UNIVERSITY OF GOTHENBURG

Solar Energy for a Brighter Life

A Case Study of Rural Electrification through Solar Photovoltaic Technology in the Eastern Province, Zambia

Mathias Gustavsson

PhD Dissertation, Human Ecology, Göteborg

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This dissertation is dedicated to the friendship and memory of Clotilda Mwanza

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Abbreviations and special terms

AC	Alternating Current
Boma	Word used in every day language in Zambia to refer to the district capital or chief town in the municipality
CHESCO	Chipata Energy Service Company Ltd
DC	Direct Current
DOD	Depth of Discharge
DOE	Department of Energy, Government of Republic of Zambia
EML	Electrical Maintenance Limited, Lusaka based firm
ERB	Energy Regulation Board, Zambia
ESCO	Energy Service Company
GEF	Global Environment Facility
GIS	Geographic Information System
GPS	Global Positioning System
HDI	Human Development Index
HDR	Human Development Report
LED	Light Emitting Diode
LESCO	Lundazi Energy Service Company Ltd
Light point	a light source, lamp candle etc
LPG	Liquefied Petroleum Gas
MDG	Millennium Development Goals
MFS	Minor Field Study (Sida programme to support degree projects for Swedish students in developing countries)
NESCO	Nyimba Energy Service Company Ltd
NGO	Non Governmental Organisation
O&M	Operation and maintenance
OPPPI	Office for the Promotion of Private Power Investment
PTA	Parent Teacher Association
PV	Photovoltaic
REA	Rural Electrification Authority, Government of Republic of Zambia
SAPP	Southern African Power Pool
SEI	Stockholm Environment Institute
SEK	Swedish krona
SHS	Solar Home System
Sida	Swedish International Development Cooperation Agency
SOC	State of Charge
SSA	Sub Saharan Africa
UN	United Nations

UNZA	University of Zambia
USD	United States Dollar
VCR	Video recorder
Wp	Watt peak, rates the maximum power from a solar panels under defined standard test conditions (1 kW/m^2 irradiance, AM1.5 spectral distribution and 25°C cell temperature)
Zesco	Zambian energy utility (not an abbreviation)
ZMK	Zambian Kwacha
ZNS	Zambia National Service

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… and my family Elmer, Vanna and Maria.

Foreword

This thesis will present results from a case study of how access to solar electricity has changed people's lives in the Eastern Province of Zambia. Even though there have been a large number of solar projects in Africa, there is relatively little data on the actual changes in people's lives as a consequence of these interventions. This thesis is my contribution to the knowledge on how solar technology can contribute to improving people's lives in rural settings in Sub Saharan Africa.

Solar technology has many potential benefits such as producing electricity in remote areas for good lighting and operating radios, TV:s and computers, but at the same time there are problems associated with the use, distribution, and maintenance of the technology. It is a renewable energy technology which has the potential to improve people's lives, but the application of this in a social context results in both technical and social opportunities and challenges, as the technology will become a part of the users' livelihoods. Many of the solar energy systems in operation have been introduced as part of a development intervention, there is also another level that concerns the implementation of the development interventions and choice of technology. This level is affected by national policies and international development agendas, which will affect the conditions of access to solar technology for users.

I have followed a long and circuitous road since my first attempts to approach the issue of technology use in development interventions. It started with an exam paper on hydropower and Swedish technical assistance in 1989. My interest continued, and in the mid 90s I wrote a BSc paper on biogas use in Orissa India (Gustavsson 1995), which was followed by a study on the diffusion of small-scale biogas technology in India. This study was presented in a Philosophy Licentiate thesis in 2000 (Gustavsson 2000). From 2001, my focus has been on solar photovoltaic (PV) technology in Sub-Saharan Africa, and particularly on a solar PV project in Zambia – the Zambia PV-ESCO (Energy Service Company) project. This thesis presents experiences of the role that small-scale solar technology can play in rural electrification through analysing and discussing the impacts seen and experienced by users of solar services in the Eastern Province of Zambia.

In the course of this research I have had the opportunity to meet and work together with highly qualified people in Lundazi, Nyimba, Chipata, and Lusaka. This has not only resulted in the collection of the empirical data found in this thesis, but also in the sharing of experiences, laughs, and friendships. I have had great fun, but what a long … trip it's been!

Mathias - Styrsö, May 2008

1 Introduction

This thesis studies the impacts that access to electric power generated through solar photovoltaic (PV) systems have had on users living in three areas of the Eastern Province of Zambia. Today these users are dependent on charcoal, fuelwood and fossil fuels (mainly kerosene), and by changing parts of the energy system to include reliance on solar energy technology, the livelihood situation for households and organisations using the new technology is changed. The energy services provided by the new technology, for example in the form of changed working conditions, improved lighting , improved indoor climate, or the possibility to enjoy news and entertainment from TV and radio, can have large effects on the economic and social development among the users of the new technology. To successfully transfer technology from one place to another is known to be a challenge (Rogers 1995; UNDP 2001; Wilkins 2002) and this thesis will present data on some of the problems and the consequences of the introduction of a technology that is new to all the users.

The introduction of a novel technology in a rural environment is based on the assumptions that the users will gain a number of benefits from using the new technology. However such effects cannot be taken for granted. There are numerous examples on how difficult it is to get *target* groups to accept and use the technology or technical artefact. Problems can involve everything from the acceptance of the technology per se to the long-term effects of a new technology on the environment, social relations and livelihood situation for poor people who often are assumed to be main beneficiaries of the new technology.

Technology transfer in developing countries, especially in Sub Saharan Africa (SSA) has been shown to be more problematic than expected. This is partly because of a lack of financial resources, little know-how, and problems with the dissemination process. For example, the large energy savings that could be brought about by changing from traditional stoves to *new* energy saving stoves have not been forthcoming despite the large efforts invested in the introduction of this "technology" (Barnes *et al.* 1994). In almost all cases of technology introduction and transfer, the major problems are associated with the *poverty dimension* i.e. the fact that the poor do not have the money, the education, or the power to influence the external agents promoting the technology, which creates a situation which is not appropriate for the new technology (Dudley 1993).

But it is not only the socio-economic and political context in which the technology is introduced that is the problem. Assessments of the environmental and health impacts must be made before the technology is introduced. The sustainability of the technology must be assured. There are also problems associated with the operation of the technical artefact, i.e. the maintenance and management of the technical system. (Gilbert *et al.* 1996; Hedger *et al.* 2000; Trindade 2000; Wilkins 2002). There lies also a challenge in how a new technology is introduced, especially if the technology process is envisaged to affect the poverty situation in a country. Technologies are in such cases generally introduced and disseminated through a "project" approach and not through a market approach. This is of course just another face of the poverty dimension: the poor cannot generally afford the money or the time which the operation of the new technology demands. An introduced technology is also supposed to function and become part of people's lives, and to continue doing so after the project is ended. There are numerous examples of projects where the introduced technology works as long as there is project support for the users such as financial aid, training, technical backstopping, and encouraging the users to continue, but once the project is terminated, the introduced technology cannot be maintained. See, for instance, the examples of the slow introduction of improved chulhas (stoves) in India (Sarin 1986, 1987; Goldemberg 2000), solar cookers in South Africa (Wentzel *et al.* 2007), or wind pumps in Kenya (Harries 2002).

