and grid–electrified households show dominance by the husband and wife with other family members being well below 20%. This is particularly pronounced in the grid–electrified households where the participation of wives exceeds 50% and the contribution of husbands is less dominant. The battery–only and unelectrified households show a greater spread in the participation of family members in IGAs, this pattern being most pronounced in the battery–only households.

Sons contribute significantly more than daughters, a pattern that persists in all the electrification categories. Farming provides greater scope for family participation compared to employment where the job is for the employed family member, and usually no other member can assist. This and the fact that farming is less profitable than employment (explained in 4.2.1) may explain the association between the participation of more family members and the battery–only and unelectrified categories. It was shown in Figures 4.9 and 4.10 that battery–only and unelectrified households generally have lower incomes than the SHS–electrified and grid–electrified households.

4.2.7 IGAs by electrification category

The comparison of IGAs across the different electrification categories is preceded by an overview of all IGAs in Figure 4.17 to see the impact of grid power, since this option provides greatly increased access to electricity with no capacity or time limit for normal household applications. A metered domestic grid connection in Zimbabwe is limited to 60 amperes (equivalent to 13.2kW at 220 volts), a far cry from the time–constrained 20–60Wp installed at SHS–electrified households.

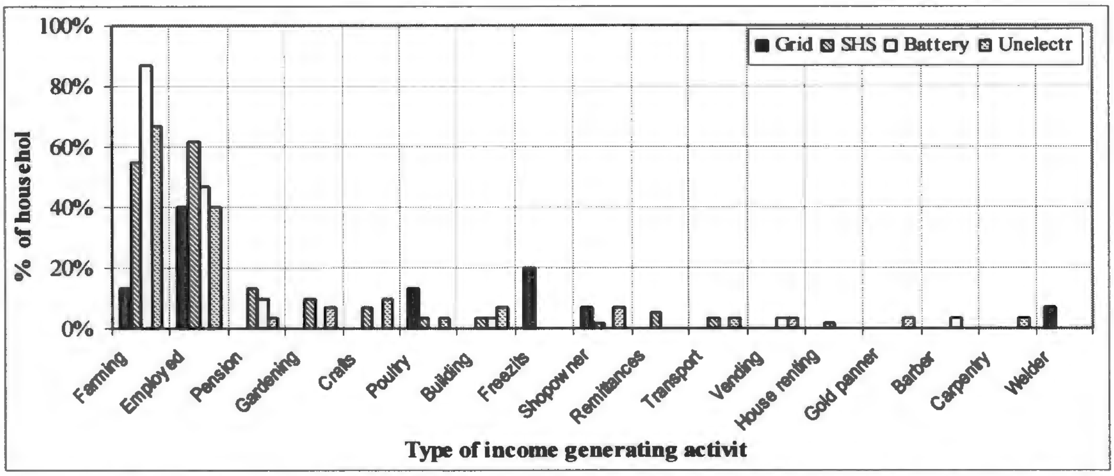

Figure 4.17 Percentage of households reporting IGAs across all electrification categories

Figure 4.17 shows that farming is less important for grid and SHS–electrified households compared to the battery–only and unelectrified households. It has already been shown in this chapter that low–income households tend to practice farming more than high–income households, and that more grid and SHS–electrified households are in the high–income groups.

The availability of grid power opens up opportunities for IGAs like electric arc welding and *freezits* (frozen drinks in 170ml plastic pockets, deep freezer required), which demand more power than is normally available in the other electrification options. These IGAs are unique to the grid–electrified households which also tend to own the necessary appliances because of their higher income status.

4.2.8 Income–generating activities by SHS dissemination mode

Figure 4.18 shows the percentages of households involved in farming and employed across the SHS dissemination modes.

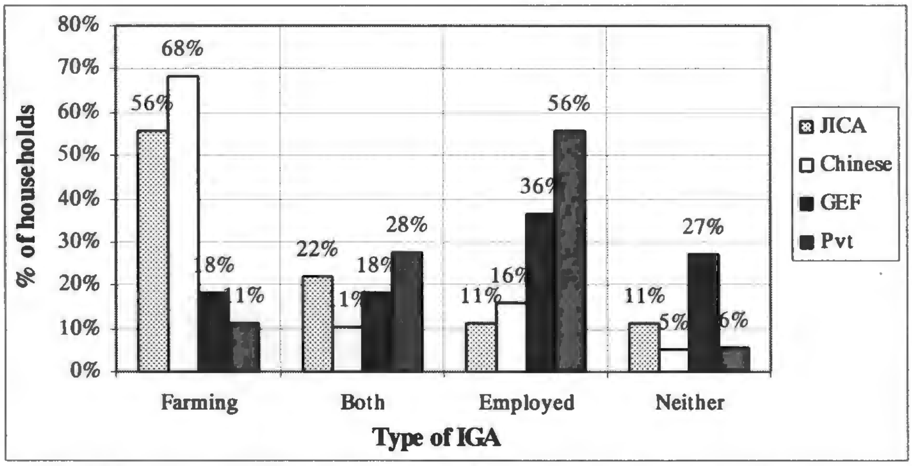

Figure 4.18 Percentage of households involved in farming and employment across SHS dissemination modes

The most noticeable patterns are the strong JICA/Chinese involvement in farming, contrasting with the GEF/Private involvement in employment. The latter group *bought* their SHSs and can be expected to have higher incomes. A similar pattern was encountered in Figure 4.11 where high–income groups dominated the GEF/Private dissemination modes. Geographical area has an influence on the above links between SHS dissemination mode and type of IGA.

It was indicated in Table 3.2 that most of the private SHSs are in Makosa, and Figure 4.15 shows that employment is the dominant IGA in Makosa. Similarly Figure 4.15 shows that farming is dominant in Sanyati and Nzvimbo, the areas where the JICA and Chinese project are based respectively.

4.3 Chapter conclusions

4.3.1 Socio economic issues

When ownership of SHS is examined in each area in comparison with the *local income levels*, more low–income households own SHS in Sanyati and Makosa than in Nzvimbo. This is the opposite of what might be expected, given that the SHSs in Nzvimbo were donated, and the poor would be the expected beneficiaries in such cases. However, because there were no clear criteria for the allocation of the donated SHSs, it seems that the more affluent households were able to use their influence and contacts to obtain the free SHSs. If donations are meant to reach the poor, the criteria to be used for determining eligibility need to be developed with clear knowledge of the target area.

The low–income group households were shown to be generally excluded from grid and SHS electrification options in the survey areas due to their inability to afford these options. With increasing incomes, households tend to procure larger SHSs where availability is not a constraint. This tendency seems to be masked by availability constraints as was seen in Makosa in comparison to Sanyati, in the discussion of Figure 4.7 in Section 4.1. Some of the incomes in Makosa suggest that the households should be able to afford SHSs, yet they do not possess these systems. The *income/PV module size* relationship in Sanyati may be an argument for the promotion of energy for productive activities, since households tend to choose higher capacity energy options when they have better incomes. This is seen in Figures 4.7, 4.8 and 4.9.

4.3.2 Income generating activity–related issues

Major factors determining which IGAs are possible are geographical location, and the influence of local climate and soil types on agriculture. This is the basis for the differences in incomes and IGAs observed between the three survey areas. At the national level, agriculture is the largest employer, a trend that came through from analysis of the survey sample where the most prevalent IGA was farming. The comparatively low incomes from farming were also confirmed in the national trends and the survey sample. The correlation between falling GDP and increased formation of new SMEs points to the need to pay more attention to the SME sector at this time when Zimbabwe's economy is going through a crisis.

4.3.3 Role of SHSs in IGAs

SHSs can power a very limited range of IGAs. Low power application that were found being powered by SHSs and automotive batteries were normal ac soldering irons and hair clippers, powered through inverters that converted the 12V dc output of the solar PV systems to 230V ac. Soldering irons were used in electronic repairs. The power requirements of the major IGA, agriculture, are well outside the capabilities of SHSs.

In most cases, SHSs provided light to enable existing IGAs to be more easily carried out at night. The IGAs benefiting in this way were typically household–based, and could still be done without SHSs but this would not be as convenient. Casual observation shows that rural shops do not close at the onset of darkness; they use candles and paraffin lamps to continue business for some hours after sunset. It is therefore debatable by how much PV systems extend the opening hours of shops in rural areas, though they may attract more customers to watch television, listen to the radio, and drink beer in better–lit surroundings. SHSs are therefore not *decisive* in determining whether or not such IGAs can be carried out. The key constraints for SHSs are the low power capability and time–constrained availability of the power. It will also be seen later that reliability issues and limited diffusion also affect their impact.

ENERGY

ELECTRICITY AND NUCLEAR BRANCH

Position	Surname	Name	Title	Telephone	Fax	E-mail
Deputy Director-General Electricity and Nuclear	Magubane	Nelisiwe	Ms	012-317 9293	012-320 0713	Send
Secretary	Nanna	Direro	Ms	012-317 9239	012-320 0713	Send

ELECTRICITY CHIEF DIRECTORATE

Position	Surname	Name	Title	Telephone	Fax	E-mail
Chief Director: Electricity	Aphane	L F	Mr	012-317 9217	012-317 9539	Send
Secretary	Vacant					

ELECTRICITY POLICY ANALYSIS & REGULATION DIRECTORATE

Position	Surname	Name	Title	Telephone	Fax	E-mail
Director: Electricity Policy Analysis & Regulation	Mahuma	David	Mr	012-317 9519	012-317 9539	Send
Secretary	Wagenaar	Lucretia	Ms	012-317 9219	012-317 9539	Send
Deputy Director: Electricity Policy Analysis & Regulation	Bantsijang	Matthews	Mr	012-317 9524	012-317 9539	send

ELECTRIFICATION DIRECTORATE

Position	Surname	Name	Title	Telephone	Fax	E-mail
Director: Electrification	Kotzé	Izak	Dr	012-317 9026	012-317 9539	Send
Secretary	Wagenaar	Lucretia	Ms	012-317 9219	012-317 9539	Send
Deputy Director: Electrification Planning	Montwedi	Molatelo	Ms	012-317 9214	012-317 9539	Send
Deputy Director: Electrification Regulation, Monitoring and Evaluation	Vacant					
Deputy Director: Administration and Macro Control	Moloi	Tubatsi	Mr	012 317 9501	012 322 5224	Send

ELECTRICITY SUPPLY DIRECTORATE

Director: Electricity Supply	Du Toit	Elsa	Dr	012-317 9216	012-322 5224	send
Secretary	Rakgolela	Bertha	Ms	012-317 9190	012-322 5224	Send
Deputy Director: Distribution	Angelides	Costas	Mr	012 317 9447	012 322 5224	Send
Deputy Director: Generation and Transmission	Moholola	Koena	Mr	012-317 9231	012-322 7319	Send

NUCLEAR CHIEF DIRECTORATE

Position	Surname	Name	Title	Telephone	Fax	E-mail
Chief Director: Nuclear	Maqubela	Tseliso	Mr	012-317 9008	012-320 0713	Send
Secretary	Nawa	Tebogo	Ms	012-317 9007	012-320 0713	Send

NUCLEAR SAFETY DIRECTORATE

Position	Surname	Name	Title	Telephone	Fax	E-mail
Director: Nuclear Safety	De Waal	Schalk	Dr	012-317 9283	012-317 9539 012-317 9282	Send
Secretary	Moyake	Thando	Ms	012-317 9203	012-322 5224	Send

NUCLEAR TECHNOLOGY DIRECTORATE

Position	Surname	Name	Title	Telephone	Fax	E-mail
Director: Nuclear Technology	Haricharun	Haresh	Mr	012-317 9215	012-317 9539	Send
Secretary	Theko	Kedibone	Ms	012 317 9340	012 322 5224	Send

NUCLEAR NON-PROLIFERATION DIRECTORATE						
Position	**Surname**	**Name**	**Title**	**Telephone**	**Fax**	**E-mail**
Director: Nuclear Non-Proliferal	Motlhaloga	Shane	Mr	012-317 9347	012-322 5224	Send
Secretary	Theko	Kedibone	Ms	012 317 9340	012 322 5224	Send
Deputy Director: Nuclear Non-Proliferation	Monale	Elsie	Ms	012-317 9347	012-322 5224	send
HYDROCARBONS BRANCH						
Position	**Surname**	**Name**	**Title**	**Telephone**	**Fax**	**E-mail**
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Secretary	Kemp	Eugenie	Ms	012-317 9005	012-322 0810	Send
Executive Assistant: DDG Energy	Deshnee	Govender	Ms	012-317 9071	012-322 0810	Send
Chief Director: Hydrocarbons	Gumede	Henry	Mr	012-317-9694	012-317-9604	Send
Secretary	Moyake	Doris		012 317-9604	012-317-9604	
ENERGY PLANNING CHIEF DIRECTORATE						
Position	**Surname**	**Name**	**Title**	**Telephone**	**Fax**	**E-mail**
Chief Director: Energy Planning	Nassiep	Kevin	Mr	012-317 9617	012 322 5224	Send
Secretary	Sollo	Pamela		012-317 9674	012 322 5224	
ENERGY PLANNING DIRECTORATE						
Position	**Surname**	**Name**	**Title**	**Telephone**	**Fax**	**E-mail**
Director: Energy Planning	Vacant					
Secretary	Vacant					
Deputy Director: Energy Planning	Maake	Robert	Mr	012 317 9025	012 322 5224	Send
ENVIRONMENT & ENERGY EFFICIENT DIRECTORATE						
Position	**Surname**	**Name**	**Title**	**Telephone**	**Fax**	**E-mail**
Director: Environment & Energy Efficient	Tyatya	Sandile	Mr	012-317 9020	012-322 5224	Send
Secretary	Matsomela	Thembi	Ms	012-317 9209	012-322 5224	Send
DATABASE AND ADMINISTRATION DIRECTORATE						
Position	**Surname**	**Name**	**Title**	**Telephone**	**Fax**	**E-mail**
Director: Database & Administration	Vacant					
Secretary	Vacant					
Deputy Director: Administration	Vacant					
Deputy Director: Data Base	Van Wyk	Johan	Mr	012-317 9024	012-322 5224	Send
RENEWABLE ENERGY DIRECTORATE						
Position	**Surname**	**Name**	**Title**	**Telephone**	**Fax**	**E-mail**
Director: Renewables Energy	Lisa	Kosi	Ms	012-317 9307	012-322 5224	Send
Secretary	Moyake	Thando	Ms	012-317 9203	012-322 5224	Send
Deputy Director: Renewables	Golding	Tony	Mr	012-317 9213	012-322 5224	Send
Deputy Director: Renewables	Otto	Andre	Mr	012-317 9225	012-322 5224	send
HYDROCARBONS CHIEF DIRECTORATE						
Position	**Surname**	**Name**	**Title**	**Telephone**	**Fax**	**E-mail**
Chief Director: Hydrocarbons	Vacant					-
Secretary	Vacant					-

PETROLEUM & GAS REGULATION DIRECTORATE						
Position	**Surname**	**Name**	**Title**	**Telephone**	**Fax**	**E-mail**
Director: Petroleum & Gas Regulation	Burger	Theunis	Mr	012-317 9114	012-317 9388	Send
Secretary	Oosthuizen	Marie	Mrs	012-317 9181	012-317 9388	Send
Deputy Director	Dreyer	Boy	Mr	012-317 9223	012-322 5224	Send
Deputy Director	Baak	Hein	Mr	012-317 9221	012-322 5224	Send mail
PETROLEUM POLICY DIRECTORATE						
Position	**Surname**	**Name**	**Title**	**Telephone**	**Fax**	**E-mail**
Director: Petroleum Policy	Singh	Manny	Mr	012-317 9549	012-322 5224	Send
Secretary	Vacant					
Deputy Director: Petroleum Policy	Pearce	Stephen	Mr	012-317 9206	012-322 5224	send
COAL & GAS DIRECTORATE						
Position	**Surname**	**Name**	**Title**	**Telephone**	**Fax**	**E-mail**
Director: Coal & Gas	Surridge	Tony	Dr	012-317 9204	012-317 9388	Send
Secretary	Oosthuizen	Marie	Mrs	012-317 9181	012-317 9388	Send
Deputy Director: Coal & Gas	Grobbelaar	Chris	Mr	012-317 9232	012-322 5224	Send

CHAPTER 5: IMPACT OF SOLAR HOME SYSTEMS ON ENERGY USE

This chapter examines the impact of solar home systems (SHSs) on energy use among households by first examining the fuels used for selected end uses, then by looking at fuels switching preferences and finally by looking at energy expenditure. In each case the impact of SHSs is evaluated.

In considering solar home systems (SHS) impact on fuels used, the patterns of appliance ownership are also looked at, because the type of appliances owned have a direct effect on what forms of energy are used. The forms of energy that a household has access to will also determine what appliances it can use. The examination of fuel switching preferences will indicate the extent of user satisfaction with the different energy sources and show the extent to which SHS is a preferred fuel in comparison with other energy sources. The last section looks at the links between energy expenditure and income levels, electrification category, and SHS dissemination mode. This is to see what comparative impact on energy expenditure SHSs have.

5.1 Impacts of solar electrification on main energy end uses

In Zimbabwe the *typical fuel use pattern in rural areas* is to cook and heat with wood, and illuminate with paraffin (Campbell & Mangono, 2000; Central Statistical Office (CSO), 1998). This contrasts sharply with the pattern in urban areas as shown in Figure 5.1.

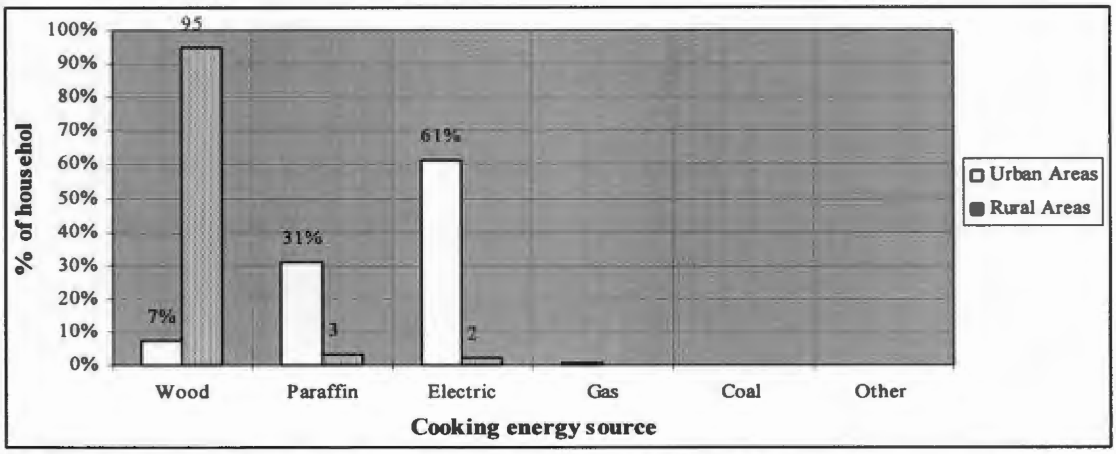

Figure 5.1 Percentage of urban and rural households using specified cooking energy sources in Zimbabwe

Source: Based on data from CSO, 1998

Figure 5.1 shows the urban and rural energy use patterns, and also shows that there is negligible household use of liquefied petroleum gas (LPG) and coal in Zimbabwe. A table with cooking fuel data for all Zimbabwe's provinces is given in Appendix 5.1.