In this thesis the effects of a project approach to introducing solar technology in Zambia will be discussed and analysed. It was deemed important to undertake the study in Zambia both from the technology transfer point of view, but also in order to study some effects of the technology on the livelihood situation in the areas investigated.

The introduction of solar cell technology must among other things be viewed from the perspective of the many beneficial effects the introduction of new renewable energy sources can have, for example: improved health through reduction of indoor air pollutants (Smith 1994; Ellegård 1997), improved quality of life (Ravindranath *et al.* 1995), ease of use and labour saving (Wilkins 2002; Huacuz *et al.* 2003), improved working situation for women (Economic Commission for Africa 2005), and new economic opportunities for the poor (Practical Action 2002). It is therefore that energy services as supplied though a new technology are seen as an important component in achieving the Millennium Development Goals (DFID 2002; UN-Energy 2005). But they are also important as they can lead to increased opportunities for people to access information and communication technologies (World Bank 2005a; Britz *et al.* 2006).

In SSA about 65% of the people live in rural areas (World Bank 2005b) and the majority of the rural households are not connected to any electric grid. In most SSA countries less than 10% of the households in the rural areas are electrified (Figure 1).

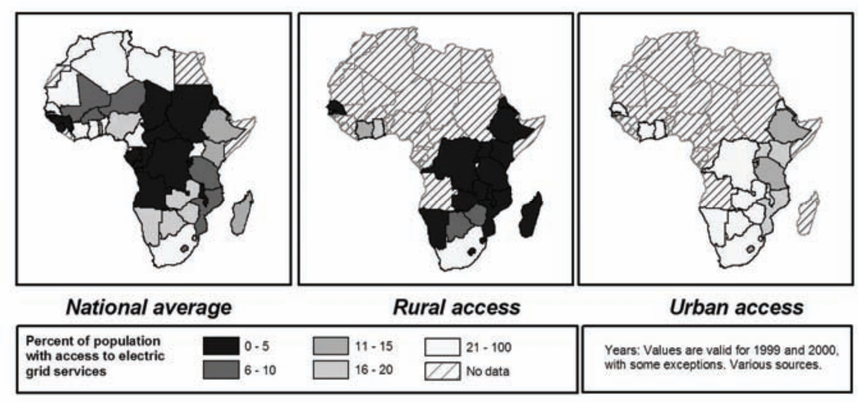

Figure 1: Electrification rates in Africa 2000. The data in figure 1 are based on National, rural, and urban averages from 2000. Various sources

The overview presented in Figure 1 is based on national averages and the access to electricity does not reflect the large differences between users and regions within individual countries (O'Sullivan *et al.* 2002; Redwood-Sawyerr 2002). An analysis of electrification rates shows that there are even larger differences than shown in Figure 1, when one compares urban and remote rural areas. With a user perspective the differences in electricity use between the poor and people with access to resources are striking. Places of political, national, or economic importance tend to have higher levels of grid electrification than all other areas, which is the case in for example Zambia (CSO 2004a; Mbewe 2004).

The major means of electricity production in Sub-Saharan Africa is hydropower (Redwood-Sawyerr 2002). As a consequence, the conventional route for rural electrification has been through extending the national grid, using technology well developed in other countries. Grid electrification requires substantial investments in hardware, and also extensive maintenance of the installed equipment. The costs per electrified unit are high, and under market conditions poor consumers in rural and remote areas cannot afford the electricity thereby making grid electrification generally not an option for the electricity producers unless there are substantial subsidies for users. Grid electrification thus becomes a system that is dependent on paying consumers, and these are generally found in urban and developed areas and among the affluent.

The introduction of grid electrification in Africa, which started on a larger scale in the 1970s, was originally almost totally based on state-managed enterprises often using foreign aid as the major financing source for the introduction of the new energy system (World Bank 1993; Strickland *et al.* 1998). The economic viability of these enterprises was in many cases dubious. With the strong emphasis in the 1990s of donors on deregulation and market initiatives, this also spilled over into the power sector in Africa. The World Bank, for example, put forth de-regulation as a condition for lending money to the power sector (Wamukonya 2003b). As a consequence the energy policies in individual countries were changed, and today many of the energy utilities in Sub-Saharan Africa are operated as parastatal or commercial companies, and in many cases the services provided to the customers have improved (Wamukonya 2003b). But as indicated above, this mainly came to affect affluent users and urban areas.

Rural electrification prior to de-regulation was slow and not a major priority in rural development policies, and with power sector reforms this process has not been prioritized and progress is slow (World Bank 1996; Bhagavan 1999; Wamukonya 2003a). The changed energy policies and the subsequent deregulation have led to the situation that subsidies, which earlier were used in supporting for example rural electrification, in general should not be allowed. A number of studies undertaken show that it is very difficult if not impossible to achieve rural electrification of low income areas. Targeting the poor and less affluent requires substantial subsidies (Foley 1992; Zomers 2001). Another problem associated with electrification projects based on a high level of subsidies was that despite the fact that the monetary resource flows to the projects were under government control, evaluations often revealed both mismanagement of funds and corruption with ensuing negative effects on the rate of electrification (Wamukonya 2003a; Barnes *et al.* 2004).

The power sector reforms opened up the sector for new actors, which in a number of cases has led to that the structures and functions of the energy sector has undergone large changes. But the lack of resources, and the often precarious economic situation in most countries in Africa south of Sahara, have restricted improvements in electrical levels to only marginal changes (Wamukonya 2003b, 2003a).

There is however one niche where local actors have entered the power sector, and that is in the introduction, dissemination and operation of energy systems based on distributed energy generation (see for example Cabraal *et al.* 1996; Andersson *et al.* 1999; Sakairi 2000; Hankins *et al.* 2004). Distributed generation is defined as an electric power source that is directly connected to a distribution network or directly to a place of use and which has a site-specific technical requirement. (Ackermann *et al.* 2001; Turkson *et al.* 2001; Poullikkas 2007). Distributed generation is generally based on the decentralisation of economic and administrative control, and that know-how about the operation of the energy source is transferred to the users (Alanne *et al.* 2006). This thesis is about a distributed energy system, and some of the characteristics of this system in three areas in Zambia will be discussed here in some detail.

The type of generation/technology is not defined in the definition of distributed generation; thus solar PV technology, mini hydro power, diesel or petrol engine generators, wind power, or biomass-based electricity generation technologies are all examples of distributed generation systems. Distributed generation can range from small installations of the specific energy technology located at an individual household, to mini-grids connecting and supplying a number of users in one locality with electricity[1].