The use of candles is limited since paraffin has always been subsidised because the poor use it. Growing abuse of the paraffin subsidy by industry has forced government to enact measures to target the subsidy more accurately. Current practice is for paraffin bought in small quantities to be sold at subsidised prices whilst bulk purchases are not subsidised.

5.1.1 Cooking energy sources

Figure 5.2 shows the percentage of households in the different electrification categories using grid electricity, wood and paraffin as their main cooking fuels. Clearly the possession of batteries and SHSs do not make any difference to cooking fuel. An obvious reason is that cooking requires power in the range of several kilowatts, well outside the range of batteries and SHSs. Cooking with paraffin was not encountered in the Thesis survey areas. This is consistent with Zimbabwe's *rural* energy use patterns, where wood is the predominant cooking fuel, and paraffin is used for lighting, not cooking.

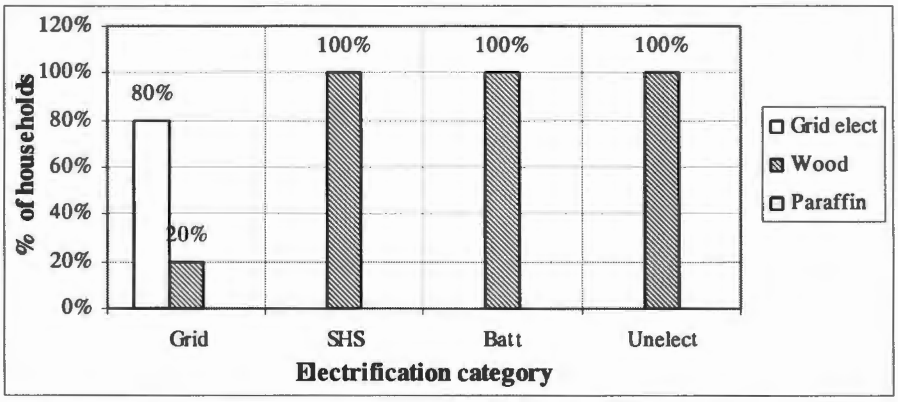

Figure 5.2 Percentage of households in the different electrification categories using specified main cooking fuels

Grid–electrified households differ from the typical rural pattern by predominantly cooking with electricity. Eighty percent of grid–electrified households cook with electricity while the remaining 20% cook with wood in an effort to reduce electricity bills.

This pattern of cooking with grid electricity is similar to that in grid–electrified urban households in Zimbabwe, shown in Figure 5.1.

SHSs do not have any impact on cooking fuels as shown by the dependence on firewood by SHS electrified households, which is no less than that of battery–only and unelectrified households. This fact is not surprising given the level of power that SHSs provide, ranging from 10Wp to 83Wp against the minimum of 1 000W for a small single hotplate for cooking. The burden of collecting firewood, which is borne by women, is consequently not alleviated by the dissemination of SHSs. This situation makes it necessary to include other energy sources or technologies such as LPG, biogas and improved woodstoves. One approach that attempts to provide a range of energy supply options is the ***energisation*** approach. Energisation entails the supply of a range of energy sources and services, for example solar photovoltaic (PV), liquefied petroleum gas (LPG), and paraffin, and is a part of efforts to improve supply of energy to rural areas in South Africa.

5.1.2 Lighting energy sources

Figure 5.3 shows the percentage of households in the different electrification categories using grid electricity, solar photovoltaic, paraffin, candles, automotive batteries, and combinations of solar PV with candles and paraffin. Virtually all SHS–electrified households use PV electric lighting.

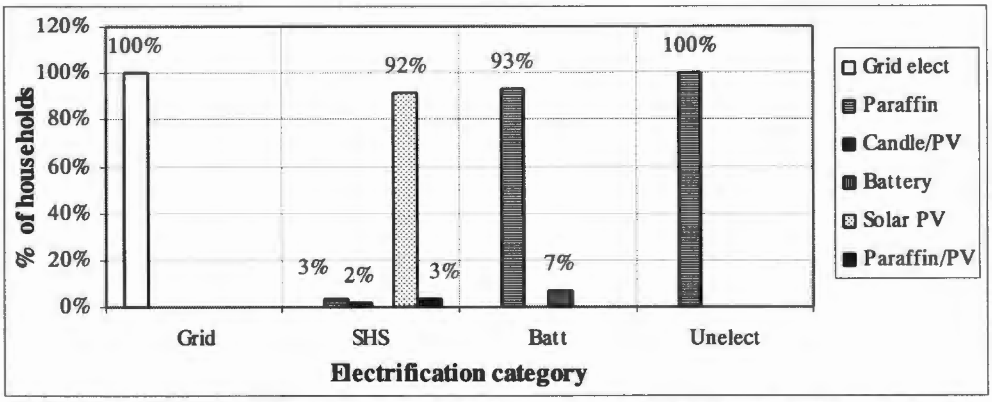

Figure 5.3 **Percentage of households in the different electrification categories using specified fuels as main lighting fuels**

The unelectrified households depend entirely on paraffin for lighting, and battery–only households show predominantly the same pattern; lighting with automotive batteries is rare. The picture changes dramatically for SHS–electrified households where the use of paraffin as the main lighting fuel drops dramatically. Grid electrified households show a similarly high dependence on electric lighting.

It is important to note that in most cases not all rooms at SHS–electrified households are fitted with PV lights. This, and the fact that PV lights are fixed installations which cannot be moved from room to room, means it is normal practice for households to have other lighting devices for moving from room to room at night, and when the SHS lighting fails, either due to a burnt out tube or system fault. This implies that households rarely, if ever make a complete switch from paraffin to SHSs. This is not unusual because urban households with grid electricity that is much more reliable than SHSs routinely keep candles. They are also known to have bought solar lanterns from the GEF Solar Project to use as backup lights when there are grid power outages.

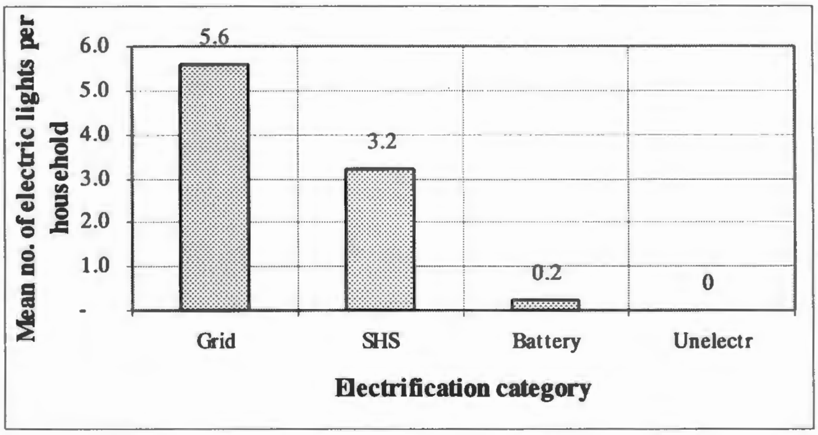

Figure 5.4 **Mean numbers of electric lights per household across different electrification categories**

Figure 5.4 shows that SHSs allow greater ownership of electric lights compared to battery–only households, but the number of lights remains more limited compared to the grid–electrified households. Often the number of solar lights is less than the number of rooms to be illuminated. This leads to dual use of paraffin and solar lighting. In one case a SHS is also used to power the radio in an attempt to reduce electricity bills, though this is misguided.

The main impact of the SHSs on lighting is the replacement of paraffin, which is normally used in wick lamps for illumination in rural households. The switch to fluorescent solar lights leads to a major improvement in light quality. A candle or paraffin wick lamp provides about 10 to 15 lumens of light with an efficiency of roughly 0.1 lumens per watt of input power. In comparison, a 12–volt fluorescent light will produce 150 to 500 lumens of light (depending on wattage of the light) with a higher efficiency of 24 to 50 lumens per watt of input power (ESD, 2003). The higher light output allows activities like reading, studying, sewing, and knitting to be comfortably carried out in the evening. The quality of lighting in rural shops is also improved, though the impact on hours of opening of these businesses is not clear, because they already operate after dark with candles or paraffin lighting.

5.1.3 Media applications

Figure 5.5 shows the percentage of households using specified main energy sources for their radios. The percentage of SHS–electrified and battery–only households using their SHSs and automotive batteries for powering radios is the same. These two energy sources are similar in that they both rely on energy stored in a battery. The SHS has the convenience of having on–site charging while battery–only households periodically have to take their batteries for charging. Grid electricity shows the highest percentage of households using this energy source for their radios. The low power requirement of radios means that unelectrified households are able to purchase dry cell for their radios. Thus all electrification categories can power radios.

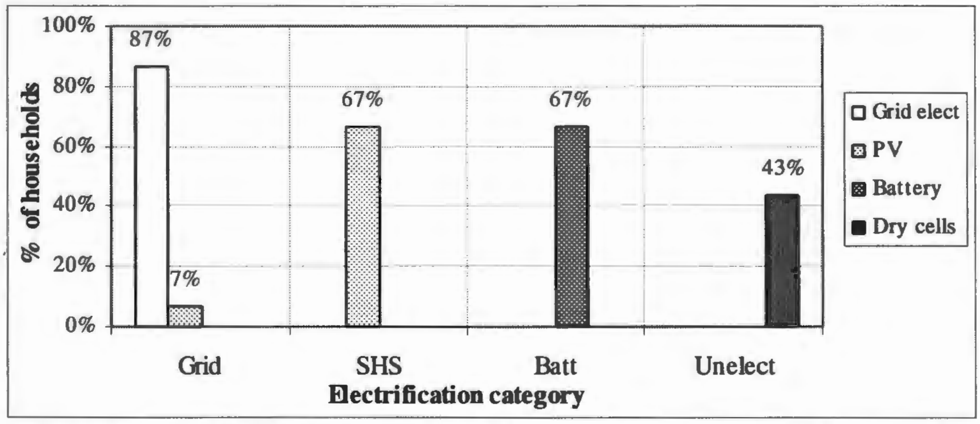

Figure 5.5 Percentage of households in the different electrification categories using specified radio energy sources

Battery–only and unelectrified households face interruptions if they do not have cash to purchase dry cells, or to take their automotive battery for charging. The major impact of SHSs in the use of radios is to overcome this break in service faced by both the unelectrified households and battery–only households. Battery protection is an added bonus in having SHS, particularly where a charge/discharge controller is fitted. Even on a SHS without a charge/discharge controller, the daily replenishment of charge is better for the battery than being always fully discharged before the next charge.

Figure 5.6 shows the percentage of households using specified main energy sources for their televisions. There is similarity between the SHS–electrified households and battery–only households.

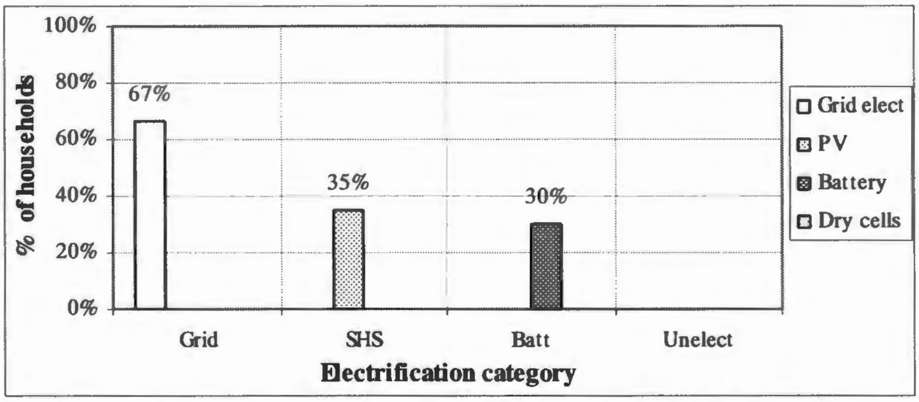

Figure 5.6 Percentage of households in the different electrification categories using specified TV energy sources

The percentages of households using SHS and automotive batteries for powering televisions fall to about half of those seen in Figure 5.5. SHSs have a small advantage over automotive battery–only systems in powering televisions through having integral battery charging.

A major difference from Figure 5.5 is that unelectrified households no longer appear. This is due to both the scarcity of televisions among these lower income households, and because powering televisions with dry cells is impractical. The higher current drain of televisions would require very frequent purchases of dry cells, leading to unacceptably high running costs. Grid–electrified households show a much higher percentage powering televisions with grid electricity. This is because they face no constraint in powering both black and white and colour televisions, and also because they tend to have better incomes and are better able to afford televisions compared to all the other households.

5.2 Impact of solar electrification on appliance ownership

The type of appliances owned by a household can have a link to income–generating opportunities. What appliances can be used however depends on the sources of energy at the disposal of the household. Figure 5.7 shows the percentage of households owning selected electrical appliances across different electrification categories. The major impact of SHS is on light and television ownership. Light ownership, at 95%, is over four times greater than among battery–only households, and comparable to the 100% ownership among grid–electrified households. Television ownership is slightly more than that among grid–electrified households, though this seems to be at the expense of cassette radios when compared to the other two categories.

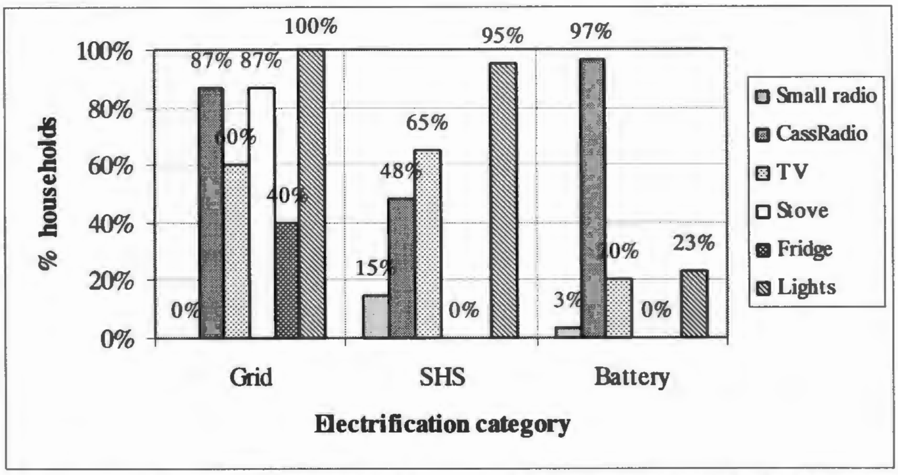

Figure 5.7 Percentage of households owning selected electrical appliances across different electrification categories

The explanation for this may be that the SHS–electrified households sacrifice cassette radios for televisions while grid electrified households can afford both comfortably. On the other hand, battery–only households, largely unable to afford televisions, spend their money on cassette radios rather than on cheaper radios that have no cassette capability.

The major advantage of SHS over automotive batteries is that the inconvenience of taking the battery for charging is removed, and more energy is available every evening since the PV module charges the system battery everyday.

Electric stoves and refrigerators are unique to grid–electrified households. This is because neither of the other two categories can power these appliances. There is also 100% ownership of electric lights, coupled with a high level of television ownership, comparable to that found in SHS–electrified households.

The most notable feature among battery–only households is the nearly universal ownership of cassette radios (97%) coupled with far less televisions (20%), lights (23%) and small radios (3%).

Figure 5.8 compares appliance ownership among different SHS dissemination modes. The SHS–electrified households show a high level of light ownership, particularly in the case of project systems, which always include lights. Light ownership among privately bought SHSs is only slightly lower, since one of the reasons for procuring a SHS, as opposed to a battery alone for example, is better lighting.

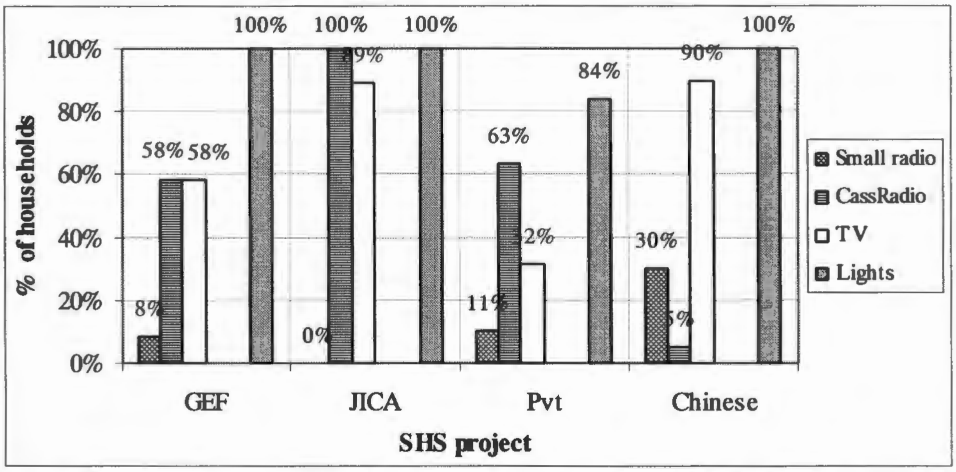

Figure 5.8 **Percentage of households owning selected appliances across the different SHS dissemination modes.**

TV ownership is high in the JICA and Chinese projects. In the Chinese project this is because the TVs were handouts, and in JICA Study Project because all systems are in Sanyati, a high–income area.

Ownership of small radios without cassette players is very low, these being more than cassette radios only in the Chinese donation project. In fact, without the Chinese project donation of TVs (and lights with the systems), the households in the Chinese donation project would look dismal in comparison here. Figure 5.9 compares appliance ownership across the three income groups. It shows that generally radios without cassette capability are unpopular with all income groups.

This is probably because these radios do not allow the user the flexibility to record and play their own music, and also because the price difference between plain radios and the cheapest cassette radios is not large and is therefore not a significant barrier to low–income households.

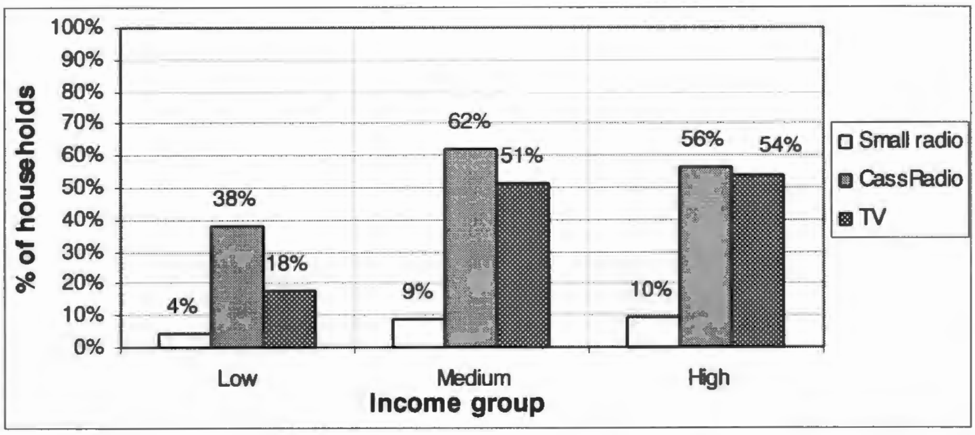

Figure 5.9 **Percentage of households owning audiovisual appliances across income groups**

Ownership of the more expensive cassette radios and TVs is higher in the medium and high–income groups. The high–income group has slightly more televisions and less cassette radios than the medium income group. In estimating the load for SHSs when sizing, it is important to note the considerably higher power consumption of cassette decks, which is largely due to the electric motors in them.

5.3 Impact of solar electrification on fuel switching preferences

Figure 5.10 shows the energy source preferences among SHS–electrified households. The preference for grid electricity for all applications is quite similar to that found among grid–electrified households shown in Figure 5.11. Also similar, though lower, is the preference for wood for thermal applications, namely cooking, space heating and ironing. There was also the misguided belief in three percent of households that lighting with solar PV would save on grid electricity costs.

The most pronounced difference between grid–electrified and SHS–electrified households is that SHS–electrified households show equal preference between grid electricity and SHS for powering radios. This suggests that SHSs perform satisfactorily for this low power application, and that users are not satisfied with the performance of SHSs for lighting and televisions, their other common applications.

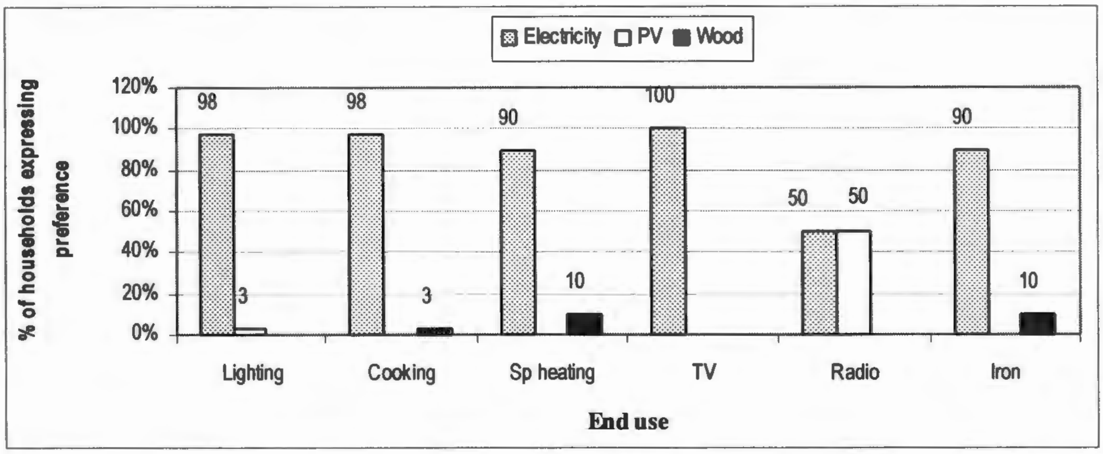

Figure 5.10 **Energy source preferences for selected end uses among SHS–electrified households**

Figure 5.11 shows the preferred energy sources among grid–electrified households. Satisfaction with the grid is clearly apparent from the almost total absence of desire for other energy sources.

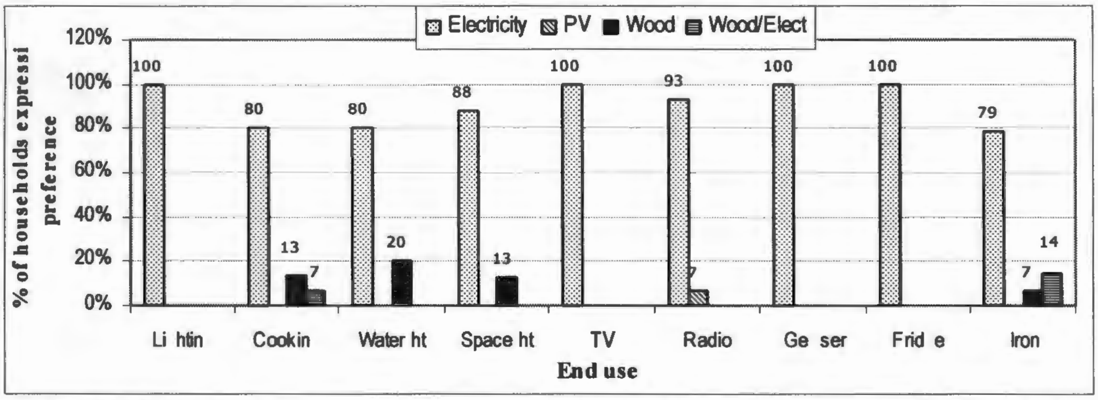

Figure 5.11 **Energy source preferences for selected end uses among grid–electrified households**

The major exceptions are the thermal applications, water and space heating, and ironing, where wood is preferred by seven to twenty percent of the households. The reason given for this preference is the need to reduce electricity bills. This trend suggests that when electricity becomes more expensive, more households will opt to use other energy sources for thermal applications like cooking and space heating to cut their electricity bills.

In Figure 5.11 seven percent of households preferred to use solar PV for their radios, a misguided belief that this would be cheaper than using grid electricity. This belief stems from the fact that once paid for, SHSs do not have a monthly usage bill and many SHS owners regard the energy supplied as free. They generally do not consider occasional costs like repair and replacement costs in comparing the cost of SHSs with monthly grid electricity bills. The preferences of automotive battery–electrified households are shown in Figure 5.12.

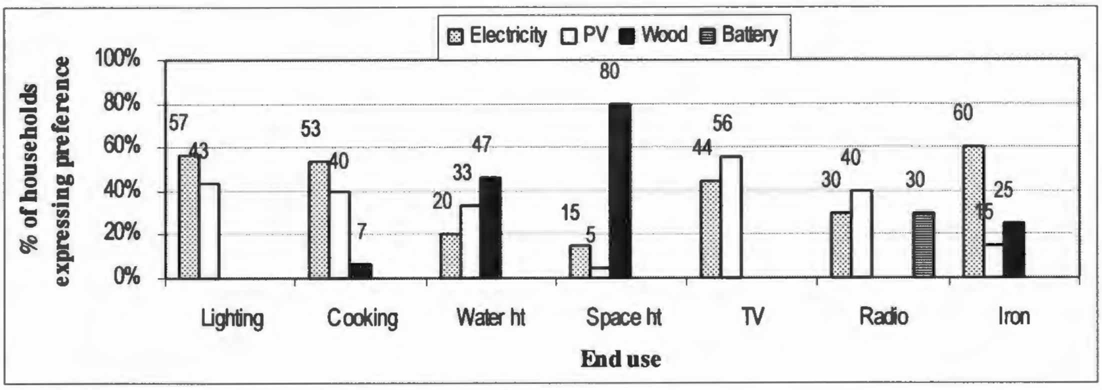

Figure 5.12 Energy source preferences for selected end uses among automotive battery–electrified households

These change considerably from the SHS and grid–electrified households. The preference for wood is much greater, particularly for space and water heating. Grid electricity is still widely desired, but preference for solar PV surpasses that for grid electricity in some cases. Those households wishing to use solar PV for cooking, space and water heating, and ironing are clearly not sufficiently informed of the limitations of this energy source. It is interesting to note that like the SHS–electrified households, some 30% of battery–only households find radios to be the only load for which they are happy to use their batteries. Again this is due to the low power consumption of radios, which makes the use of automotive batteries acceptable by allowing many hours of daily usage and longer periods between battery charges when compared to more power–hungry application such as lighting and televisions. The preferences to power radios and televisions with solar PV are greater than for grid electricity, pointing to a belief that SHSs will cope well with lighting, radios and televisions. This expectation is not supported by those who have experienced the limitations of SHSs, as shown by the different preferences of SHS–electrified households in Figure 5.12.

The preferences of unelectrified households are shown in Figure 5.13. Once more, grid electricity and wood predominate as the most desired energy sources. Wood is most desired for thermal applications, and the most pronounced preference for solar PV is for lighting, for which it is preferred by 60% of households, compared with 30% for the grid.

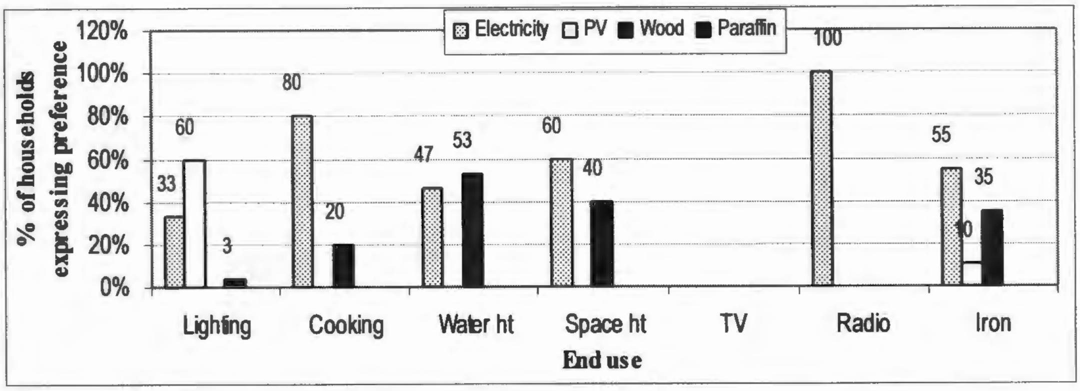

Figure 5.13 **Energy source preferences for selected end uses among unelectrified households**

There is little preference for solar PV for other end uses, the only other preference being 10% of households, for ironing, which is due to a misunderstanding of the capabilities of SHSs. Dry cells, which are normally used for radios by unelectrified households, are clearly not liked as shown by the 100% preference for grid electricity for powering radios among these households.

The foregoing comparisons show that some households unfamiliar with SHSs may show unrealistic preferences for SHSs out of ignorance. Households exposed to SHSs are happy to use these systems on small loads, particularly radios, where the limitations of the SHSs are less pronounced. Obviously where the grid will not reach, SHSs give their owners the advantages of greater convenience, and battery protection over those using automotive batteries. Households using dry cells face more severe load limitations and higher battery costs.

The impact of SHSs on user preferences can be seen to be mainly through greater awareness of the capabilities of these systems. Users exposed to SHSs seem to be frustrated by the limited service delivery of the SHSs. In the absence of the grid, these users have little choice because alternative sources of electricity like small hydro, gensets, biogas and wind generators have not been promoted as vigorously as SHSs. It is likely that current SHS users will be receptive to different energy sources that promise more power and flexibility than SHSs.

5.4 Energy expenditure

The overall pattern of percentage of household income spent on energy for all households in the Thesis survey is illustrated in Figure 5.14. The relatively heavy burden placed on lower income households by energy expenditure is clearly apparent.

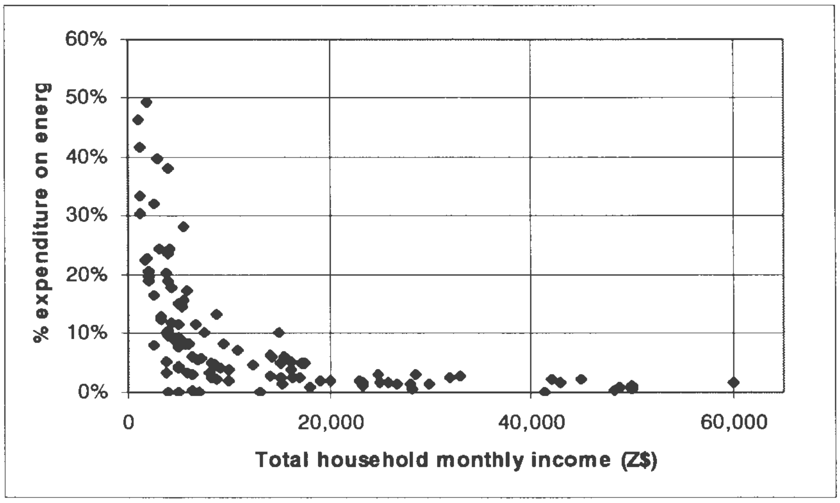

Figure 5.14 Change in percentage of total monthly household income spent on energy with rising income

In the Thesis survey, the average fraction of income spent on energy for the poorest households was 19%, compared to 2% for the high–income group households. The mean percentage of income spent on energy for each income group is given in Table 5.1.

Table 5.1 Mean percentage of income spent on energy by different income groups

Income group	*% of income spent on energy*
Low income	19%
Medium income	6%
High–income	2%

Table 5.2 shows that the actual expenditure on energy is not dramatically different across all electrification categories. There is similarity in the size of the *energy burdens* of the battery–only and unelectrified households because of their similar average monthly incomes.

Table 5.2 Mean income and expenditure on energy in different electrification categories

	SHS	*Battery*	*Unelectrified*
Mean income Z$/month	*17 262*	*8 533*	*9 921*
Mean energy expenditure Z$/month	*496*	*552*	*575*
% of monthly income spent on energy	*3%*	*6%*	*6%*

By virtue of their ***higher average monthly incomes***, almost double those for the battery–only and unelectrified categories, SHS–electrified households spend a smaller proportion of their incomes on energy. Similar patterns have been reported within the region, for example in Botswana (Afrane–Okese, 2001).

Compared to the overall differences in the energy burden, the differences across SHS dissemination modes are not large as shown in Table 5.3. The mean monthly income and mean monthly energy expenditure for the GEF Solar Project households are notably higher than for the other dissemination modes. The major reason for this is that the majority of the clients for the GEF Solar Project were ***salaried civil servants*** working in rural areas. These are generally professional earning more than other rural inhabitants. The energy expenditure of the better–paid civil servants is, not surprisingly higher.

Table 5.3 Expenditure on energy by SHS dissemination mode (Z$ per month)

Project	*Mean monthly income Z$*	*Mean monthly energy expenditure Z$*	*% of income spent on energy*
GEF	32 801	856	3%
JICA	16 349	373	2%
Chinese	13 312	507	4%
Private	19 131	456	2%

Since each solar light replaces a paraffin lamp, the cost of replacement with solar is an additional cost. This is because each paraffin lamp costs Z$8.19 per month in paraffin costs (***using figures provided in sub section 6.1.2 in Chapter 6***), and a 5 ampere load–limited grid connected household using 6 incandescent light bulbs and no other load would pay $12.50 per month per bulb. A two–light SHS–electrified household paying a Z$75 monthly maintenance fee would be paying Z$37.50 per light each month. Thus for each paraffin light replaced with a PV light under the JICA Study project in 1997, the net increase in expenditure per light would be Z$29.31, or over 350% of the original cost of illuminating with paraffin. This calculation is ***not based on a quality of light*** *comparison*, because households changing from one lighting energy source to another do not use this criterion to determine number of lights needed to obtain an equivalent luminous intensity.

5.5 Chapter conclusions

The impact of SHSs on energy use among households is most pronounced on lighting where it replaces paraffin lamps in the rooms where PV lights are installed *and working*. The improvement in the quality of lighting is high when compared to paraffin or candle lighting. This impact is limited by the low reliability of SHSs, which obviously forces households to have backup paraffin lamps. Rooms without PV lights still have to be illuminated with paraffin. The failure of SHS to make an impact on major energy service needs including cooking and heating makes it necessary to also offer other options; the *energisation* approach.

Grid–electrified households have no time constraints on use of their electric lights, and for many other uses. These households have more electric lights on average than the other electrification categories. Because the power consumption of electric lights is insignificant in the context of a grid–electrified household, grid–electrified households can install lights in every room, and outside security lights, without making much difference to their bills. Cooking, water and space heating influence the size of the electricity bill much more by virtue of their much higher power consumption.

Media applications (radio and TV) benefit considerably more from SHSs when compared to automotive batteries. This is because the SHS battery is charged automatically every day, and is able to give consistent output daily. Battery–only systems have to put up with a slowly depleting battery, till the battery is too weak to operate connected equipment. The battery must then be taken for charging, leaving the household without electric power. Batteries exposed to this pattern of use will have a short service life due to damage caused by the frequent deep cycling. Grid electricity provides the greatest benefit for media applications by not placing any constraints on usage.

The level of satisfaction with SHSs and automotive batteries is lower than with grid electricity. The level of power and versatility of grid electricity removes the inconveniences imposed by the other energy sources. These inconveniences include smoke from wood and paraffin fumes, and limitations on availability of electric power, which imposes a limit on what appliances can be used, and how long they can be used each day. Some households with grid electricity feel the need to reduce the monthly electricity bill, in some cases reverting to wood for thermal applications. Thermal applications like cooking and heating are the major contributors to the monthly electricity bill by virtue of the relatively high power of the appliances used for these applications.

SHS–electrified households spend a smaller proportion of their incomes on energy than do battery–only and unelectrified households, which are generally the poorest households in the survey sample. The absolute amounts spent on energy are not dramatically different between the different electrification categories, but these amounts represent a greater proportion of the considerably smaller incomes of the poor.