Installed electricity production based on distributed generation is marginal compared to electricity produced by water power, coal, diesel, or oil based power generation. On the other hand with a user perspective in mind this type of energy system has a number of characteristics from an energy service point of view which are important in an impoverished and rural context, something which is discussed in the thesis. The fact that the distributed generation is decentralized and local gives it an important role in the development strategies of many countries

During the last 20 years small solar PV systems have been used in supplying rural areas with electric energy services (see for example Nieuwenhout *et al.* 1999; Foley 2000; Lorenzo 2000; Nieuwenhout *et al.* 2001a). There has been a two-pronged development effort in the introduction and dissemination of the technology, one market oriented, and one state oriented. Solar PV technology is now accessible through market based initiatives. Thus for example solar cells can now be found and purchased in shops in most cities in Africa. In many countries this market coexists with solar technology introduced through development interventions implemented by governmental institutions, international organisations and non-governmental organisations.

The country most often mentioned as an example of having reached a market stage of Solar Home Systems (SHS) is Kenya, and several studies have been made of the experiences of this diffusion of the technology (see for example Acker *et al.* 1996; van der Plas *et al.* 1998; Duke *et al.* 2002; Jacobson 2004). The solar systems ac-

[1] The amount of energy produced are not a part of the definition of distributed generation. Ackermann *et al.* (2001) suggest that the ratings of distributed energy production should be made from as follows: micro (~1<5kW), small (5kW<5MW), medium (5MW<50MW) and large (50<300MW). In the majority of cases solar technology found in Africa will fall in the micro distribution category.

quired by people in Kenya are often based on small (less than 50 Wp[2]) solar modules.

The country best representing governmental support to distributed generation based on a large solar diffusion programme is South Africa. The official governmental policy is universal access to electricity for all, and this has been the goal of the government in South Africa since 1994 (Ranniger 2004a). Here solar technology is seen as a way to reach those areas that are presently not connected to the national electricity grid. A concession program was thus initiated in the late 1990s, where the concessionaire who provides the energy systems to the clients will receive a subsidy from the government. The clients of the concessionaire will pay a monthly fee for the service provided by the solar energy system.

GEF (Global Environment Facility) is an international actor in distributed generation that has funded and supported a number of solar PV provision programmes in Africa (Martinot *et al.* 2001) for example in Zimbabwe (Mulugetta *et al.* 2000; Afrane-Okese *et al.* 2003), Ghana (Abavana 2000), Benin, and Togo (Martinot *et al.* 2001). Most of these programmes have targeted rural households and tried to introduce market mechanisms in the implementation of the programmes. But electrification through PV technology is also found when the recipients of the electricity are institutions such as health clinics, hospitals, schools, churches etc.

There are thus today a number of distributed generation systems based on solar systems in different parts of Africa. The rationale for introducing the systems has been that they do supply energy services that are important to individual households and institutions, and that it has been assessed that the access to electricity will improve the livelihood situation for individuals. Many of the solar systems have been a part of planned interventions and thus generally project oriented. There are however only few studies and assessments of both the impacts of the energy services supplied through the distributed generation and the sustainability of the solar systems. The studies that have looked at some of the impacts of access to solar electric services are relatively few in number and scattered (examples of impacts studies from SSA are found in Afrane-Okese 1999; James *et al.* 1999; Nieuwenhout *et al.* 1999; Wamukonya *et al.* 1999; Afrane-Okese *et al.* 2003; Jacobson 2004; Ranniger 2004b, 2004a; Jacobson 2005).

[2] Wp, or Watt peak, is the power rating used to give a representative value of the maximum electric power generating capacity of a solar panel. This Wp value is measured under standard conditions of 1 kW/m^2 irradiance, AM1.5 spectral distribution and 25°C cell temperature (Luque *et al.* 2003). The Wp is thus a value given under lab conditions and different from the electric power produced under real conditions.

1.1 Aim and structure of the thesis

The aim of the thesis is to study how the introduction of solar electric technology in some selected rural areas of Zambia affects people's lives and livelihood situation, and how the implementation process was brought about. The solar electric technology studied is the small-scale solar energy system, so-called Solar Home Systems (SHS), that were made available to users through rural electrification projects implemented with government support. The thesis focuses on how the introduced energy system is managed at the institutional and household levels and what effects the different energy services supplied have at the household level.

The main research question posed is *what is the role of solar home systems, introduced as part of the Zambia PV-ESCO (Energy Service Company) project, in the user's everyday life? Users* in this study are not only individual households, but also schools and other institutions. The Zambia PV-ESCO was a project aiming at establishing local energy service companies offering solar electric services to customers, and for this service charging a fee. These ESCO:s would then operate several distributed energy systems as an alternative to a grid electrification route.

A distributed electricity system is comprised of i) the technical artefacts used for the generation, distribution and transmission of electricity, and the maintenance of the technical artefact, ii) the organisational setup for delivering and supporting the production of electricity, and iii) the end users of the electricity (Debir *et al.* 1991)[3]. A study of the introduction of a new technology should therefore look into these three dimensions and also the interaction between these three system components. The interaction between these different aspects of technology will affect the operation of the energy system and the services which the users receive from it. But what perhaps is even more important, the introduction of a novel energy system can have effects on the livelihood situation of the users as well as promote new development pathways in a rural area.

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[3] Debir *et al.* (1991) also include an ecological component in their definition of energy system. These aspects are often linked to effects found on a global or regional level, while local environmental concerns are limited. Disposal of old batteries is an example of an environmental aspect of solar PV energy systems. An environmental analysis of solar PV energy systems will have to consider regional, national, and global levels, and it seems that the main environmental effects are found in the production of the components, rather than during their use (Nieuwlaar *et al.* 1998; Alsema *et al.* 2000). Recycling and managing the storage of old batteries, as well as taking care of broken modules, can have a negative environmental impact (Alsema 2000), but this is outside the scope of this thesis.

The main research question was answered by undertaking a number of studies where the core of the investigations centred around collecting information in three subject areas.

1. *The technical dimension of the use of Solar Home Systems:* The solar energy system represents an advanced technical artefact that in most cases is new to the users. The way it is managed and operated has effects on the artefact's operational life-span, and also what types of services that can be obtained. The results from the studies on the handling of the technical artefacts by the users were important as they give a better understanding of the limits set by the technology *per se*.
2. *The impacts of Solar Home Systems on daily routines and lives:* Questions such as what people use the electricity for, and how daily routines have changed, are discussed. In order to get access to the solar technology it is necessary to pay a fee for the service, but at the same time a switch in fuel can take place, thus possibly saving some expenses.
3. *Consequences of access to solar energy services on institutions and communities:* The energy services from a SHS can provide a number of opportunities in terms of services offered to the communities and people visiting the institutions. The role that (micro) distributed generation plays in energy infrastructure is problematic due to the high number of energy systems, the lack of control over these, and the organisation of ownership.

The thesis consists of an introductory essay giving a general introduction to the background of the work and also summarising data from the five papers comprising the thesis. The introductory essay also puts the findings in the research papers into a rural development, technological and energy systems context. The five articles present data on access to solar services in the Eastern Province of Zambia. The following five articles are included:

I. Gustavsson, M. and A. Ellegård. (2004). "The impact of solar home systems on rural livelihoods. Experiences from the Nyimba Energy Service Company in Zambia". *Renewable Energy* 29(7): 1059-1072.

II. Gustavsson, M. (2004). "The Impact of Solar Electric Services on Lifestyles – Experiences from Zambia". *Journal of Energy in Southern Africa* 15(1): 10-15.

III. Gustavsson, M. (2007). "With Time Comes Increased Loads – an Analysis of Solar Home System Use in Lundazi, Zambia". *Renewable Energy*, 32(5): 796-813.

IV. Gustavsson, M. and D. Mtonga. (2005). Lead-acid Battery capacity in Solar Home Systems – Field tests and experiences from Lundazi Energy Service Company, Zambia. *Solar Energy* 79(5): 551-558.

V. Gustavsson, M. (2007). "Educational Benefits from Solar Technology – Access to Solar Electric Services and Changes in Children's Study Routines, Experiences from Eastern Province Zambia". *Energy Policy*, 35(2): 1292-1299.

Article I is based on a survey undertaken in 2001. The article was written together with Anders Ellegård who contributed to the preparation of the field work, as well to the final presentation of the results and analysis in the article. Article II is based on two surveys undertaken in 2001 and 2002. The paper was originally presented at the ISES conference in Göteborg 2003 (Gustavsson 2003), but was later re-written and submitted to the Journal of Energy in Southern Africa. The Journal of Energy in Southern Africa is edited by the Energy Research Institute at the University of Cape Town. Article IV is based on controlled battery tests performed in Lundazi, and Daniel Mtonga assisted me in the performance of these tests. The design of the tests and setting-up of the test equipment, as well as the writing and revision of the article were my sole responsibility.

2 Energy services and rural development

Much of the introduction and popularisation of small solar home systems in Sub-Saharan Africa is driven by the assumption that provision of modern energy sources will facilitate a development process. Such assumed changes are, however, not determined by the technology, but rather how the users will adopt and integrate the technology and adapt to the changed situation caused from the access to new energy services. In order to study this it was deemed necessary to look into the concept of energy service. The observation that issues related to maintenance and actual use of solar cell system had been poorly covered in the dissemination process, made an understanding of what is entailed in the energy service concept necessary.

This chapter will thus give a brief and a not all-encompassing presentation of some of the concepts and terms used in the thesis. Here the concept of energy services is deemed especially important. This concept will therefore be treated in some greater detail than others. The development of the concept of energy services was important for putting the data collected into an analytical framework.

2.1 A framework to analyse impacts of access to energy services

The conceptual framework is based on the Millennium Ecosystems Assessment (MA) and Millennium Ecosystems Assessments Methods (Reid *et al.* 2002; Millennium Ecosystem Assessment 2005c). The MA approach focuses on the linkages between ecosystem services and human well-being. The novel dimension in the MA approach is that the ecosystem concept is extended to include more than only the physical side of the ecosystem. Thus ecosystem services are also

> *"the benefits people obtain from ecosystems. … These include goods such as food and water, services such as flood and disease control, and nonmaterial benefits such as spiritual, recreational and cultural benefits"* Reid *et al.* (2002, p. 3).

The services that people receive from the ecosystems are thus central in order for people to manage their livelihoods, but also for cultural and recreational reasons. The service concept has led to a broader view on how one should look upon the use of ecosystems and consequently descriptions about the state of the world have been dramatically changed and the environmental problems facing modern society is now described in a more *holistic* manner. A consequence is that the descriptions of the state of the environment in the world are seen as more problematic than previously envisaged, and the dystopic nature of the assessments gives a special flavour to the publications (see for example Millennium Ecosystem Assessment 2005c, 2005a, 2005b). The conceptual framework for understanding and analysing the role of ecosystem services in different parts of the world is now accepted and adopted by the major international actors with the United Nations (UN). A perfect example of this being the latest publication of the UN (UNEP 2007) where the analysis is based on the MA concept and approach. The service concept was also accepted early on by international donors and integrated into discussions on societal use of energy, in gender analysis, and in livelihood analysis (DFID 2002; Sida 2005).

It is the concept of services as used in the MA that I have applied in the thesis to look into the connection between the development process in the three rural areas investigated and the introduction of solar home systems. Using MA as an analogy, electricity produced by solar cells is equivalent to the ecosystem which produces different services functions. The electricity generated in the solar home system will provide the users with a range of services that can be directly beneficial for them in their everyday lives, but which in a longer time perspective can have larger effects. There is one aspect of the MA which has not been included in the analytical framework presented here and that is the spatial and temporal dimensions (see for example Reid *et al.* 2002; Millennium Ecosystem Assessment 2003).

As the provision of electricity generated in solar home systems is the result of a development intervention in Zambia, the steps in the development sequence from project formulation to outcome of the project must be connected to the service concept.

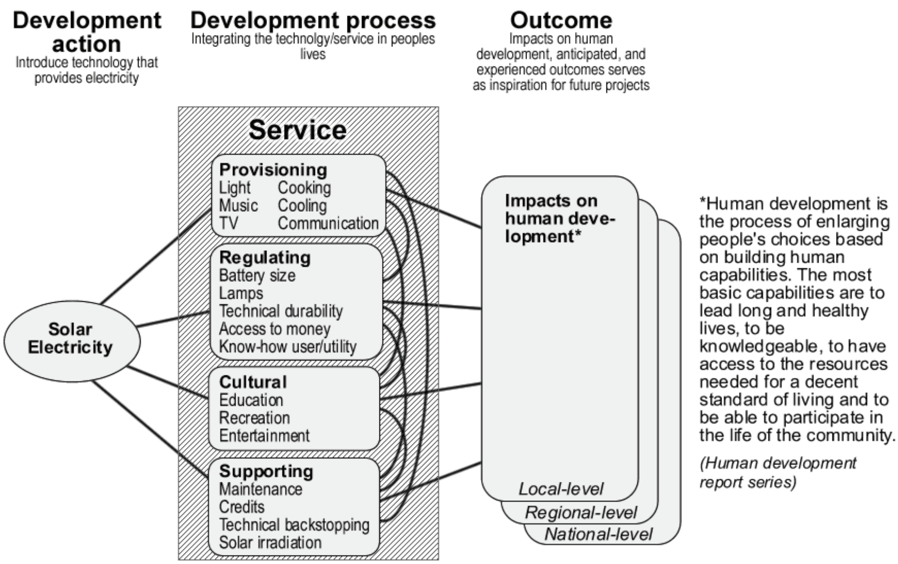

Figure 2: A framework for the analysis of development action and energy services supplied though solar cell technology

This development of the service concept is the novelty in the MA system, not because it was new when introduced, but because in the MA the service concept was operationalised and used in a novel manner in an economic, social and environmental context which was important in describing present-day global problems. Thus it is not the electricity *per se* (or the ecosystem) that is beneficial to the users, but the services obtained from the electricity produced in a solar home system. The MA approach includes a categorisation of the services into four groups. The four groups show the different functions affecting the energy services that are relevant in the analysis of how access to solar electricity will affect people's lives.