CHAPTER 6: EFFECTIVENESS OF SOLAR PHOTOVOLTAIC POWER SYSTEMS AT HOMES AND PUBLIC FACILITIES

This chapter looks at selected issues affecting the effectiveness of solar photovoltaic (PV) systems at homes and public facilities. The first section of the chapter looks at the access, service level and cost of service to clients of solar home systems (SHSs), compared to grid–electrified and unelectrified households. In this comparison paraffin is the fuel examined for the unelectrified households because it is the fuel used for illumination. The second section compares selected issues between different solar electrification initiatives. The issues examined are financial viability, maintenance provision, flexibility in level of service provision, ownership and payment, battery and light replacement, design of systems, theft of modules, and environmental impacts. The third and final section assesses the effectiveness of solar PV systems on the basis of user views and preferences.

6.1 Comparison of households using solar home systems, grid electricity, and paraffin

6.1.1 Access to solar home systems, grid electricity and paraffin

This section looks at how many households have access to SHSs, and how this access compares that to paraffin and the electricity grid.

Zimbabwe had 2 653 082 households at the end of 2002 (Central Statistical Office (CSO), 2003). About 65% of the population lives in rural areas, which translates to about 1 724 500 rural households. The estimated national total of 85 000 SHS represents access to SHSs for 4.9% of rural households, or 3.2% of all households in Zimbabwe. In 1997, about 35.2% of all Zimbabwean households were grid–electrified, but this percentage falls to 6.8% when only rural households are considered (CSO, 1998). While *rural* access to SHSs and grid electricity is not very different, the *national average access* to grid electricity is nearly six times that for SHSs. Paraffin is used for lighting in virtually all rural households, implying widespread access to this fuel. The lower level of diffusion of SHSs necessarily limits their national significance and impact. In addition, SHSs fail to reach the poor as already shown in Figures 4.8 and 4.9 in Chapter 4.

6.1.2 Service level and cost comparison of solar home systems with grid electricity and paraffin

Figure 6.3 shows that small modules of SHSs dominate in the survey areas because households buying SHSs primarily select on the basis of affordability. The mean module size for all SHS–electrified households in the survey sample is 46.4Wp, and the corresponding median value is 43.5Wp. The peak at 70Wp is due to the Chinese–donated solar PV systems at Nzvimbo. It is also clear from the trend line in Figure 6.1 that without the Chinese–donated solar PV systems, the mean module size would be closer to 30Wp. This dominance of small size modules severely limits the ability of the SHSs to meet the needs of most households who wish to run larger electronic appliances like colour televisions and videocassette recorders, or to run their small appliances for longer periods each day.

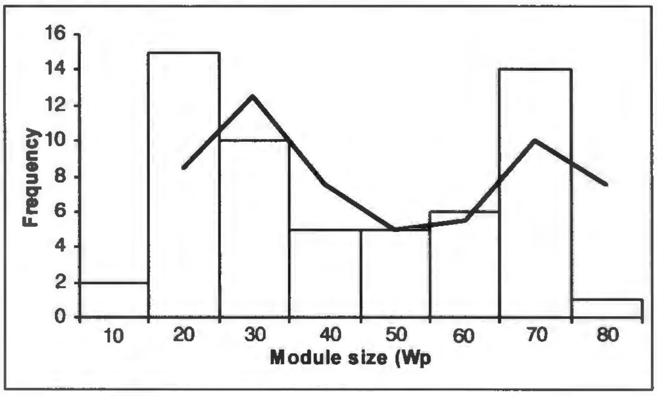

Figure 6.1 **Histogram and trendline showing the frequency of solar module sizes**

A small SHS with a 60Ah battery would supply 24Ah of energy daily (288Wh at 12 volts) if the battery was discharged to 40%. A grid–connected household with a small five ampere load–limited supply would have up to 26.4kWh of energy per day (five amps x 220 volts x 24 hours) available.

The load in the following comparison is assumed to be:

- Electric lighting for three hours per day
- One x 10 watt cassette radio used for 10 hours daily
- One x 30W monochrome television viewed for three hours daily.

A *SHS–electrified household* would consume 289Wh (*3 x 11W lights x 3 hours, plus 1 x 10 watt radio x 10 hours, plus 1 x 30W television for three hours*). This means all the estimated 288Wh available energy is used up. If the battery is a shallow cycle automotive type, a 15% depth of discharge gives only 9Ah (*108Wh at 12 volts*), which is just *one third* of the required amount of energy. Shortfalls like this cause dissatisfaction with SHSs, causing a desire to switch to grid electricity.

A *grid–connected household* would normally use incandescent electric bulbs (60W assumed, the closest equivalent to 11W fluorescent lights in terms of light output). The energy used by the grid–electrified household would be 730Wh, which is about two and half times that used by the SHS–electrified household. This is due to the less energy–efficient lights generally used with grid electricity. In addition, most grid–electrified households cook with electricity. Assuming a cooking time of two hours with a 2kW hotplate, another 4kWh would added to the daily energy consumption, giving a total of 4.73kWh. This is only about 18% of the total energy potentially available from the 5A grid connection daily, and is more than 16 times the energy used by the SHS–electrified household.

The above comparison underlines the much greater power that thermal applications demand, well out of reach of the capabilities of any SHS.

In 1997 in the Japan International Cooperation Agency (JICA) Study Project, the households having the option of *one light and one power point*, or *two lights* only, were paying Z$75 monthly for the service. Based on the same year's domestic tariff (see tariff table in Appendix 6.1.3), a grid–connected household would be able to consume over 225kWh of energy each month for the same payment of $75 per month. This is apparent from the calculated monthly bills for grid electricity consumption shown in Figure 6.2 (*see the 1997 line, third from the bottom*).

This is nearly 67 times as much energy as the 3.38kWh that each 25Wp module used in the Japan International Cooperation Agency (JICA) Study Project would collect in a month, assuming 4.5 peak sun hours daily (*25Wp* x *4.5hrs* x *30 days*). With the load–limited five ampere connection, *18* x *60watt incandescent electric lights* can be operated with no time limits. Using a paraffin wick lamp for illumination, Z$75 would buy 41 litres of paraffin at the subsidised 1997 price of Z$1.82 per litre.

One wick lamp consumes roughly 50ml per hour (IAEEL, 1999), which is equivalent to 4.5litres per month at three hours illumination per night. The quantity of paraffin bought with Z$75 would therefore be able to run *nine wick lamps* (*41 litres/4.5litres*) for three hours every night for one month.

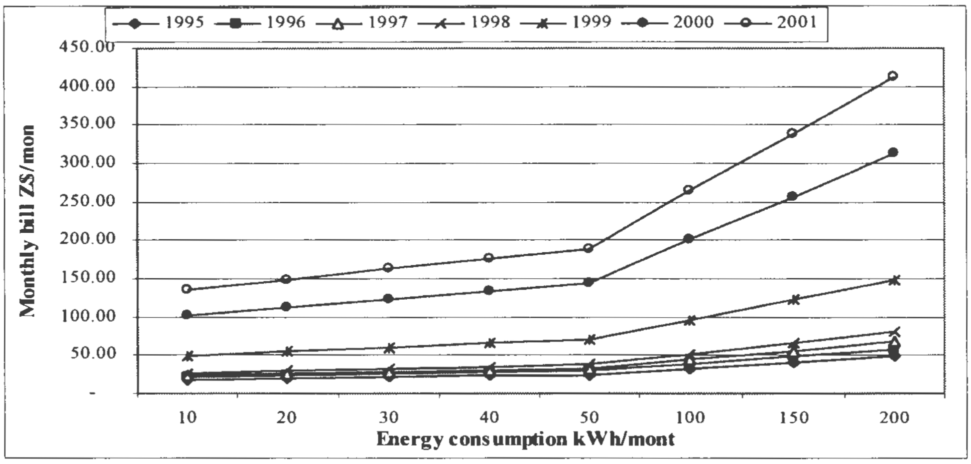

Figure 6.2 **Variation of monthly electricity cost with increasing consumption, calculated for 1995 to 2001 tariffs**

For the monthly cost of Z$75 per month, the JICA Study Project was able to provide a maximum of two lights per household, with time constraints. For this amount, a grid connection would provide lighting for all rooms of a normal household, with power to spare, as would paraffin using wick lamps. In terms of cost per light point, the grid connection provides *twice as many* lights as paraffin and *nine times as many* as the SHS. SHS fares worse that the two other options on the basis of number of light points. The above comparison does not attempt to look at the same level of illumination because, when households replace a paraffin lamp with a solar light, it is on the basis of *one lamp in place of the other*, not on the basis of luminance.

6.1.3 Environmental impacts of solar electrification compared to grid electrification and use of paraffin

The comparison of environmental impacts of solar PV electrification and other options is not always balanced because the comparisons are often selective in what they choose to include. SHS projects are often justified because of their replacement of paraffin, and the consequent reduction in the emission of greenhouse gas emissions. This section also highlights other less–commonly acknowledged impacts that may need to be considered.

The section does not attempt to quantify the different environmental impacts, an exercise that is beyond the scope of this Thesis.

The impact of SHSs on emissions from paraffin depends on a number of factors. Among them are:

- How many SHSs are installed, or more to the point, how many solar *lights* are installed in place of paraffin lamps? In most SHS installations, the cost limits system size, which means that at many homesteads some rooms are left out and must be illuminated with paraffin.
- Types of paraffin lamps replaced, which will determine paraffin consumption rate and emissions.
- Operational status of the SHSs; because when the SHSs are not working, households revert to paraffin lamps. The issue is not simply how many SHSs are working/not working. It was indicated in Table 2.3 that some 80% of do–it yourself (DIY)–installed SHSs were only partly functional. The extent of displacement of paraffin is likely to vary from case to case, depending on the seriousness and nature of each fault.

Table 6.1 shows calculated avoided carbon dioxide (CO_2) emissions from the SHS projects implemented in Zimbabwe on the basis of the following assumptions:

- Hours each light burns daily 3
- Kerosene emission in kg carbon dioxide per litre burnt 2.6 (calculated from OECD/IEA, 2001)
- Wick lamp consumption of paraffin, litres per hour 0.05 (IAEEL, 1999)

The average number of lamps per installation in each project is based on Thesis survey figures. The number of private SHSs is estimated on the basis of national total, less Global Environmental Facility (GEF) & JICA project installations. *This calculation assumes all systems to be working.*

Table 6. 1 Estimation of avoided CO_2 emission by the SHS projects in Zimbabwe

Project	*SHS physical installations*	*Lamps per installation*	*Total lamps*	*Kerosene displaced (litres)*	*Emissions avoided (kg CO_2)/day*	*Emissions avoided (tCO_2)/yr*
Private	76 000	2.1	159 600	23 940	62 244	22 719
GEF	8 000	4.7	37 600	5 640	14 664	5 352
JICA	600	1.7	1 020	153	398	145
Chinese	110	4	440	66	172	63
TOTAL						**28 279**

The 28000 tons avoided annually is some 0.2% of the total national emission figure of 14.04million tons of CO_2 for 1998 for Zimbabwe (OECD/IEA, 2001). This impact is insignificant, and the cost of emission reduction is very high, for example about US$1 400 per tonne of CO_2 for the GEF Solar Project on the basis of total project budget of US$7.5m, and estimated number of paraffin wick lamps replaced.

An unintended potential environmental impact of the dissemination of SHSs is the risk of *lead (Pb) poisoning* if old batteries are discarded recklessly. In Zimbabwe, old batteries are bought back by battery company agents because there is a long tradition of recycling lead. It is therefore rare for used batteries to be thrown away, and if any were, they would be collected and sold.

Fluorescent tubes contain mercury (Hg) vapour[11] (quantity is about 0.01% of tube mass). This mercury is released in the vapour form at ambient temperature when the fluorescent tubes are broken. This level of mercury vapour is considered low from a health perspective, but mercury vapour can form the far more toxic *methyl mercury*[12] (CH_3Hg) under anaerobic organic environments (see for example Young 1992) such as those found in landfills (UK Environment Agency, 1996). This means the potential for methyl mercury toxicity partly depends on how used fluorescent tubes are disposed.

Grid electricity from coal forms the bulk of Zimbabwe's electricity supply. The combustion of fossil fuels for power generation, and the use of pesticides are among other sources of mercury pollution of the environment. Fossil fuel combustion in power stations is also responsible for a large number of environmental pollutants, among them particulates and oxides of sulphur, nitrogen and carbon. The mining, transportation, storage and combustion of coal also pollute the environment.

The displacement of paraffin wick lamps by solar lights leads to the elimination of CO_2, soot, and fume (paraffin vapour) emissions from the paraffin. A minor hazard for households using paraffin or liquefied petroleum gas (LPG) *mantle lamps* is the presence of the radioactive element *thorium (Th)* in the fabric mantles. It is advisable to avoid breathing in mantle ash and dust, and to wash hands immediately after changing

[11] Though almost all household fluorescent tubes giving off white light contain mercury, not all fluorescent tubes contain mercury. Streetlights, which usually give off yellow light, contain sodium vapour instead of mercury.

[12] Methyl mercury is known to be particularly harmful to the developing nervous systems of unborn and young children. In some countries pregnant women have been advised against eating certain fish (FDA 2001) that are at the top of their respective food chains. Toxins generally concentrate in species higher up the food chain.

mantles. Bulk storage of mantles should be in areas not frequented by people. When the mantle is first burnt to prepare it for use, *beryllium (Be)* fumes are released. These fumes can cause lung disease if inhaled (ARPNSA, 1999).

Clearly the environmental issues are numerous and none of the energy supply options can be considered beyond reproach. A balanced account of all foreseeable environmental impacts is necessary in order to make a meaningful comparison between SHS and the alternatives.

6.2 Comparison of selected issues between different solar home systems dissemination modes

6.2.1 Financial viability

The issue of financial viability remains one of the more difficult problems facing the dissemination of SHSs in rural areas. Credit schemes run by commercial lending agencies require collateral, which is difficult for rural households to provide because they have no title deeds to their land, and often have limited assets. The use of special soft loan windows of state–owned banks has been one of the measures adopted to overcome this restriction.

An alternative approach has been to allow non–governmental organisations (NGOs) to use their local knowledge of communities in which they are active to decide on eligibility for loans. The normal commercial lending approach has proved to be financially viable in Zimbabwe, as evidenced by the large number of SHSs installed by the private sector. This has been at the expense of the poor who fail to meet the loan conditions. The NGO approach has worked well where installations are clustered, along with facilitation of payment through the use of local agents who collect and bank instalment payments from clients for a commission. Energy service companies (ESCOs) operating with rural farmers who often pay seasonally are exposed to the risk of collapse in drought years when most clients fail to pay the full amount due. In this situation the dilemma facing the ESCO is that an overly aggressive automatic disconnection policy for missed payments will rapidly decimate the client base, thereby eroding overall viability, yet the ESCO needs the fees to survive. One way out of this is to have ESCOs that are diversified in their business activities, so that they can weather temporary cash flow fluctuations in fee payments. Lasschuit (2001) has recommended such an approach on the basis of work done in Swaziland.

In the *GEF Solar Project*, special import duty and surtax concessions were negotiated *for the duration of the project* (GEF Project Management Unit (PMU), 1998). These concessions fell away at the end of the project, causing prices to escalate suddenly. The value of this type of subsidy, which cannot be sustained beyond the project, is not clear.

In the aftermath of the project, many of the installing companies that had sprung up fell victim to the harsher operating climate (SEIAZ, 2001), leaving their clients without maintenance backup. The loan default rate for Agribank is not known. One of the participating NGOs, the Biomass Users Network, has collected instalments for over 80% of the Z$2.25 million value of all systems sold.

The *JICA Study Project* ESCO has shown that it was not possible to cover operating costs from the maintenance fees collected from clients. Having larger clusters of SHSs per technician, or having the ESCO closer to the cluster sites are some of the ways to reduce costs. The major problem remains macroeconomic in the case of Zimbabwe. The fall in the value of the Zimbabwe dollar against that major currencies, and rising inflation, have meant that fees would have to be hiked dramatically to keep pace. This has not been possible. Droughts also affect the ability to pay because most clients are farmers. The failure to demonstrate financial viability has meant that large–scale replication of the project has not been possible.

In the *Chinese–donated* SHSs, the ability, or even the willingness of recipients to pay for maintenance and spares was not assessed. The issue of financing maintenance of the donated SHSs remains unresolved. Replication of this mode of dissemination demands continuing availability of funds to procure further equipment for donation. Most solar PV donations have focussed on public facilities, particularly clinics, where it is easier to justify such donations from a social welfare point of view.

6.2.2 Maintenance provision

The experiences with provision of maintenance have been varied in Zimbabwe. The ESCO approach, and the use of facilitators in the GEF Solar Project NGO mode have proved to offer the most reliable maintenance through clustering installations, and using local, well–trained technicians to maintain the SHSs. Donated systems have generally not had integral maintenance plans, and serious maintenance problems have been experienced at public facilities, the main recipients of donated systems.

In *private sales and DIY* dissemination, the owners realise at the outset that maintenance responsibility is in their hands, and can be expected to prepare for it. The cost of calling out companies for repairs is prohibitive, with the cost of transport alone sometimes outstripping the cost of spares and labour. Thus, even though maintenance capacity exists, it may not be tapped and the outcome is equivalent to a situation where maintenance support does not exist. Users are often not well informed about basic maintenance procedures, particularly topping up of batteries. Topping up batteries with acid instead of pure water is one of the serious mistakes encountered.

In the *GEF Solar Project*, post–warranty maintenance was the owner's responsibility. Another source of maintenance problems was allowing Agribank to enforce collection of instalments from clients regardless of the state of their SHSs. Figure 6.3 shows the fault response times during the GEF Solar Project, with only 20% of fault reports being attended to within one month. Half of all faults were attended to between one and three months after being reported.

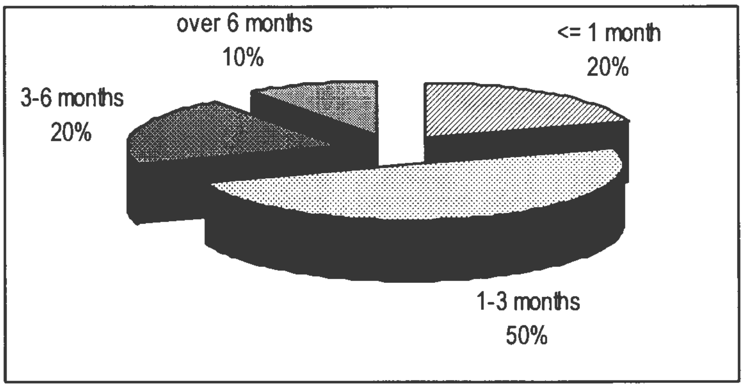

Figure 6.3 **Fault response times in the GEF Solar Project**
Source: GEF PMU, 1998

Figure 6.4 shows that the component found to have failed most frequently during maintenance visits was the battery. This is not surprising given the long fault response times.