- *Provisioning:* Goods produced or provided by the solar energy service. This is perhaps the most obvious process considered in an evaluation of a solar home project – the changes in people's capacity to produce and access goods. Increased work hours, increased sales from shops and new income-generating activities are some examples.
- *Regulating:* In the MA framework, the regulating mechanism denotes regulating ecosystem processes, for example hydrological cycles. In the solar system case, regulation of the system results from size of battery, types of lamps and the durability of the technology. The analogy to the ecosystem is here the solar generated electricity. These energy services can eventually be experienced by the user as both positive and negative, but the essential point is that these aspects regulate the use of the energy service.
- *Cultural:* This function refers to the improved or changed possibilities to get education, recreation and entertainment by access to television and radio broadcasts. In addition through the availability of electricity the users can get access to information and communication technologies such as mobile phones (that require charging), internet and email, which create opportunities to reduce the distance between people (communication).
- *Supporting:* Supporting functions to enable the users to get access to the technology. Without enough solar irradiation, solar technology is probably not the most appropriate choice for generating electricity. But there are several other supporting functions. For many technologies that have been part of a development intervention there are several supporting functions in terms of funding, technical backstopping, and structures to ensure maintenance. Without these there would not be any introduction of the technology at all.

The different service functions described above will interact with each other. For example, the possibility to operate a TV on the solar system is dependant on the system specifications. The solar systems found at given locations – their specifications and quality of components – are generally determined by the available funding and the delivery mechanism applied. The functions are interlinked, and there are positive and negative feedback mechanisms between them. The energy services can also have both positive and negative impacts on its users. For example access to news can be positive for people's education, but access to TV can make people watch this instead of doing homework, and thus have a negative impact on time spent on study. There is little reason to think that, for example, Sida (Swedish International Development Cooperation Agency) would provide funds for a project to support people watching karate movies. There might be a better chance for funding if the aim was to supply the same group with the possibility to access news and audio-visual educational information.

Observed impacts on various levels form the basis for what is labelled *outcome* and is found to the right in the framework (Figure 2). The impacts observed are indications of change, and without change there cannot be any development. Development here is understood as human development, following the definition found in the Human Development Report (HDR) series, (Anand *et al.* 1996; UNDP 2007b). The wish to promote human development is seen as the main driving force for introducing and supporting solar energy as a distributed energy technology[4].

To understand the line of argument put forth in this thesis it is necessary to go a bit more in depth into some of the conceptual parts of the framework. The conceptual framework includes subject matters that have all been thoroughly studied and discussed. I do not argue that the presentations given here, on for example the concept of 'development', cover all angles of the concept, but they will introduce the concepts to the reader.

2.2 Development as a goal and an activity

As the terms development action and development process are a part of the analytical framework presented above, it is necessary to briefly describe how I have used the term development in this thesis. Development is a concept that has many different definitions. Hettne (1990) for example argues that there cannot be *any* fixed and final definition of the concept as it is contextually defined. Often development is

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[4] Distributed solar energy technology will, according to Posorski *et al.* (2003), result in a reduction of greenhouse gas emissions, provided it replaces kerosene lamps and dry cell batteries. This is, of course, a valid argument, but the argument depends on solar electricity replacing already existing uses of climate-affecting energy sources. In many cases the solar system enables *new* services, and not a replacement (i.e. there is no additionality), hence the reduction potential concerning climate change becomes somewhat unclear.

referred to as a process of change in general. Thus for example Chambers (1997, p 1743) present development as *"to do better"*. But this is of little use from an analytical point of view. Development has to be qualified in the dual sense that the context in which the development is to take place must be described and that it is also necessary to qualify the *aims* of the development process if it is a part of an external intervention. It is also necessary to describe actors involved in the development action and how one envisages the development process when such a process is driven by, for example, the authorities or an aid organisation. It is therefore not appropriate to say that access to modern energy sources will facilitate a development process, as it neither says anything about who the beneficiary is nor who defines the goal of the development process.

Human development as a concept is well defined and has been elaborated in the Human Development Report (HDR) series (UNDP 2007b). Human development focuses on improving the situation for people, and the goal is to enlarge the choices people have to live lives that they value. The report series gives perspectives on human development from different themes such as new technologies and human development (UNDP 2001), challenges to international cooperation in aid, trade and security issues, (UNDP 2005a) and recently, challenges to human development set by climate change (UNDP 2007a). The focus in these reports is not primarily on the accumulation of economic wealth and commodities, but rather people and their opportunity to live a good life. According to this view, human development should provide people with opportunities, make them able to live healthy lives, to be knowledgeable, to live at a decent standard of living, and to be able to participate in the life of their communities. The definition defines the target groups of interventions aiming at human development as those who lack the opportunities described above, and that the goal of interventions will be to ensure that people can live good lives. The HDR series has been influential not only in generating momentum in the discussion on human development, but also in presenting an index that takes the aspects of human development into account and calculates a national index of relative human development. Thus a Human Development Index (HDI) is published yearly in the HDR series and the changes displayed in the rankings of countries have become an attractive feature of the reports. The value of the index is, however, disputed, as it is a crude measure of a highly complex issue (for an introduction to some of the critique of the HDI see Sagar *et al.* 1998, 1999; Morse 2003). The HDI will provide some information in tracking processes of development in a general sense, but as soon as a more regional or local approach is applied the information provided through the HDI will add little to the knowledge.

Most people in Sub-Saharan Africa live in rural areas (World Bank 2005b) and in most countries the rural areas are marked by poorly developed infrastructure (Economic Commission for Africa 2005). In these areas there is often a lack of safe drinking water, lack of schools, lack of health care, lack of roads and transportation, and lack of modern energy sources. There are many reasons for this state of affairs that are amply described in old and recent assessments of development in Africa (Skr 1998; UNEP 2004; Economic Commission for Africa 2005) The recent focus on Africa as the continent in need of the most aid and support (see for example G8 2005) just reflects its poor economic development and lack of infrastructure. The problems with introducing and developing the infrastructure in a rural areas are that the areas which need to be covered are large, that there tend to be more poor people living in rural areas, and that central funds are not available. Dissemination efforts for changing the infrastructure thus often becomes totally dependent on centrally allocated funds, which are hard to come by.

Overseas support (aid) to rural development projects has a long history in developing countries (Hettne 1990; Black 1999; Singh 1999) and has generally been designed following a development strategy which at a specific time seemed appropriate. Each decade since 1950 has had its development strategy, and the changes from one strategy to another have often been dramatic, but the best that can be said about this is that the knowledge that has been accumulated from a specific rural/human development strategy has often been applied when a new strategy is introduced. Rural development is more specifically a *development* which refers to an

> *"overall development in the rural areas with a view to improve the quality of life of rural people" (Singh 1999, p. 20).*

The term includes development stretching over several sectors including, for example, agriculture, health, energy, empowerment, and education. Rural development however often has a strong connotation of targeting poor and vulnerable sections in the society. This point was explicitly expressed in Chambers (1983) where rural development was presented as

> *"a strategy to enable a specific group of people, poor rural women and men to gain for themselves and for their children more of what they want and need… The group includes small-scale farmers, tenants, and the landless".* (Chambers 1983, p. 147)

This is a definition that suggests that rural development should target the most vulnerable groups in the rural setting, while the more general meaning of rural development does not have this focus on a specific group. In for example the draft to the Fifth National Development Plan for Zambia (GRZ 2006) rural development is found as one activity among many to provide opportunities to reach the main aim formulated as *"to target in the next five years both wealth creation and poverty reduction"* (p. 18). The plan does not specify rural development in terms of targeting a special group living outside urban areas, the focus is on areas that are not urban.

The categorisation of an area into rural and urban space is a construction[5], and it is often treated as is there were substantial differences between urban and rural areas. For most purposes the two areas cannot function without each other, and there is a risk in treating them as separate units. Urban areas, for example, provide rural areas with services such as universities and specialist health care that cannot be supported in many rural areas. The rural areas provide food and other resources, which are then used in urban areas. It is this dependency that makes the provision of an adequate infrastructure in rural areas a common goal in most rural development policies (GRZ 2006) as well as in international development goals such as the MDG (Millennium Development Goals) (MillenniumProject 2005). The introduction, development and maintenance of infrastructure is costly, and the people living in rural areas can seldom provide the financial means to develop and maintain the infrastructure asked for. The infrastructural demands of an electrification effort thus are a problem. Initially when rural electrification was a government goal, funds for infrastructure connected to the electrification were supplied through the state budgets. With the changed financial policies, as described above, financial resources for both grid based and distributed rural electrification were expected to change the situation.

When the earlier state-controlled power sector was opened up for commercialisation, it was expected that the private initiatives could lead to more conducive conditions for rural electrification. But this has not been the case. One of the problems is that there is often not enough expected load to provide the infrastructure as such, the infrastructure must be serviced and maintained. In rural electrification schemes, the running expenses for the distribution or transmission lines can be greater than the income generated from the sales of the power. This, when coupled to the fact that most users in a rural area have smaller energy demands and less money than those in urban areas, makes power companies and electric utilities less interested in connecting and maintaining grid extensions to rural areas. In this context the introduction of distributed electricity production becomes an interesting alternative to

[5] Rural and urban areas are often defined by the number of people living in an area, and it is not uncommon that the definition concerns what is urban, and then defines rural as non-urban (Salvatore *et al.* 2005). The threshold for what is labelled urban can vary between countries which results in the fact that an area categorised as rural in one country might very well be considered urban in another (Mwabu *et al.* 2004; Salvatore *et al.* 2005).

the large grid electrification projects. The infrastructural demands put forth in these solutions are small in comparison to grid electrification. One of the problems with the decentralised energy production, as will be shown in this thesis, is that the maintenance and servicing of the solar home system is more problematical than presumed in the planning phases of the projects. The characteristics of the distributed energy systems are in a rural development context now looked upon as an important factor in state policies for rural development. That they are small, and less costly per unit, can be adapted to local conditions where the actual demand is small and resources limited, which makes them an important instrument in the arsenal of weapons that can be used to support human development and the eradication of poverty in rural areas. Finding delivery models in the provision of these energy and infrastructure services that are efficient, effective, relevant and sustainable have attracted much attention from the international donor community over the years (for the case of solar technology see for example Villagran 2000; Martinot *et al.* 2001; Martinot *et al.* 2002; Hankins *et al.* 2004; ESCAP 2005).

2.3 Use of technology in rural development

Technology and technical artefacts are a part of our everyday life, and most of us do not reflect overly much on the role of technology in societal development. Our modern society is closely interlinked with the use, development and access to technologies. In the last decades the role of technology in, for example, economic development (WCED 1987) has been much discussed, and today technological development is seen as one of the major drivers of economic development (see for example the Lissabon agreement in EU Mandelson 2006). Technology is one of the things that has given humans a strong position in evolution (Foley 1995) and provided a means to survive and to cope with environmental and social changes. A good example of this is for example Boserup's studies (Boserup 1977) of the relation between population, agriculture expansion and technical development. As this thesis to a large part is about introducing a new technology in a rural environment, it is therefore important to briefly delve into the problems in introducing new technologies as part of development interventions. Here it is helpful to briefly describe how the concept of technology will be used in the thesis.

As there is no simple single definition of *technology* (MacKenzie *et al.* 1985; Pitt 2000) I will, as a point of departure, use three dimensions of technology in the analysis of technology introduction in a development process. The three dimensions are: i) the technical artefact (hardware), ii) the context in which the technology is operated, iii) the knowledge and skills needed to access the technology (software) (MacKenzie *et al.* 1985; Rogers 1995; Bruun *et al.* 2000; Wajcman 2002; Harris *et al.* 2004).

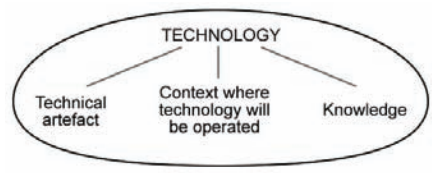

Figure 3: Three dimensions of technology

The technical artefact is the physical side, and one could say the operational side of a technology. Technical artefacts are continuously changed and developed, and in a temporal perspective they represent different levels of sophistication of specific technology, but all are based on a specific scientific principle. There are thus two trends in the technological development, one being the development of the technical artefacts within a given scientific framework, and the other the change in technologies brought about by the development in research. There are a number of technical artefacts that we are able to design and produce ourselves, but most technical artefacts are based on a scientific principle and can generally only be developed and changed by research, design and controlled manufacture. A technical artefact such as a solar cell is good example of this. Here also the manufacture of the artefact also often takes place elsewhere. The complexity of the manufacturing process is then a problem as a developing country initially does not have the capacity and the manpower requirements to take over and develop the manufacturing of an artefact deemed important. The technical artefact can *per se* be seen as just an artefact to be used in a specific context, but it is not so simple. The development of the artefacts undertaken by institutions is decided by a large number of factors, not only economic and scientific in nature. One such factor is what can be called the appropriarity of the artefact. Unless subsidised, poor people cannot afford the sophisticated technical artefacts used today in the developed world. When this is taken into consideration the designer tries to come up with a design which fits into the environmental and socio-economic context, i.e. is viewed as more appropriate. This means that the development and introduction of an artefact is not neutral (Winner 1985; Bruun *et al.* 2000; Faulkner 2001) which can lead to problems when an artefact is to be introduced. For example many technical artefacts have been considered second rate by the users, as they are not the modern looking artefacts that people know exist in other places (Dudley 1993). In some cases a technical artefact is both sophisticated and appropriate, the mobile telephone being an example of such a technical artefact.