The use of local 'facilitators' who were given basic training in system care and maintenance by NGOs stands out as a particularly effective way to deal with issues of money collection, information dissemination, and maintenance support. All systems in each facilitator's area have access to the facilitator, regardless of dissemination mode.

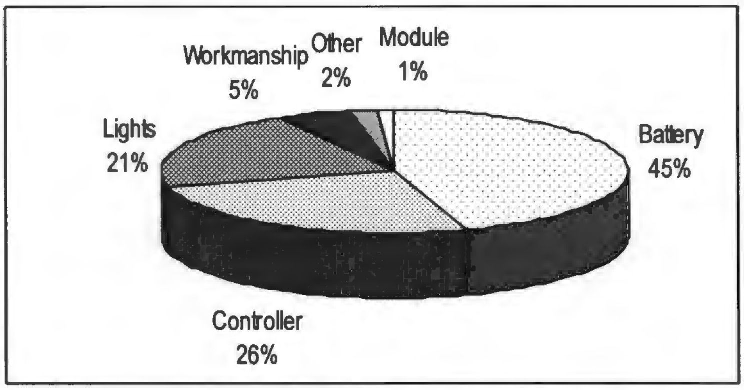

Figure 6.4 Component failure rates in the GEF Solar Project

Source: GEF PMU, 1998

Despite maintenance being central to the design of the *JICA Study Project* ESCO scheme, the prevailing economic crisis in Zimbabwe, and the inability of clients to keep up with the US dollar equivalent of fees, forced the ESCO to adopt some cost cutting steps including reducing the frequency of maintenance visits. This entailed reduced salaries for the technicians, resulting in some disruption when the technicians started to engage in other work to supplement their incomes. The solutions to these complications are still to be developed, but this is unlikely to be within the current JICA project, which is in its final year.

There is no maintenance service provider for the *Chinese donation project* in Nzvimbo because no plans for long–term maintenance were made at the time the SHSs and water pump were donated. The Department of Energy (DoE) has unsuccessfully tried to negotiate with the beneficiary households for a maintenance fee to be levied. The English–only manuals provided seem to have been prepared in China. The English is not always easy to comprehend, and the pictorial representations not always familiar. It would have been better for the manuals to be revised in Zimbabwe, with local language versions also made available.

6.2.3 Flexibility in level of service provision

Projects usually prescribe one size of module for all recipients. This can be seen in the Zimbabwean JICA Study and Chinese donation projects, and in South Africa (Afrane–Okese *et al*, 2001). The most satisfaction seems to have been where clients were free to select systems that suited their needs. Satisfaction with such systems obviously depends on the client receiving good advice on systems sizing, something not always possible where company salespersons are keen to make a sale. It is interesting to note that regardless of system size, clients end up wanting more power than SHSs can provide.

In *Private and DIY* dissemination, costly components not seen as critical are often left out – in most cases the charge/discharge controller. The outcome in practice is that many of these SHSs are not optimally configured and installed. The mismatched systems may perform poorly due to weak links, bringing down the overall level of service delivered to the owner.

In the *GEF Solar Project*, the main constraint was that the project equipment warehouse did not always have the full range of component sizes. This forced participating companies to make design compromises. Figure6.5 shows the prevalence of different sizes of PV modules installed by the GEF Solar Project, and illustrates the popularity of PV modules in the 40–60Wp range. Modules larger than this range were less popular because of high cost, and smaller modules because of inadequate power delivery.

Ability to afford was the other obvious constraint for clients in this project, but in such cases clients would get smaller, but still well matched systems. All key components were included to ensure approval of the installation by the Project Management Unit (PMU). The *JICA Study Project* initially took a rigid approach whereby all systems had to be small to ensure inclusion of poorer households, but the project was forced by popular pressure to relent and offer an expansion option to 56Wp systems with three lights.

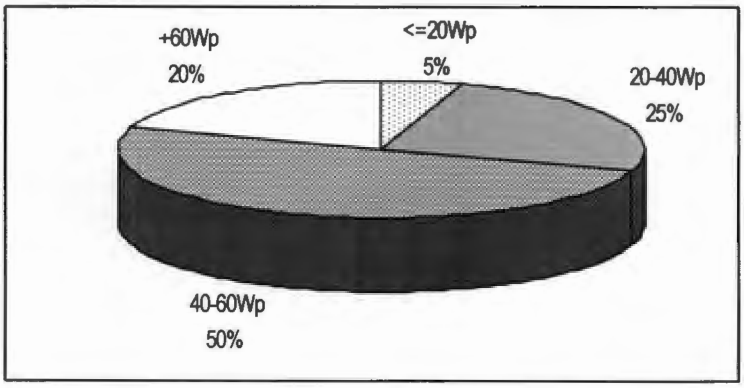

Figure 6.5 Sizes of modules disseminated in the GEF Solar Project
Source: GEF PMU, 1998

Only one 70Wp four–light option was offered in the *Chinese donation project*. No clamour for larger systems was seen after installation of the SHSs. Expectations were still unrealistic, with households wishing to power stoves and other high power appliances with solar PV systems. This could be an issue of low awareness, or it could indicate general discontent with the power level of SHSs, even if the 70Wp systems provided are at the upper end of the available module power range in Zimbabwe.

6.2.4 Ownership and Payment

The ESCO approach, where clients do not own the systems installed at their households continues to be difficult for clients to fully understand or accept. This has been compounded by the already stated provision for eventual ownership of the systems, meaning that some clients may have joined the project as a way to own SHSs. Payment of fees for the JICA ESCO systems has been erratic because most clients pay annually after selling their crops. In drought years, payments become unreliable, a situation that can threaten the survival of the ESCO. In contrast, commercial loan schemes with stricter eligibility screening criteria tend to have formally employed clients who have steady incomes and can pay regularly. The risk faced by ESCOs in rural markets where payments are linked to harvests suggests that the ESCOs must diversify their business activities in order to have several income streams, which will help them to cope with fluctuations in payments. This is the approach that enabled the Biomass Users Network (BUN) to cope as an ESCO.

Ownership of SHSs in *Private and DIY* dissemination immediately passes to the client where a cash sale is concluded. If the SHS is bought on credit, ownership only passes to the client upon full repayment of the loan. This approach is well understood by clients because it is widely used for other purchases. In terms of collection of payments, this is the most effective approach, but will generally exclude the poor. The collection of instalments, or follow up on defaulters becomes more costly when clients are scattered, as they are in the GEF Solar Project

Table 6.2 shows fee payment by clients in one of the ESCO clusters by BUN. In years with good harvests, for example 1999, payment of arrears leads to the collected amounts exceeding invoiced amounts for the year.

An important lesson for *donated systems* is that the recipient community must be selected on the basis of considered criteria, since they will need to meet costs of maintenance and component replacement. Where a communal facility like a village water pump is included, equity, ownership, administrative arrangements, and raising of funds for maintenance need to be finalised in advance.

Table 6.2 Payment of maintenance fees for one cluster of the JICA Study Project

Year	*Turf cluster payment record*		
	Collected	*Invoiced*	*Balance*[13]
1997	36,390	30,300	-6,090
1998	48,953	66,735	17,782
1999	114,909	111,545	-3,364
2000	92,080	136,080	44,000
2001	19,140	137,160	118,020
2002	127,291	189,700	65,909
Total	438,763	671,520	236,257

Source: Supplied by BUN accounts 2003

6.2.5 Battery and light replacement issues

The issue of battery replacement is raised because it is one of the more difficult problems that arise in the aftermath of solar PV projects and impacts on effective service delivery. Imported deep cycle batteries were introduced by all the SHS projects into Zimbabwe. These types of battery are not locally available, or are prohibitively expensive if available, which is rare. Replacement batteries will inevitably be local automotive batteries. The difficulty arises because the setting of charge/discharge controllers must match the type of battery connected to the systems in question.

The majority of Private, DIY, and some GEF Solar Project SHSs use locally available automotive batteries, which are easily replaced. The question of controller settings does not arise in these cases. It is however doubtful whether owners are fully aware of the danger of disconnecting the battery on an active system during daylight, when module voltage can exceed 20volts, and will damage controllers and connected appliances.

[13] The balance is the amount outstanding. A negative balance indicates that collection exceeded the invoiced amount in that year.

On systems with controllers originally set up for solar batteries, automotive batteries may not last long because they will not reach their optimum charging voltage (which is higher than for deep cycle batteries), and will also be deep discharged, because they need a controller set to disconnect the load at a higher voltage than for deep cycle batteries.

Fluorescent lights used with PV projects have electronic ballasts that often need repairs. This has generally been possible in Zimbabwe because some of the solar companies manufacture solar lights and can repair them. These companies are in the cities and are therefore far from the areas where SHSs are installed. Fluorescent tubes are not made locally and need to be imported. These will be more expensive to procure because of the smaller quantities compared to orders made for project supplies during the dissemination phase. The scarcity of tubes and electronic components in Zimbabwe has been exacerbated by the shortage of foreign currency, and the worsening exchange rate of the local currency has led to exorbitant prices.

The result has been a tendency by clients to use flashlight, automotive and halogen bulbs instead. These lead to much higher loading on the SHSs, which will lead to shorter working hours before low voltage disconnection. For example, the load is tripled where an automotive turning indicator (normally rated at 21W) is used to replace a 7W fluorescent light in a SHS. This change means a 3 light SHS will be able to run one light for the same number of hours. Another scenario is where all three lights are replaced with automotive bulbs (total power 3x21W=63W). In this case the lights will burn for one–third of the time they originally did, and the current going through the controller to the load will rise from about 1.8A to about 5.3A. If this small system had a 5A controller, the controller would be overloaded and the fuse would blow, failing which the controller would be destroyed. It seems sensible to standardise on lights across all projects so that repair and availability of spare tubes can be facilitated.

6.2.6 Subsidy requirement

The government finds it necessary to subsidise fuels used by the poor. The electricity tariffs in most years have low rates for the first 50kWh and 300kWh to keep costs lower for small users (see figure 6.4). Paraffin, *when sold in small quantities*, is subsidised because of its widespread use for lighting in rural areas, and for cooking by low income households in urban areas. On this basis, it would seem reasonable to subsidise SHSs *if* *they are seen as an option for the poor*. The GEF Solar Project successfully negotiated import duty and surtax concessions with the Government of Zimbabwe. These concessions benefited other projects, in particular the JICA Study Project, which procured its modules and batteries from the GEF Solar Project warehouse. Any imports of the same hardware outside the GEF Solar Project attracted full duty and surtax.

Private acquisition of SHSs components by households could not take advantage of the subsidies on equipment sourced through the GEF Solar Project. Since poorer households were less likely to qualify for the GEF Solar Project loans, they were forced to take the more flexible option of acquiring components as and when they had sufficient funds.

In the GEF Solar Project, the contribution of subsidies to poor households' access to SHSs was limited because the majority of the GEF Solar Project clients were rural–based civil servants, especially teachers and nurses. The impact of the GEF Solar Project on the overall number of installations is only about 10% of the total number of *physical* systems installed in Zimbabwe to date. This fact, and the limited accessibility of GEF Solar Project installations to the poor, brings into question the justification for the subsidies.

The JICA Study Project sought out areas with identifiable sources of income to ensure high level of repayment of maintenance fees. This process virtually ensured that the really poor areas got screened out. The question of the need for the subsidy, given the type of beneficiaries who got the SHSs, arises again in this case.

The Chinese donated systems in Nzvimbo were fully subsidised from the point of view of the recipients. Where a project is intended to be a donation, this is obviously unavoidable. The question that may arise is whether long–term costs like spare parts and maintenance fees can and should also be subsidised. This is pertinent where the recipients have been determined to be genuinely poor, and it directly impacts on the sustainability of the service provision.

6.2.7 Design of systems

The major system design problem in design is with systems put together by clients who purchase components as and when they can afford them. In many cases the charge/discharge controller is not included, and amorphous modules may be selected because of their lower cost. Because a 12Wp amorphous module can be of the same physical size as a 40Wp crystalline silicon module, clients may not realise that there is a large difference in power output due to the different technologies used. This mistake stems from the fact that the output of a solar module is related to its physical dimensions, *as long as modules being compared are of the same type.*

The lack of charge/discharge controllers may explain the higher incidence of battery failures among Private and GEF systems. All JICA project systems have charge/discharge controllers, and have not experienced battery failure problems to the same extent.

6.2.8 Theft of modules

Solar PV modules are valuable and not always readily available. For this reason they can be targeted by thieves. In Zimbabwe theft of modules from households has not been a major problem. In the JICA Study Project, not more than about five modules have been stolen from households over the last five years, and the community has recovered almost all the modules within a short time. Often, outsiders have come in to steal the modules, and have been caught before leaving the area. The difficulty of accessing the roof–mounted module without causing enough noise to be heard, and strong traditional values in rural areas may explain this low rate of theft from households. In Zimbabwe, it has become standard installation practice to bend the bolts holding the module, or to damage the thread in some way, to make removal of the nuts securing the module more difficult. A thief would have to resort to cutting off the bolt or using a lot of force, thus causing more noise and attracting attention.

The experience with modules installed at public facilities has been different however. All the modules installed at the communal water pump at Nzvimbo were stolen within one year of installation. They were replaced by the Department of Energy, and the site was fenced and an alarm system installed in 1999. The secured replacement modules have not been stolen, and some of the stolen modules were recovered locally with the assistance of the community. PV installations at schools and clinics have experienced both abuse and theft of modules and other components. The lack of physical security seems to be one of the major causes of theft of modules at public facilities. The past role of communities in the recovery of stolen modules suggests that community structures could play a useful role in safeguarding installations at public facilities.

6.2.9 Impacts on energy use

Because of the very low power output of SHSs, their impact on total household energy use is very limited, given that most rural household energy is used for cooking and space heating in winter. Typically rural households cook and heat with fuel wood, and SHSs do not impact on this fuel use. In the study surveys, 54 out of the 60 (90%) SHS–electrified households felt that they were using less paraffin than before they had SHSs. One household believed that, in addition, less candles were used. Thus, SHSs have induced a switch in lighting fuels only, a minor change. The factors that reduce the impact of SHSs on energy use include:

- The very limited diffusion of the technology, 85 000 systems (ESMAP, 2000) among the 2 653 083 households in Zimbabwe in 2002 (CSO, 2003), or about 3% of households.
- The high levels of system downtime due to lack of maintenance cover.
- Low power output, which makes the technology incompatible with most applications (Karekezi and Kithyoma, 2002).
- High prices, which put the systems out of the reach of the majority of rural households.

6.3 User views and preferences

6.3.1 Maintenance related

Ownership of SHS manuals varies from place to place. Ownership of manuals in Sanyati is low because the JICA ESCO does not provide manuals, and many private systems did not have manuals especially if built up in stages. Nzvimbo systems are part of one project, which gave out manuals. Many systems in Makosa had manuals since GEF project did give out manuals and many systems there were installed under the GEF Solar Project.

Figure 6.7 shows the users opinions on six maintenance–related issues. The meaning of the labels used for each of the issues is given in Table 6.3.

As shown in Figure 6.8, training was rare in all areas, though somewhat better in Makosa, again through GEF affiliated companies, especially the GEF NGO mode which had a local facilitator. The ESCO in Sanyati did not train users in detailed maintenance because they are not responsible for maintenance.

Table 6.3 Meaning of labels used in Figure 6.7

Label	*Explanation*
Trained	Households reporting that they were trained at the time their SHS was installed.
Maintaining	Households undertaking any maintenance activity on their SHSs.
Cleaning+	Households undertaking more advanced maintenance on their SHSs *beyond cleaning.*
Basking	Households using unmounted modules which they bask in the sun during the day and take indoors at night.
Dump battery	Households throwing away used batteries
Post primary	Households where the person looking after the SHS had received post–primary education.

It seems the Chinese donation project also did not provide training for users, despite not offering maintenance backup. During the survey, most users reported performing some maintenance activity of their systems; typically *cleaning* the module and battery terminals (see Figure 6.7). However beyond this it was rare to find users doing more advanced maintenance (shown as *Cleaning+* in Figure 6.7). Some were even adding acid to their batteries, which is unacceptable because it will upset battery chemistry.

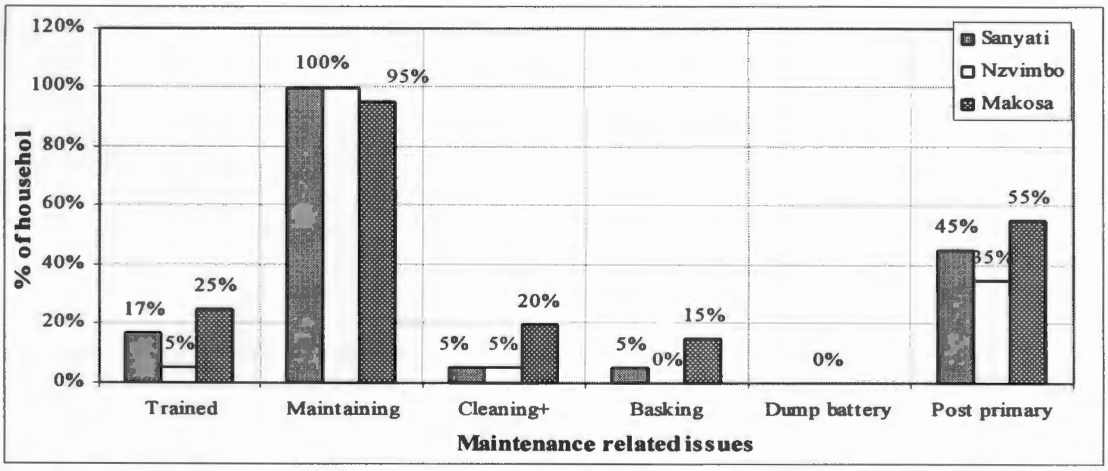

Figure 6.8 User reported maintenance–related status of SHSs and activities in survey areas

Fortunately, as shown in Figure 6.8, no batteries were dumped since it was always possible to sell old batteries to agents. Very few households had unmounted solar modules that they bask in the sun during the day, and take indoors every evening (shown as *basking* in figure 6.8). Makosa reported the highest percentage of family members responsible for the SHS and having post–primary education, and Nzvimbo the lowest. The differences between the three areas are not however not dramatic. The significance of those differences on maintenance of SHSs by users is not easily isolated because there are other factors like level of user training, ownership of manuals, and project maintenance policies that vary between areas.