The second dimension of technology relates to the context in which the technology is introduced. The technical artefact will always be operated in a context, which includes ecological, socio-economic, and cultural conditions. The operation of the technology will create changes in these systems, but the point is that these changes cannot be determined in advance. It is tempting to consider the provision of technology to be a solution to perceived societal and environmental problems, but we are all aware that technology itself does not create these changes. In technology studies this is often referred to as *technological determinism*, which refers to a perspective where technology will be a

> *"powerful and autonomous agent that dictates the patterns of human social and cultural life"* (Pfaffenberger 1988, p. 239).

Here a complex problem is tackled by proposing to use a technology that is perceived as having the potential to target these problems. The technology will, in this perspective, take hold of the users and make them take on the role that the technology dictates in its context. Few would agree that technology alone creates patterns of life for people, as we are well aware that there is always a degree of freedom in how to use a technical artefact, but it also a fact that the driving forces for technological development especially in an economic sense can lead to dramatic changes in people's lives – just reflect on the role of the car in modern societies. A solar electric system can be used to operate a TV or to produce good lighting. In the first case one can thus have the choice of watching a karate movie or the news, in the second case to do homework or handicrafts. This is where the contextual dimension is so important. It is necessary to identify and analyse the developmental problem to be tackled with the introduction of the technical artefact. Here, for example, values and different restrictions of the introduction of an artefact have to be considered. If this problem analysis only tackles a part of the problem, the consequences of introducing a new technical artefact can be problematical, as it can enhance, for example, the economic differences between people living in urban and rural areas. The access to new technical artefacts in urban areas means that the differences between the urban and rural areas are increasing and not decreasing as expected due to the fact that there is considerable economic growth in many countries today (Economic Commission for Africa 2005). The increasing Gini coefficients today in some countries in Africa probably reflect this (UNDP 2007b)[6].

Another view of technology is *social constructivism* (Sismondo 2004). Here technology is seen as one of many factors which in a specific social context will come to affect its users, and the outcome cannot be planned in detail or foreseen. The acceptance or non-acceptance of the technical artefact will not be dictated by the technology, but will be based on the users' own motives and desires (Khong 2003).

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[6] The Gini coefficient is a numeric expression that measures inequality between a uniform distribution (perfect equality) and the actual distribution (typically presented as the Lorentz curve) (Jacobson *et al.* 2005).

In this perspective the outcome of the introduction of new technology becomes unique and highly dependent on the local context.

The third dimension of technology is linked to the knowledge and skills required to access, operate, and maintain the technical artefact. Knowledge can be defined as how people understand, interpret, and put meaning into their experiences of the world (Blaikie *et al.* 1997). This means that how one looks on knowledge will be dependant on who owns the knowledge and how knowledge has developed over time in, for example, a rural environment. The experience of a solar home system, for example, will not be the same for the teacher in Hoffmeyer school compound outside Nyimba and the doctoral student from Sweden, even though we would talk about the same technical artefact. Thus the transfer of the *appropriate knowledge* becomes important when a new technology is to be introduced in an area. In fact there will always be what today is called *traditional knowledge* among people that must be taken into consideration when a new technical artefact is to be introduced. The modern discussion on knowledge and transfer of knowledge is important, and in these discussions, for example in connection to cultural studies and studies of development interventions, it is common to find *knowledge* split up into dichotomies (Nygren 1999) such as local and global knowledge, traditional and modern knowledge, indigenous and exogenous knowledge (Blaikie *et al.* 1997; Sillitoe 1998b, 1998a). I will not enter into a discussion of what type of knowledge the users acquire, but look instead at the channels through which the knowledge is transferred.

Transfer of knowledge is one of the central components of projects involving technology introduction. The transfer of knowledge can take place through either i) formal channels, or ii) informal channels. The formal channels are those that are planned in the development context, whether policy oriented or project related. Here actors in the international, governmental, and non-governmental sectors are found. The technology introduction driven by economic actors, companies etc, are a part of the formal channels. The transfer of know-how and knowledge is often based on formal training organised in special training/teaching sessions, generally at the site where the technology is to be introduced. The information that is to be transferred is based a specific dissemination concept where practical exercises combined with or based on written/ visualized materials are used. Factors related to gender issues, local knowledge, participation and societal factors are today important factors in such dissemination concepts. The informal channels, on the other hand, are those that are not part of the project setup or part of a company strategy, and include experiences accumulated from the use of the technology. Here direct observation and interpersonal communication are important. In many cases the technology introduced will be new in the context in which it is introduced, and there will be no prior experience of the handling, operation, or maintenance of the artefacts. The formal channels have the potential to provide information on proper handling, while the information passed on in the informal channels is less possible to control. The two transfers of knowledge, through the formal and informal channels, will be complementary to each other.

3 Rural electrification and models for diffusion

In an influential report published by the World Bank (1996) it was stated that 2 billion people in the world lacked access to modern energy sources. According to this report, most of these people relied on traditional energy sources such as fuelwood for cooking and space heating. As this resource use is associated with major environmental and health problems (Naeher *et al.* 2007; UNEP 2007) switching to other energy resources such as electricity would result in improvements in people's livelihoods. Electricity is a modern energy carrier that has the potential to bring a number of benefits to those who have access to it. An estimated 1.6 billion people globally lack access to electricity worldwide (IEA 2006).

The effects of switching from one energy resource to another are often described in development studies as an energy ladder (Leach *et al.* 1988; Leach 1992) where economic development leads to a changeover from traditional energy resources to more *energy efficient* resources, where electricity is found at the top of the energy ladder. One of the main challenges when planning for development where the target groups are the less affluent, women, and children often found living in rural areas of Africa, is to find ways and means to give these groups access to energy resources other than the traditional ones, and which would entail progress in the energy ladder.

The strategies proposed for how to do this were in line with the general trends dominating bilateral and multilateral aid during the nineties. One trend here was to consider putting market forces at the centre, and when markets were regulated by state policies deregulating them to enable competition that leads to more efficient resource allocation. New, more market-oriented stakeholders were to be allowed to work in the power sector, and if subsidies were to be used, they should be allocated in such a way as not to distort the new markets created as a consequence of the deregulation (Halpern *et al.* 2001). In the power sector – especially regarding rural electrification – this turned out to be difficult. The investments required for grid electrification are large, but in most countries in Africa most of the power users in the rural areas are poor. The loads that can be anticipated are generally low and the population/user density is by definition low. Thus it turned out to be very difficult to create an environment which could attract investors and commercial ventures within the power sector. Despite this several countries, as described briefly above, initiated and promoted rural electrification through solar cell technology. Evaluations have shown that access to electricity can have major effects on both the livelihood situation and the rural economy. In India, for example, part of the increase in agricultural production which has taken place since the 1970s was dependent on access to subsidised electricity (Mukherji *et al.* 2005). Rural electrification is thus not only seen as an important part of the economic strategies of individual countries, but is also considered an essential component of their poverty reduction and to achieve the Millennium Development Goals (Modi *et al.* 2005; UN-Energy 2005; UNDP 2005b).