6.3.2 Attitudes to Solar Home Systems

Figure 6.7 shows that most households would buy SHS again, with the benefit of hindsight. This seems to be due to the need for electricity in a situation where grid electricity is not an option for most households.

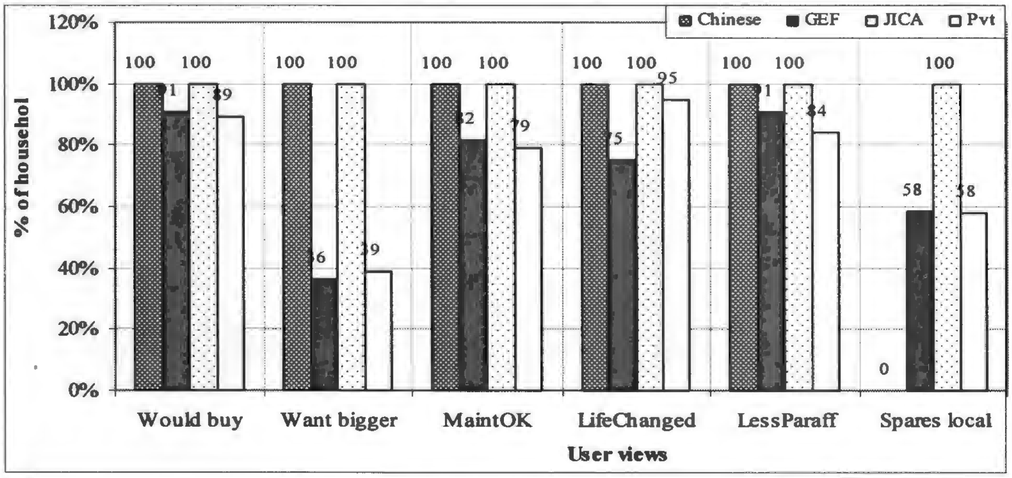

Figure 6.8 **Percentage of SHS–electrified households grouped by SHS dissemination mode and their SHS related opinions**

All households in the Chinese and JICA projects wanted bigger SHS, though in some cases there was a misguided belief that they could cook and run refrigerators as a result. Many people mistakenly believe that a *12 volt dc to 240 volt ac* inverter will power any mains appliance because its output *voltage* matches mains voltage. The difference between power and voltage is not always understood.

There is a notable difference between the GEF/Private and the Chinese/JICA category households on the desire for larger systems. The latter category of households did not have to buy their systems and therefore find it easy to indicate their desire for larger systems, whose costs they are not expected to pay. On the other hand, the GEF/Private category households who had to buy their systems probably take cost implications into account in expressing the wish for a bigger system, thereby showing a much lower desire for larger systems.

The reasons for wanting a bigger system are more to do with powering larger appliances than with lighting as shown in Figure 6.9. The desire to power income generation activities was most pronounced in Sanyati, which is not surprising given the higher prevalence of income–generating activities (IGAs), and the involvement of more family members in IGAs in that area.

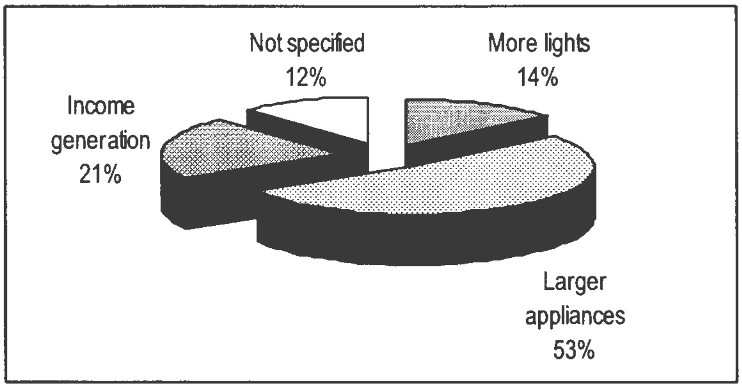

Figure 6.9 Reasons for wanting bigger system

Generally there was a feeling that maintenance was satisfactory. This happy situation is not reflective of the national situation, as shown by the wider BUN/JICA/DoE survey. The factors leading to better maintenance situation in the survey areas are:

- The relatively new Nzvimbo donation systems have all been repaired under warranty so far. Clients have not yet faced the consequences of not having effective long–term maintenance cover.
- There is ongoing ESCO maintenance service in Sanyati
- There is a BUN facilitator who can attend to any PV systems in Makosa.

The finding that there is a surprisingly high level of satisfaction in Makosa, underscores the importance of maintenance to clients' attitudes towards SHSs.

Figure 6.10 shows that most households felt that SHSs had changed their lives, particularly with access to news and entertainment via radio and TV. Again here it is apparent that more households appreciate other benefits above lighting, in this case access to media and entertainment, a better standard of life, and a healthier household environment through the elimination of paraffin fumes and the soot and smoke that can come from wick lamps. A total of 16 respondents out of the 60 households with SHSs did not want bigger systems. Four of these were in Sanyati. The reasons for not wanting bigger systems are very different between Makosa and Sanyati.

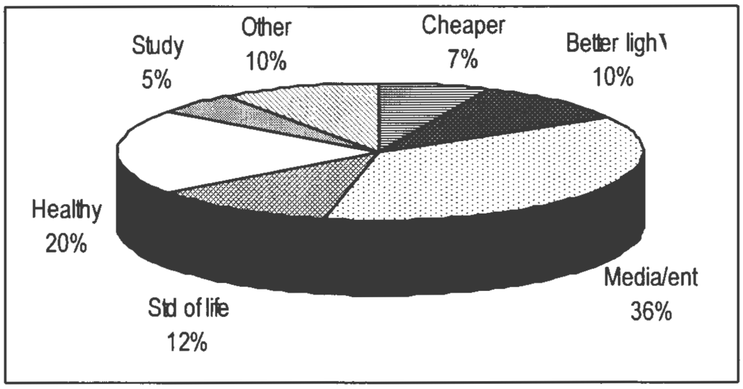

Figure 6.10 **Nature of reported change to life made by solar home system**

Households not wanting bigger SHSs

In **Sanyati**, the four respondents who did not want larger systems had had disappointing experiences with their SHSs.

- All said that maintenance had been poor; the systems were in bad condition, or not working.
- All said that SHSs had not had a positive impact on their lives; they were the only respondents to say this among the 60 SHS–electrified households in the survey.
- Three of the SHSs had been installed under the GEF solar project, and one was a private installation. The respondent with the private system reported adding acid to the battery.
- Two of the four respondents would not buy SHSs again, but the other two would be willing to buy again despite their disappointment.
- The educational status of the private SHS respondent was not disclosed, but the three GEF SHS respondents had received secondary education

In **Makosa**, all 12 households who did not want larger SHSs were satisfied with their systems. Four of these were GEF project installations installed through the NGO mode by BUN; the remainder were all private installations. Out of all 60 surveyed SHS–electrified households, only eight indicated they had received training, and five of those eight are in this group. Two of the five trained SHS–electrified households in Makosa had private systems, but had received training from BUN. The maintenance experience of the satisfied group is good, all reporting *no faults* except one battery replacement on a private SHS, and one household indicating *few faults*.

The positive situation in Makosa is partly because, even though there is no project support as is the case with Sanyati (ESCO) and Nzvimbo (Chinese donation project warranty repairs), there is a freelance BUN 'facilitator' who is a resident of Makosa. Makosa is in one of the BUN cluster areas for the NGO mode where a facilitator was trained and is operating. This facilitator attends to SHS faults regardless of origin of the SHS, and charges fees on the basis of a schedule agreed with BUN. He gets BUN logistical assistance to have components repaired in Harare, or to procure replacements.

6.4 Chapter conclusions

Solar photovoltaic electrification compared to grid connection and paraffin

Solar PV power systems have less impact on rural energy supply than grid electricity and paraffin because only about three percent of all households have PV systems. In comparison about 35% of all households have grid electricity, and at least 65% (rural fraction of population) have paraffin lamps. In addition, the level of service provided by PV power systems has been shown to be lower than that provided by grid electricity and paraffin light points for the money paid. SHS light is however superior to that from paraffin wick lamps on the basis of luminosity.

Financing arrangements and concessions have often been put in place to facilitate the attainment of solar electrification project goals. Post–project dissemination of SHSs has not benefited from these special short–term conditions. In contrast, rural grid–connected households are connected on commercial terms. In Zimbabwe, paraffin has historically been subsidised, but this subsidy has become meaningless in view of the prevailing shortages and high parallel market prices being charged for this fuel. The paraffin subsidy was difficult to target and was subject to abuse by commerce and industry, but the urban and rural poor did benefit from it for many years.

Short–sighted maintenance provision by solar PV projects has left owners of PV power systems without maintenance support after the end of the projects. This has the effect of reducing the effectiveness of installed PV power systems through faults that leave systems dead or partially functional. This problem does not affect unelectrified households using paraffin, because the simple wick lamps that they use are generally fabricated at home from scrap bottles or tins. Grid–electrified households are subject to mandatory professional inspection of the wiring prior to connection by the utility, and the power line up to the meter box is maintained by the electricity utility. For these reasons, the maintenance and reliability problems for grid–electrified households are much less.

The environmental benefits of PV power systems need to be assessed in a more balanced way, taking into account the continued use of multiple lighting fuels, emissions associated with project vehicles, potential lead pollution from discarded batteries, and the introduction of mercury into the local environment from broken fluorescent light tubes. The fact that many systems are either dead or only partly functional needs to be taken into account in assessing the extent of the replacement of paraffin and candles.

In comparison, the environmental damage associated with fossil fuels and large dams (in this context; coal fired power stations, petroleum fuels and large hydro–electric dams) is better documented. At the local level (the remote rural village), paraffin is associated mostly with health hazards due to fumes, smoke and soot from wick lamps. The fire hazards seen in South African informal settlements are not generally present in Zimbabwe because of the less crowded housing and use of different building materials. The danger of poisoning from accidental ingestion is also not seen as a major issue, judging from user perceptions in Figure 6.10. The environmental damage from grid electricity at the local level is largely negligible. The main point to be made is that the environmental impacts associated with the use of SHSs have been selectively highlighted, which influences the perception of the effectiveness of SHSs in mitigating environmental damage. A more balanced presentation of these impacts is necessary.

Issues specific to solar PV dissemination modes

The top down approach taken by projects has in most cases included prescription of systems size at both households and public facilities. This approach has met with popular resistance in the JICA Study Project, underlining the need for greater flexibility in the sizing of systems to allow better matching to the needs of users. It remains a fact though that all sizes of PV power systems still leave widespread desire for more power to run larger appliances like cookers and refrigerators.

The replacement of batteries and lights is becoming an important issue that needs to be considered in project planning. Questions of availability of the correct type of replacement batteries, light tubes and electronic components have to be resolved for long term viability of PV power systems, particularly in developing countries where such availability cannot always be taken for granted.

Subsidies and donation of PV power systems have not been effective in reaching the poor, and the usefulness of these measures remains questionable in Zimbabwe. It has been shown that donations can be effective if they are disseminated where maintenance planning has been undertaken and recipients are assisted to plan for major costs like battery replacement (Niewenhout *et al*, 1999).

Theft is not an insurmountable issue for SHSs, but it is clearly a problem for public facilities in the light of experiences in Zimbabwe. The role of communities in the recovery of stolen solar modules in Nzvimbo and Turf (where the second JICA Study Project cluster is located) suggests that greater community involvement in the ownership and administration of installations at public facilities may alleviate the problem of thefts of modules from these facilities.

User views and preferences

The priority attached to the provision of solar lighting by households was found to be lower than that attached to operating radios and televisions. This is out of step with the major reason usually advanced by sponsors for the promotion of PV power systems, which is lighting. It also means that the sizing of solar PV systems needs to take these appliances into account as far as possible.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

This Thesis has looked at the socio–economic issues around the dissemination of solar photovoltaic systems in Zimbabwe, and compared these systems with other rural electrification options. It has been established that solar photovoltaic systems make a contribution where the grid is unlikely to reach in the near future. Despite the numerous well–funded projects that have been executed, the overall impression is that relatively little impact has been achieved in the target areas compared to rural grid electrification and the diffusion of diesel gensets for example. The sustainability of the dissemination efforts were undermined by the top down approaches that sidelined the needs of the users, and short–term goals that overlooked the need for long–term repair and maintenance support. It seems likely that donors will continue to dominate project dissemination of solar home systems. These efforts are likely to continue to be top down and experimental, with little regard for lessons from past initiatives unless these fit in with the donors' objectives. Efforts to standardise components will suffer because each donor is likely to specify the source of project hardware.

The private dissemination of solar PV systems seems to hold the greatest promise provided the issues of sustainable financing, customer education, product quality, component availability, and sustainable maintenance support can be resolved satisfactorily. There are however numerous problems with the implementation of solar photovoltaic system dissemination. Lessons were identified for future dissemination, maintenance, financing, and payment options.

This chapter presents a summary of the conclusions drawn from Chapters Two, Four, Five, and Six, and follows these with recommendations.

7.1 Summary of conclusions

7.1.1 Dissemination of solar photovoltaic systems in Zimbabwe

Inadequate community involvement leads to lack of long–term maintenance

Public facilities, especially clinics and schools have been the recipients of donated solar photovoltaic (PV) systems, but the recipient communities and parent bodies of the schools and clinics have not been adequately involved to ensure commitment to long term maintenance. The procedures by which the donations were provided were not uniform; different donors have selected recipient public facilities on the basis of their own specific criteria. The majority of schools and clinics are owned by either local councils or government, and the plans of these parent bodies did not include the requirements of the solar PV systems because of the lack of consultation prior to installation. The lessons from the early installations of solar PV systems at public facilities were not taken into account in subsequent installations at public facilities. This failure to take into account *lessons from past experiences* can be partly attributed to the dominance of donors in the planning and funding of almost all solar PV projects.

For example, in the Japan International Cooperation Agency (JICA) Study Project installations at clinics and schools, and the community photovoltaic water pump donated by the Chinese government at Nzvimbo, the responsibility for meeting future costs of maintenance of the installed solar PV systems was not discussed and settled in advance. A similar approach was adopted for the communal PV water pump at Nzvimbo; the community benefiting from the pumped water was not consulted about ownership and maintenance of the PV pump. When the pump broke down, there was no maintenance budget to meet the cost of repairs.

Sustainable financing in solar PV projects remains inconclusive

Financing in solar PV projects remains inconclusive because project incentive support is usually withdrawn at the end of each project, or project conditions do not simulate commercial dissemination, thereby limiting the usefulness of lessons provided by such projects.

For example the JICA Study Project *energy service company* (ESCO) trial did not simulate a realistic commercial model because the solar PV equipment was donated to the Department of Energy. The way the Chinese donated solar PV systems were disseminated does not provide convincing positive lessons for future dissemination using that mode. Instead it demonstrates that dissemination of donated equipment is not viable.

Collection of payments in rural areas remains a challenge

This is due to the scattered rural settlement patterns amongst which solar home systems (SHSs) are sparsely distributed. This sparse distribution of clients causes escalation of collection costs and complicates logistics. Payment in commercial dissemination of solar PV systems is generally more reliable than in projects because the latter generally offer lenient or innovative criteria for eligibility in an attempt to reach the poor. The ability of rural farmers to pay reliably is compromised by frequent droughts that unpredictably reduce farm yields and therefore incomes. Enforcing collection of payments by clients under these circumstances is more difficult than with formally employed clients earning fixed incomes.

In Zimbabwe, the severe deterioration in economic performance and exchange rates have had a drastic impact on ongoing solar PV projects by imposing extreme conditions that invalidate key initial project assumptions.

Quality assurance is critical but expensive

Quality control is better in project dissemination of SHSs, but this comes at the price of greater expenditure per installation. The JICA Study and the Chinese donation projects had to replace several unsatisfactory components on all their systems in the initial stages. Close monitoring and data logging contributed to timely and accurate identification of problems. These measures undoubtedly added to transport, labour and hardware costs.

Quality control in private dissemination is variable, with the worst case being do–it–yourself (DIY) installations, because of lack of adequate user information, and cost–cutting by clients and suppliers.

Local trained technicians enhance maintenance support

Maintenance support benefits from the availability of local, trained technicians. This arrangement reduces the cost of calling for maintenance and ensures that reliable advice is readily available to users of SHSs. Such a situation leads to higher proportions of SHSs remaining functional, and results in greater user contentment.

This is shown by the generally good operational status of SHSs in the Thesis survey areas compared to the situation depicted by the Biomass Users Network (BUN)/JICA/Department of Energy (DoE) survey where local maintenance support is not available. Users were generally unhappy in the BUN/JICA/DoE survey areas where 80% of the DIY systems were malfunctioning.

The ESCO approach has maintenance built–in, but its financial viability has not been demonstrated. The *facilitators* who act as local agents of non–governmental organisations (NGOs) are a variation on the ESCO approach. Because facilitators are not salaried and charge only per service call, they have lower administrative overheads and costs to clients. Clustering of installations is an important factor in the viability of the approach for easy access to clients. Clustering is more difficult to achieve in dissemination models where SHSs are sold or installed in response to client demand without regard to location. Projects that target specific areas accomplish clustering more easily, but can suffer from slow start–up where the required minimum number of clients cannot be raised from the predefined target area at a rate required by the project schedule. NGOs participating in the Global Environment Facility (GEF) Solar Project successfully used facilitators, and some have continued beyond the end of that project.

The large investments in solar PV systems are not justified by their minimal impact

There is much greater donor interest and funding for solar PV systems than other energy supply options. This is despite the very limited capabilities of solar PV systems. It may be asked whether such investments could not have had better impact had they been used to provide water for irrigation, grid extension or to meet other development needs like provision of schools, health facilities, and roads.

7.1.2 Socio–economic and income–generating issues

Subsidies and incentives have not been targeted correctly

While carefully designed and targeted subsidies to improve access to SHSs for the poor may improve their access to SHSs, the targeting of such subsidies is often difficult. It is not useful to tie subsidies and incentives to specific projects, because such arrangements are not sustainable unless the projects in question are trials, *and* a plan to implement usable findings is in place.

Poor households are generally unable to acquire SHSs, and even if the SHSs are donated, the costs of repairs and maintenance still have to be met. The GEF Solar Project showed that the import duty and tax concessions made on capital equipment benefited affluent rural households, while the Chinese–donated SHSs reached more middle and high income households than poor households.

Solar home systems have not contributed significantly to poverty alleviation

The often–cited *poverty alleviation* aspect of rural PV electrification has not been borne out by results on the ground because SHSs are not sufficiently prevalent to make an impact on a significant number of households. The power level of SHS renders them unable to make a meaningful impact on income–generating activities, and the poor generally do not have SHSs since they cannot afford them.

The most prevalent income–generating activity (IGA) in rural areas is agriculture, for which the main power requirements are shaft power (irrigation and crop processing) and heat (food and crop processing).

The deteriorating economic situation in Zimbabwe is leading to formal sector shrinkage, which forces more people into the informal sector. The need to address the energy needs of small to medium enterprises (SMEs) is therefore even more important. SHSs are not able to make a significant contribution in this case.

7.1.3 Impact of Solar PV systems on energy use and expenditure on energy

Solar home systems have not had significant impact on energy use

The major impact of SHSs on energy use among households is on lighting, where they introduce much higher quality lighting compared to the paraffin wick lamps that they partially replace. Lighting is a relatively minor user of energy when compared to cooking and heating. SHSs also benefit media applications (radio and television) more when compared to the use of automotive batteries or dry cells.

The small numbers, limited power, and low reliability of SHSs limits their impact however. In comparison, grid–electrified households rarely run into power limitations unless the connection is load–limited, or there are power cuts. Users consequently indicate the highest preference for grid electricity.

By virtue of their higher average incomes, SHS–electrified households spend a smaller proportion of their incomes on energy than do battery–only and unelectrified households, which are generally the poorest households in the survey sample.

7.1.4 Effectiveness of solar photovoltaic systems

Solar PV power systems have less impact on rural energy supply than grid electricity and paraffin

This is because only about three percent of all households have PV systems, compared to about 35% for grid electricity, and over 65% for paraffin wick lamps. Solar PV systems provide good quality light but cost more per light point than grid electricity and paraffin. They are also less reliable and many are not fully functional.

Claims for the environmental impacts of PV power systems are often unbalanced

Claims for the environmental benefits of solar PV systems generally dwell on displacement of paraffin in lighting without taking into account the limited sizes and low reliability of these systems, factors that lead to multiple fuel use. The emissions of other related activities like project motoring are often ignored though they can be comparatively large.

Project dissemination of solar PV systems have been top–down and prescriptive

The commonly applied top down and prescriptive approach to SHS sizing has proved unpopular, underlining the need for greater flexibility in the sizing of SHSs. A more difficult problem is the widespread desire for more power to run larger appliances. Availability of the correct type of replacement batteries, light tubes and electronic components have to be assured for long–term viability of PV power systems, particularly in developing countries where such availability cannot always be taken for granted. Users attach a higher priority to the operating of radios and televisions than the provision of solar lighting, yet one of the major reasons advanced for the dissemination of SHSs is the provision of lighting. This suggests that the top down approach is preventing sponsors from realising the wishes of the intended beneficiaries.

Community participation can enhance security of installations of solar PV systems at public facilities

Theft is a relatively minor issue for SHSs, but remains a significant problem for public facilities. The lack of a sense of ownership of installation at public facilities by the surrounding community makes such installations more susceptible to thefts and vandalism.

Lack of spares has had a negative impact on the operation of SHSs

The problems around the replacement of the original deep cycle batteries left by projects remain unresolved because deep cycle solar batteries are not generally available in Zimbabwe. Problems arise because different battery types require different charge and discharge conditions if they are to give maximum service life. Charge/discharge controllers are set to match the characteristics of the batteries in the systems in which they are installed. It follows that any replacement of batteries must be with the same type of batteries, unless the charge/discharge controllers are reset to match new, different batteries.

The shortage and high cost of fluorescent lights, their tubes, and electronic components to repair these lights makes the use of incandescent bulbs almost inevitable. In Zimbabwe the use of automotive batteries to replace deep cycle solar batteries, and incandescent lights bulbs has been noted. There are numerous complications associated with the use of incandescent bulbs, in particular overloading of the SHSs.

7.2 Recommendations

The recommendations are presented in the same order as the conclusions, except that where repetition is likely to occur, specific sub headings have been omitted. Community involvement and ownership will reduce the risks of theft and vandalism at solar PV installations at public facilities. Subsidies and incentives will need to be less project–linked if they are to be sustainable. The dissemination of solar PV systems should include other energy supply options to cope with the power limitations and high cost of solar PV systems. It will also be possible to effectively tackle poverty alleviation by supporting income–generating activities of the poor with appropriate energy options. Claims of environmental benefits from dissemination of solar PV systems need to be more candid and to take into account local PV dissemination peculiarities that can significantly add to total emissions. Maintenance support, access to spares, and collection of payments that rely on local manpower and institutions will be more reliable. Quality assurance has to be budgeted for because it can be a significant cost. A more inclusive approach to PV dissemination will facilitate incorporation of lessons from past efforts and improve security of installation through community ownership and guardianship.

7.2.1 Dissemination of solar photovoltaic systems in Zimbabwe

Ensuring long–term maintenance through community involvement and ownership

Parent bodies of public facilities selected to receive donated solar PV systems should be involved at all stages, and be committed to meeting defined future costs of repair and maintenance before the solar PV systems are installed. This also applies to communities that own, or benefit from the public facilities in question. Commitment to meet future maintenance costs can only be meaningful if the parent bodies are accurately informed of the nature and magnitude of the obligations they take on when accepting solar PV systems. Consensus and clarity in defining the responsibilities and relationships of all stakeholders needs to be attained early in projects.

Sustainable financing in solar PV projects through targeted subsidies and appropriate incentives

Subsidies and concessions should only be offered if it is clear that they contribute to the sustainable dissemination of SHSs. These subsidies and concessions should not be granted merely to facilitate the attainment of donor project goals. The approval of projects needs to have criteria to check that new projects propose incentive schemes that will be sustainable.

Improving collection of payments in rural areas using local resources and systems

Clients with easy access to banks should have the option to make deposits directly into the account of the installing company or service provider, and present deposit slips as proof of payment. This was found to be the safest and cheapest way to collect payments by BUN in Zimbabwe. Clients without easy access to banks should be provided with convenient local means of making payments. One option is to pay through the local technician, who should bank the money at the most easily accessible bank. The technician has to be paid a commission as an incentive for this work. It is important to guard against embezzlement of these funds by having direct communication with the clients. One approach used by BUN in Zimbabwe is to mail all statements direct to clients without involving the technician in the chain. Any client complaints of discrepancies between statements sent out from BUN, and amounts paid via the technician should be investigated as they may indicate embezzlement by the technician.

Convenience and flexibility of payment options for clients is particularly important with low–frequency payments, such as the annual payments by most of the JICA Study Project ESCO clients. Such clients will have accumulated substantial debts over the year. Failure to collect payments timeously can result in the monies meeting competing demands.

The normal weather–induced year–to–year variations in the income of rural farmers means that an ESCO has to have diversified business activities to cope with this characteristic of its chosen market. Diversification is normal business strategy for rural shop owners who often have combinations of bottle stores, butcheries, grocery shops and grinding mills. Disconnections of clients for late payment of fees in communities need to be handled with sensitivity to avoid discord. Community representatives must be included in overseeing enforcement of agreed, transparent criteria for any punitive measures.

Facilitating and meeting the cost of quality assurance through better planning

Projects should allocate a quality control budget at the outset. This is clearly necessary given the initial problems of all solar PV projects implemented in Zimbabwe. The establishment of comprehensive national standards for PV equipment and installation will improve overall quality.

Provision of local maintenance support through capacity building and improved accessibility of installations

Clustering of PV installations should always be aimed for to facilitate maintenance provision and to make it worthwhile for local stores to stock spares like tubes and fuses. Clustering also makes holding user group meetings easier. Such meetings should be for user education and the exchange of experiences and for consultation and education.

The *Facilitator* approach is potentially the most promising model for providing all–encompassing maintenance cover to both households and public facilities with low overheads. It is important to consider the distances to be covered by the local maintenance technician, as well as the number of customers that the technician should cover to be able to operate viably.

Because of the employment and remuneration attached to it, *selection of the local technicians* needs to be transparent, based on criteria agreed with the local community. This transparency dispels suspicions about favouritism, and makes it easier for the maintenance technician to work within the community.

The *responsibilities of the service provider* can be varied from the situation where the service provider is responsible for all components to one where the user takes responsibility for minor components such as fuses and lights in exchange for a reduced service fee. The reduced fee is realised through not only the reduced component responsibility, but also reduced call outs for replacement of the minor components. It is necessary that *components are available locally*. Provided there are solar home systems in the area, there is no reason why local traders cannot stock these items just as they stock candles or paraffin appliances. Using existing shops in this way is preferable to the setting up of dedicated outlets for SHS

Financing support for existing SHSs from new project budgets

The generally poor design and installation standards of the privately installed SHSs require that some support be provided to this sector. Because batteries tend to be the component that fails most often, *battery protection* needs attention. Simple, low–cost state of charge *indicators*, and discharge *controllers* could be developed locally. Funding for this type of support for existing solar PV systems could be raised from new projects. It can be made an approval condition that all new solar PV projects allocate a small portion of their budgets, perhaps five to ten percent, to address crosscutting PV–related problems. These contributions by different projects can be pooled into a *'PV maintenance and rehabilitation fund'*, administered by a multi–stakeholder committee with representation from users, public and private sector stakeholders.

To access the *PV maintenance and rehabilitation fund*, local companies or other organisations can submit proposals to address problems affecting existing solar PV systems at households and public facilities. Activities that could be funded include technician training courses, establishment of standards, and dissemination of information for users. By using a local fund for these activities, it will be easier to address local issues more candidly than would be possible with a donor project budget.

7.2.2 Socio–economic and income–generating issues

Improved targeting of subsidies and incentives through avoidance of project tied subsidies and incentives

Any concessions and subsidies should be open to all dissemination modes since tying concession and subsidies to projects does not benefit post–project dissemination of SHSs. The selection of recipients for donated solar PV systems should be based on specified criteria, and the recipients need to be aware of the maintenance and repair obligations in advance of installation of the donated equipment.

Augmenting the role solar home systems in poverty alleviation through widening of energy supply options

It is important to broaden the energy supply options open to rural households and SMEs. The concept of *energisation* as envisaged (though not yet implemented as planned) in the South African off–grid electrification programme is one example of such integration. For example, solar PV for lighting and powering radios and televisions, liquefied petroleum gas (LPG), paraffin and biogas for thermal needs, diesel and biogas for shaft power, and small hydro for shaft power, lighting and powering radios and televisions. Obviously other criteria including cost–effectiveness will need to be used to select the most suitable option for any given end use and location.

Potential customers for SHSs need to be sufficiently informed to be able to make informed choices and to appreciate the capabilities and limitations of PV power systems. This requires *client education* coupled with a system of *labelling solar components,* and simple *rules of thumb* for matching of different components. The labelling systems adopted must be sufficiently simple to be easily understood by the client population. This means that a labelling system developed in one country may not be suitable for another country.

In some areas small hydro is an option that provides much more power, but this option is limited to a few areas by topographic features and rainfall patterns. More effort should be placed on developing energy supply options like biogas, and to facilitating access to suitable conventional energy options including gensets (petrol or diesel engine coupled to an electric generator) and pumpsets (petrol or diesel engine coupled to a water pump). The fact that the majority of the rural working population is engaged in agriculture suggests that the most effective energy services are those that will boost agricultural production. In a drought–prone climate such as that in Zimbabwe, shaft power to drive irrigation is important because of its potential impact on crop yields. Such power can also be used in crop processing. Thermal energy is also required for crop and food processing, including drying, roasting, steaming, and frying for example.

7.2.3 Impact of Solar PV systems on energy use and expenditure on energy

The dominant position accorded to solar PV systems is a major issue and the recommendations for widening the energy supply options is dealt with under sub section 7.2.4.

7.2.4 Effectiveness of solar photovoltaic systems

More realistic assessment of the environmental impacts of solar PV systems

The environmental benefits claimed for SHSs need to be looked at more comprehensively. The impacts of all project activities, particularly motorised transport have to be considered in assessing the carbon dioxide emissions and savings, and other environmental impacts of solar PV electrification. Similarly, the issue of *displacement* of paraffin and candles by solar PV lights needs to be assessed more carefully because in most cases only a limited number of solar PV lights are installed at homesteads, and some of them are not working, leading to the concurrent use of paraffin and candles.

It is advisable to include the issue of battery recovery and recycling among the standards to which solar PV dissemination initiatives have to adhere to. The potential hazards posed by mercury have to be assessed, particularly where large concentrations of SHSs exist or are planned.

Bottom up and inclusive dissemination of solar PV systems to better respond to local needs

Solar PV project recipient countries need to *insist on a more active role* in the formulation of solar PV projects intended for them. This will make projects more bottom up. Demanding such involvement may entail the risk of losing those proposed projects that do not have flexibility. The question is whether there is any real loss if the project does not in the end deliver the promised environmental, economic and social benefits?

Community participation to engender sense of ownership and improve security of installations

Community involvement is essential at all stages of solar PV projects to engender a feeling of local ownership. This is important at public facilities where a strong sense of ownership by the surrounding community will help to curb vandalism, thefts, and improve the chances of raising funds for maintenance.

Ensuring availability of spares for the sustained operation of SHSs

It is important to be sure the main components of PV systems will be available on a long–term basis. The use of affordable, locally available components needs to be given serious thought. Which components can be locally manufactured depends on the local situation.

One way to overcome the problem of changing from deep cycle to local automotive batteries after projects end is to use only *switchable controllers* on which the user can select the battery type. These controllers are relatively more expensive, and the user needs to know when to switch, and to what position. This should go hand in hand with simple labelling so that, using a colour code for example, the user can tell that the controller switch position matches the battery type. The coding systems can be part of national PV standards that force importers to affix the appropriate labels to PV equipment prior to distributing it.

To improve the supply of lights and other spares, it is advisable to *standardise* on lights and other components for all national solar PV projects. A range of say 7, 9, 11, and 13 watt solar lights can be specified, and projects can select from this set. If only these approved lights are accorded duty concessions, then even private importers will have an incentive to procure the recommended lights. Standardisation will make repair of the smaller range of components easier. Only a small range of spares will need to be imported and stocked by local shops.

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Appendix 1[14]

Glossary of technical terms

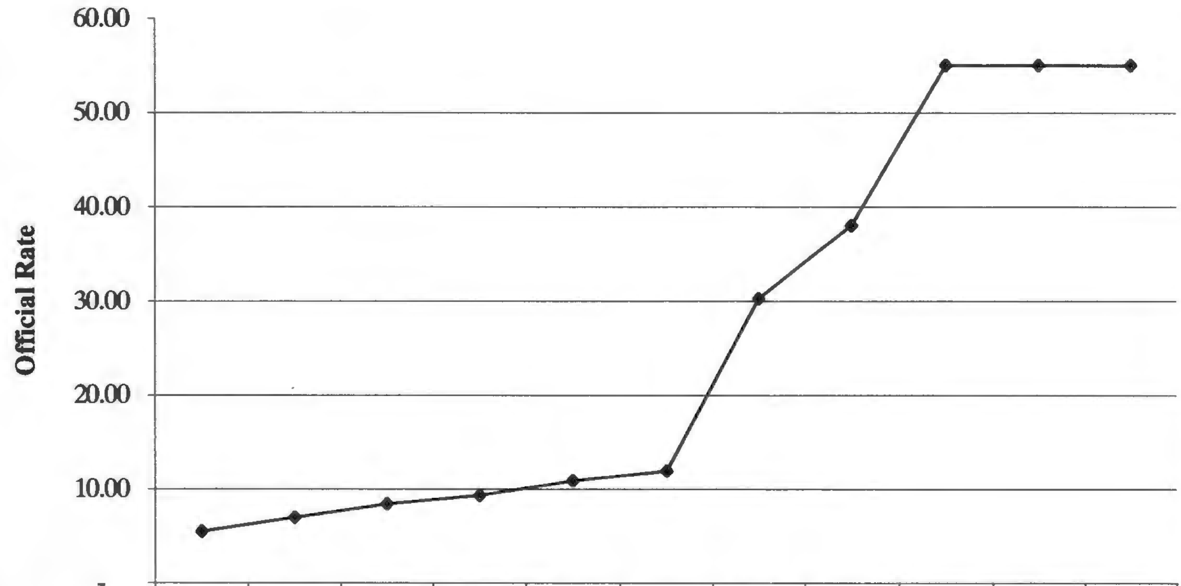
Amorphous module	A type of solar module produced by direct deposition of silicon onto a glass substrate. These are non crystalline and cheaper to produce but less efficient and more prone to breakage.
Balance of system	The components of a solar home system other than the module, battery and charge/discharge controller.
Battery cycling	The daily cycle of charging during daylight hours, and discharging during night use that a battery attached to a solar home system goes through.
Charge/discharge controller or regulator	A device that regulates the charging and discharging of the battery on a solar home system. This is a protective function to maximize battery life.
Crystalline module	A solar module made from a single wafer of doped silicon. Where this is from a single large crystal, it is termed *monocrystalline*. If it is from silicon consisting of many crystals, it is termed polycrystalline, and is cheaper to produce.
Equivalent system	A unit of measure used to compute installed capacity by dividing total installed peak watts by a figure such as 45Wp. The result obviously does not equate to total number of physical installations but was the basis of calculating installations in the GEF Solar Project in Zimbabwe. In this Thesis an equivalent system always refers to 45Wp.
Fluorescent lights	Lights that operate on the gas discharge principle. A high voltage applied across an inert gas causes it to emit light. A coating on a tube enclosing the gas emits light of a longer wavelength when struck by this light. This is called fluorescence. These lights run at low temperatures and are efficient at converting input energy to light.
Genset	An electrical generator or alternator coupled to a petrol or diesel engine.
Halogen lights	Incandescent lights that operate at a higher temperature and are therefore brighter than conventional incandescent bulbs. This is achieved by filling them with a halogen gas that allows filament surface condensation after evaporation caused by the high temperature. Quartz glass, which is highly resistant to heat, is used to enclose the lamp.
Incandescent lights	Lights in which the light is emitted by a heated filament enclosed in glass and surrounded by an inert gas to avoid combustion of the filament. Because light output depends on maintaining the filament at a high temperature, much of the input energy is converted to heat, thereby reducing efficiency of conversion to light.
Inverter	An electronic device that converts direct current (dc) to alternating current (ac). In solar home systems this is usually to enable mains ac

[14] The Appendix numbering system is not consecutive. Except for the first two appendices 1 and 1a, the Appendices are numbered to correspond to the sections of the Thesis to which they are related.

	appliances to be used with the 12volt dc power.
Median	The mid–point in a sample; the point at which half the values are less and half the values are more. Where there are outliers, the mean can be misleading and the median is to be preferred.
Outliers	Atypically high or low values in a sample.
Solar module	A device for converting solar radiation to electricity. Normally a panel of laminated solar cells. *Module* and *panel* are often used interchangeably.
Pumpset	A water pump coupled to a petrol or diesel engine or electric motor.
Photovoltaic	The photovoltaic effect is the production of a voltage across the junction of two different metals when they are exposed to light.
Set points	The voltages at which a charge/discharge controller will connect and disconnect the battery or the load. Examples are *low–voltage disconnect* (load disconnected to protect battery form over discharge) and *high voltage disconnect* (battery disconnected when fully charged to avoid over charging). These points are set differently for different types of battery.
Solar battery	A battery designed for deep discharging. These batteries are often sealed and cannot be topped up. This is why they are sometimes referred to as low–maintenance. In contrast, automotive lead acid batteries are designed for shallow discharging and will not last if deeply discharged. Automotive batteries are designed for very high current deliver for a brief period (starting a car). They have thin plates in their cells to maximise surface area for chemical reaction. Deep cycle battery cells have thicker plates which are suited to low current delivery and deep discharge.
Solar home system	Photovoltaic power system consisting of a solar module, battery, charge/discharge controller, and loads such as lights, radio, and television. In this Thesis some DIY systems omit the charge/discharge controller.
Sulphation	When the normally reversible reaction between sulphate ions (from sulphuric acid) and the lead plates in a lead acid battery becomes irreversible, often due to prolonged standing while discharged. This is due to the formation of large lead sulphate crystals instead of the normal small crystals. Battery capacity is lost as a result.
Watt peak	The unit used to denote peak watt rating, which is the power produced by a solar module under standard test conditions, that is when subject to incident radiation of 1kW per square metre at 25°C.

Appendix 1a

Zimbabwe dollar vs. US dollar exchange rate trends, 1992 to 2002



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Z$ per US$	5.48	6.94	8.39	9.31	10.84	11.89	30.25	38	55	55	55

Year

Appendix 1.4

Brief History of the Solar Energy Society of Zimbabwe

In 1975 a solar energy course was convened at what is now University of Zimbabwe (then University of Rhodesia). This was followed by recommendations for the establishment of a Solar Energy Centre at the university.

The Energy Resources Advisor in the then Prime Minister's office, a solar enthusiast, subsequently established the post of Solar Energy Development Officer in April 1978. In the same year, following numerous meetings in the two major cities, Harare and Bulawayo, the Solar Energy Society of Zimbabwe (*then Rhodesia, the name was changed to Zimbabwe at independence in 1980*) was formed.

Membership of the Solar Energy Society of Zimbabwe (SESOZ) had reached 100 individual and industrial members by 1981. In 1982 SESOZ started a magazine, 'The Sun', edited by a University of Zimbabwe academic. The magazine covered solar and other renewable energies. The industrial members of SESOZ formed an industry association, the Solar Energy Industry Association of Zimbabwe (SEIAZ).

SESOZ scored a major coup when it successfully bid to host the International Solar Energy Society conference in Harare, in September 1995. SEIAZ members were instrumental in spearheading the introduction of solar photovoltaic systems long before the GEF solar project was proposed.

Appendix 1.6

Thesis survey questionnaires

BACKGROUND QUESTIONNAIRE 2002

ENUMERATOR ____________________ DATE________

Form Area & Number	

Name of interviewee ____________________

Status in household ____________________

Address

____

No. of people living here*

men *women*	*children*	Total

**insert numbers*

Types of buildings. (Insert numbers)

brick	*pole, mud & grass*	*other*

Source of income by household member

Name of person earning the income	Status in household	Activities that generate income	Income amount	Frequency of income (*eg daily, weekly, monthly…)*	Reliability of income (*eg always, often, occasional, rare*)
Blank rows reduced to save space, original forms had more rows					

Income generating activities

Activity	Which part of the year activity is done	Does Battery help the income generating activity? (*If yes explain how*)	Energy Source for Income generating activity

Fuel end uses and preferences

In this question, first ask what the respondent uses for lighting, and tick the row for "Using" under the fuel mentioned.
Next ask if the respondent would prefer a different fuel for lighting, ie the fuel they would want to switch to if they could.
If there is a preferred alternative fuel for that end use, tick the "Want switch" box under *the alternative fuel.*

		Electricity	Gas	Paraffin	Wood	Candles	Car battery	Dry cell batteries	Petrol for generator
Lighting	Using								
	Want switch								
Cooking	Using								
	Want switch								
Water heating	Using								
	Want switch								
Space heating	Using								
	Want switch								
TV	Using								
	Want switch								
Radio	Using								
	Want switch								
Geyser	Using								
	Want switch								
Ironing	Using								
	Want switch								
Other	Using								
	Want switch								

Fuel costs

FUEL NAME	UNIT OF PURCHASE	COST OF EACH UNIT	FREQUENCY OF PURCHASE	DISTANCE TO FUEL SOURCE
Firewood				
Paraffin				
Candles				
Dung				
Cobs				

GRID CONNECTED

System background:

Who paid for the connection to ZESA ____________________ Year, month connected __________

Cost of house wiring $ ________________ Year of wiring

System Configuration

Type of connection

Metered	Load limited	Pre payment
	Limit= amps	

Rooms with electricity, incl. Outside

Kitchen	Lounge	Bedroom1
Bedroom2	Veranda (security light)	

Load details

Appliance	How many units	Power rating (W or A rating)	Make & Model	Description	Hours per day
Radio					

TV					
Lights					
Stove					
Fridge					

User Comments ______________________________

Are you happy with your ZESA connection? | Yes | No |

Please explain why ______________________________

Have you faced difficulties since connection? | Yes | No |
Explain if necessary

Are there tasks for which you choose to use another fuel instead of grid electricity? Give reasons.

Task	Choice fuel	Reasons for not using grid electricity

What do you like most about your ZESA connection ______________________________

What do you not like about your ZESA connection ______________________________

SOLAR PV SYSTEMS

Background

Who bought the solar system ______________________ Year, month bought [ ]

Cost of solar system $ ____________ Who installed System ______________________

Installing project (if any) ______________________

Cost of installation $ [ ] Payment method [Cash / Credit]

IF CREDIT How long ______ Source ______ Instalment $ ______ Freq of payment ______

System configuration

	How many	Power rating. (W or A)	Make & model	When first used	Room in which installed	Status on day of visit
PV module						
Charge controller						
Battery						
Other						

Module mounting method:

On roof sheets	On separate pole	Pole on wall	Loose

Load details

	How many units	Power rating	Make & model	Description (colour?, size..)	Room in which used	Hours per day
Portable Radio						
Radio Cassette						
Stereo System						
TV						
Lights						
Inverter						

Fault history

	Date of fault	Date reported	Date fixed	Cost of repair	Who repaired	Present status
Battery						
Charge Controller						
Lights						

User skills

Do you have a Solar system user manual? | No | Yes | Comment ____________

was manual lost?

Were you trained at installation? (If yes, by who?) | No | Yes | By ____________

What maintenance do you carry out? *(clean panel, add battery water, etc)* ____________

Highest educational qualification of person responsible for looking after solar system ____________

User comments

If you did not have solar, would you buy a solar system today knowing what you know about it? (explain answer)	Yes	No	______
Do you wish for a bigger solar system?	Yes	No	*if YES for what?*
Is maintenance of your system good enough? (explain answer)	Yes	No	______
What changes has your Solar system made to your life (*if any*)	None		Changes ______
What fuels do you use less as a result of having you solar system. How is this possible?	No change		Fuels used less ______
How do you dispose old batteries?	______		
Do you have local access to spares for the solar system?	Yes	No	If NO, where do you get spares? ______

BATTERY ONLY SYSTEM

Background

Battery type ☐ Where charged ____________

Source of battery ☐

Charging fee ☐

Cost of battery ☐

Method of transport for battery to charging place ____________

Cost of each trip for charging ____________ *explain if this is estimated*

How long each charge lasts on average ____________

When battery bought? ☐ Bought new? Yes ☐ No ☐

Condition of battery today ____________ *(e.g. in use, dead, away for charge, etc)*

Why did you not buy a solar system instead of just a battery? ____________

How do you know when to recharge the battery? ____________

Is battery sometimes not charged when flat, due to money shortage? Yes ☐ No ☐ *(write down any other reasons)*

Are batteries bought new? Yes ☐ No ☐ How long does battery usually last? ☐ months

What happens to used batteries? ____________

Load details

Load name	Make & Model	Description	Power rating (W or A) specify	Hours used per day
TV				
Radio				
Lights				

Available alternative batteries (dry cells) that can be used

Type ______ (e.g. PM9) Voltage ______ *(usually 6v or 9v)*

Cost in 2002 ______ Longevity ______ *(how long it normally lasts, in weeks)*

What do you use these batteries for? ______

If you did not have a battery, would you buy a battery knowing what you know now? ______

What changes has your battery made to your life (*if any*) None ______ Changes ______

What fuels do you use less as a result of having your battery. How is this possible? No change ______ Fuels used less and how battery leads to this ______

UN–ELECTRIFIED HOUSEHOLD *(no solar PV, no car battery, no ZESA power)*

Appliance name	Make & Model	Description	Power source	Power rating (W or A)	Hours used per day
Radio					
Torch					

Dry batteries that are used

Type (e.g. PM9)		Voltage			*(usually 6v or 9v)*
Cost in 2002		Longevity			*(how many weeks it lasts)*
Do you sometimes go without batteries due to lack of money?			Yes	No	*(note any other reasons)*

If yes, how often ______ for how long on average ______

Awareness of alternatives

Do you know about Solar home systems?	Yes		If yes, why don't you have one?	______
	No			______

Future plans

What other energy sources do you know and are considering acquiring?

Source of energy	Planning to get in next 2 years (Y/N)?	Planned use(s)	How did you come to know about this energy source?

Appendix 2.2.1

Estimation of the number of physical solar home systems and institutional solar systems installed by the GEF Solar Project.

Solar PV systems at households

The number of loans disbursed to households is known. This is a good indicator of the number of physical solar home systems installed on credit by participating private companies. Since 10% of households paid cash (GEF PMU, 1998), it is possible to estimate from these facts the total number of solar home systems installed (*sub–total 1*).

The number of equivalent systems allocated to NGOs is known. One of the NGOs (BUN) provided the database of all its clients, so the number of physical installations is accurately known. The ratio between the size of BUN–installed physical and equivalent systems is used to estimate the number of physical installations by the other NGO (ORAP) from its quota of equivalent systems (*sub–total* 2).

The number of physical systems installed by ZESA is estimated using the same ratio as for NGOs (sub–total 3) and the total of 6602 household installations is established.

Number of loans disbursed at end of project	5150	
Percentage of households who used credit	90%	
Total number of households (5150/0.9)	**5722**	***(sub total 1)***
Number of NGO equivalent systems (BUN and ORAP)	600	
Number of physical installation by BUN (200 equivalent)	160	
(i.e. each BUN physical system is 1.25 equivalent systems on average)		
Number of NGO physical systems (600 equivalent /1.25)	**480**	***(sub total 2)***
ZESA's 500 physical systems (500 equivalent /1.25)	**400**	***(sub total 3)***
Total physical SHS installations for all dissemination modes:	*6602*	

Solar PV systems at public facilities

For institutions, the average school installation was described as covering one to two classroom blocks, an administration block, a library, and in some cases one to two staff houses. Each classroom block would have an 83Wp module (GEF PMU, 1998).

It has been assumed that staff houses and the administration block would have typical household size modules in the range 40–60Wp. A library is assumed to have an 83Wp module because of the greater demand for lighting.

The number of equivalent systems in schools and clinics represented 40% of the total installed equivalent systems in 1997. If this proportion is assumed up to the end of the project, then the number of equivalent systems would be 40% of 12 000, that is 4 800.

With the above data and assumptions, the number of physical institutional solar systems installed can be estimated for two scenarios using the given school system configurations as follows:

	Small installation	*Large installation*
Classroom blocks	1 x 83Wp module	2 x 83Wp modules
Library	1 x 83Wp module	1 x 83Wp module
Administration block	1 x 45Wp module	1 x 45Wp module
Staff houses	1 x 45Wp module	2 x 45Wp modules
Total Watts peak	**276 Wp**	**384 Wp**
No of equivalent systems	6	8.5
Physical systems in 4800 institutional equivalent systems	**800**	**565**

To put these numbers into perspective, the total number of schools in Zimbabwe in 1996 was given by the Central Statistical Office (CSO, 1998b) at 4659 primary, and 1529 secondary, totalling 6188. The total number of health facilities was 1449 in 2000. The above physical installations would cover between 7.4% and 10.5% of the schools and health institutions respectively.

Appendix 2.2.1a

Sample BUN quotation form for the GEF Project NGO mode, showing component costs and charge utilisation table based on client house specification

GEF/BUN SOLAR SYSTEM QUOTATION — **Date ol quotation 1999/07/2**

Customer :Kwdz Logistics

Company BIOMASS USERS NETWORK — **Quotation valid until 1999/08/23**

P Bag 7768, Causeway, Harare

Tel. 793395/6 Fax 793313 — **4 Lights Radio & TV**

NR	Item	Manufacturer		Model	Unit	Total
1	*Solar Panel*	*Siemens*	*(German\)*	*55W*	*11,000.0*	*11,000.0*
1	*Charge Controller*	*Steca*	*(German\)*	*Solsum 6.6*	*2,500.0*	*2,500.0*
1	*Battery*	*SEC*	*(USA)*	*12-110AH*	*4,000.0*	*4,000.0*
4	*Light*	*Technosol*	*(German\)*	*13 CFL*	*800.0*	*3,200.0*
1	*Voltage Dropper*	*Nyamatsa*	*Zwe*	*12/9V*	*150.0*	*150.0*
1	*Battery Box*	*BUN*	*Zwe*	*SB1*	*550.0*	*550.0*
1	*Mounting Hardware*	*BUN*	*Zwe*	*PM1*	*550.0*	*550.0*
1	*Wiring Inputs*	*Various*	*Misc*	*Various*	*3,000.0*	*3,000.0*
				Total Equipment		**24,950.00**
				Installation Charge		
				Transport		
				Installed System		

Note: All money for the BUN Solar Project MUST be made to an approved*BUN agent or the BUN office in Harare and a BUN receipt always obtained*

CHARGE UTILISATION TABLE

NR	LOAD	Amps	Hrs per Day	Amp-Hrs
1	13 watt light - sitting room	1.1	3	3.25
2	9 watt light - spare room	0.8	1	0.8
3	13 watt light - kitchen	1.1	3	3.3
	9 watt light - bedroom	0.8	1	0.8
5	TV - small black and white	1.2	3	3.6
		Total Load AH		**11.7**
	SOLAR PANEL PEAK AMPS	3	**4.5**	**13.**
	Charge Balance		**15%**	**1.7**

I have chosen this quotation for my solar electric system

Customer ____________________ Date ____________________

Approved ____________________ (BUN Zwe) Date ____________________

This quotation is only valid for the period shown above.

Appendix 5.1

Energy sources used for household cooking in Zimbabwe

Province	*Wood*	*Paraffin*	*Electric*	*Gas*	*Coal*	*Other*
Manicaland	87.0	8.4	4.6	0.1	0	-
Mashonaland Central	84	5.9	9.3	-	-	0.8
Mashonaland East	87.6	7.5	4.7	0.1	-	0.1
Mashonaland West	72.8	11.2	16.0	0	-	0
Matebeleland North	74.5	4.7	20.4	0.1	0.4	-
Matebeleland South	85.1	2.2	12.4	0.2	-	-
Midlands	71.9	9.9	18.2	0.1	-	-
Masvingo	88.3	4.3	6.9	0	-	-
Harare	2.8	39.7	56.5	0.9	0.1	0
Bulawayo	2.5	8.5	88.1	0.9	-	-
Urban areas	**7.2**	**31.1**	**61.0**	**0.6**	**0.1**	**0.0**
Rural areas	**94.7**	**2.9**	**2.2**	**0.1**	**0.0**	**0.1**
National average	**66.02**	**14.05**	**19.08**	**0.28**	**0.42**	**0.12**

Source: Central Statistical Office Inter–censal Demographic Survey 1997

Appendix 7.1.2

Electricity tariff trends in Zimbabwe, 1995 to 2001

Tariff Structure	*YEAR*						
	1995	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*
Fixed Monthly Charge (Z$)	15.9	19.08	20	21.62	36.6	86.49	114.37
With Levies Fixed Monthly Charge (Z$)	15.9	19.08	20	22.92	43.91	91.68	121.23
I st 50kWh (Z$/kWh)	0.163	0.1914	0.2364	0.2556	0.4326	0.92	1.21
With Levies (I st 50Kwh) (Z$/kWh)	0.163	0.1914	0.2364	0.2837	0.5191	1.02	1.35
51 to 300kWh (Z$/kWh)	0.163	0.1914	0.2364	0.2837	0.4326	1.02	1.35
With Levies (51 to 300kWh) (Z$/kWh)	0.163	0.1914	0.2364	0.2837	0.5191	1.14	1.49
301to 1000 kWh (Z$/kWh)	0.271	0.443	0.673	0.727	1.231	2.88	3.53
With Levies (301to 1000Kwh ($/kWh))	0.271	0.443	0.673	0.807	1.477	3.19	3.92
Balance ($/kWh)	0.271	0.443	0.673	0.727	1.231	2.98	3.66
With Levies (Balance ($/kWh))	0.271	0.443	0.673	0.807	1.477	3.31	4.06

Source: Dube 2002