Rural electrification, whether grid based or using distributed generation, is expensive however it is done. Zomers (2001) gives a rough value of 1900 USD per customer connected to (grid extension) rural electrification schemes. This figure gives some indications of the investment requirements. But he also argues that in order to make a proper assessment of the total investment, the long-term marginal costs involved must be considered. Thus operational and maintenance expenses, energy losses in the power lines, and administration costs such as for billing need to be factored into the assessment of the economic viability of a project. The introduction of grid-based electricity has a number of indirect effects, not least in an infrastructural context. Once power is available, small or large scale economic enterprises appear such as workshops (e.g. welding), water can be pumped, affecting for example agriculture production, street lighting is introduced etc. Thus the appearance of a power line will result in several improvements in the infra-structure of an area. But at the same time the power is only available on locations determined by the distribution lines. Infrastructure development thus becomes site specific. The major problematic issue for the introduction of a grid-based electricity system, however, is the issue of paying for the electricity. The fact that the users of the power will have to pay for it becomes a problem if the economic level is such that the consumers can not afford the electricity costs. Often there is a fee to link up to the distribution line and secondly there is a fee for the power used. These expenses are barriers to energy services for people who do not have the financial means to purchase electric power. In a situation where a household chooses a livelihood strategy, the choice of energy resources for cooking, space heating and lighting is crucial. In many cases it is extremely difficult for poor people to make a large investment in a new energy technology, because the start-up costs are too high. When the long-term maintenance costs of the technical artefact are also taken into consideration, households tend to opt for a traditional energy resource which can be bought or used in smaller quantities. To understand and analyse why this is so, and how one could change this situation using the energy services concept introduced above, is important, as it is the diversity of the service options that can enable a sustainable technology transfer.

Rural electrification based on a distributed generation instead of a centralised transmission and distribution system does not rely on the already existing power system. Infrastructure can therefore be located where users and customers live. The problem with solar cell technology is then mainly that of the limited power that can be supplied by the solar technology. Peak load problems cannot be centrally dealt with in such systems, since the solar cells are not connected to each other, consequently peak load demands have to be handled by the individual user, which is a problem from a dissemination, support and maintenance point of view, as discussed in this thesis. This is *one* limitation to a widespread use of distributed generation based on solar cell technology. This means that some of the energy services, see Figure 2, cannot be supplied by the solar cells. Instead there are other energy services that can be supplied. For example energy needs for space heating or cooking are difficult to meet with a solar electric system. Solar technology also has specific restrictions due to climate factors. This means that a dissemination strategy for solar cells has to take into consideration both this aspect and the fact that most rural users of energy are small energy users compared to people living in urban areas with grid-based electricity.

3.1 Mechanisms for diffusion of solar energy technology

Diffusion of technologies (or transfer of technology) is the expression used when referring to processes whereby a technology is introduced to a new geographical area or new users. The transfer of a new technology can be either: i) *spontaneous,* or ii) planned or *induced* (Cernea 1991; Rogers 1995). The driving force for the spontaneous process is generally a market-oriented process where the economic incentives for the transfer are supplied by the *market forces*. The induced transfer of technology is often associated with projects in developing countries. The driving force for the induced diffusion of a technology in a project is based on different types of incentives or direct subsidies to users of the technology. At the same time the aim of most projects is that once a technology is introduced there will be a transition from *induced diffusion* to a *spontaneous* process.

If this transition is successful, the introduced technology will continue to spread, and the input of resources to continue the diffusion process can be reduced. During the initial stages of an induced technology transfer, human and monetary resources put into the project makes the transfer successful. Once a time-bound project is completed, and the resources are no longer forthcoming, and the subsidies and support cease, the diffusion process tends to go slower, or in the worst cases comes to a standstill. This has often been the case in projects where a technology transfer is a part of a poverty reduction strategy.

The data on solar technology diffusion presented in this thesis is a typical example of an induced technology transfer process. In order to analyse this and to assess the outcome of the process I have chosen to look upon the induced diffusion (or transfer) processes as comprised of two stages (Gustavsson 2000). The first stage is when the technology is introduced to the users i.e. *the introduction of the technology.* In a project-based enterprise this stage is based on a specific dissemination approach always determined by the local context and the supporting structures necessary for the dissemination. Here one has to look into the approach chosen to transfer knowledge to users. For example the people and organisations responsible for the dissemination process, the monetary issues involved (e.g. subsidies and/or credits to make the technology initially affordable to the user), and the control and feedback mechanisms to assess the rate of transfer and acceptance of the technology by the target groups.

The *introduction of the technology* is generally planned for and described in the programme and project plans and documents. But the introduction is only the first stage in the transfer process; the second dimension of the transfer process is when the technology introduced is integrated into and becomes a natural part of the users' everyday lives and daily routines. A successful integration is in most cases the long-term aim of a project aiming at transferring a specific technology, and if successful it can lead to the spontaneous diffusion of the technology, which will be the cost-effective conclusion of the whole diffusion process.

This second stage of the induced transfer – *the integration of the technology* – can be supported through good planning, but in the end the technology will have to stand the test of how the users experience the benefits of the technology and if it is accepted as a viable alternative to other technologies or previous use of resources. The dilemma of achieving acceptance can be seen in many projects aiming at introducing a new or modified technology. Many technologies that are introduced as development interventions aim to replace an already existing technology or technical artefact. The experiences from such projects, for example energy-saving and less polluting stoves, have shown how difficult it is to integrate the new technology among the users. In the introductory stages the acceptance is high and positive as long as the financial and organisational support is there. At the point when the integrative stage should take off, the funds are no longer forthcoming and the diffusion of the technology tends to come to a standstill once the users compare the effects of the new solutions to the traditional technology. The constraints on the diffusion of the technology are in almost all such cases that the presumed users live in poverty, and that there are problems associated with the servicing and maintenance of the new technology. This last issue will be discussed in some detail below. A technology cannot be truly integrated into an existing livelihood situation unless the sustainability of the technical artefact is ensured. It should be emphasised that the issue of maintenance, repair etc. of a technical artefact is often not taken into consideration when a technology transfer is planned.

Bottom-up, top-down and market-oriented technology transfer

The transfer of technologies and technical artefacts is an important issue in almost all approaches used in the implementation of development interventions aiming at reducing poverty or initiating economic and social development. The implementation of a development policy, strategy, or project is of course dependent on the context, but from an implementation point of view one can categorise the practical strategies to transfer a technology into three broad groups: i) top-down forced technology transfer, ii) bottom-up driven technology transfer, and iii) market-oriented technology transfer (Biot *et al.* 1995; Blaikie 2000). Some of the main characteristics of these three groups will be briefly discussed and described below, as the technology transfer of solar cells discussed in the thesis has been dependent on the choice of implementation strategy for technology transfer chosen by the Government of Zambia.

The so called *top-down approach* is based on expert implementation and decision making, with little opportunity for the local people and actors to affect the implementation processes. Decision making and resource allocation are controlled by actors other than the users, and many of the actors can be looked upon as outsiders in the area where a project is to be implemented. The power to design and implement rests with these actors. To make a crude generalisation, between the 1950s and 1970s this was the often the typical approach in technology transfer. The top-down approach had a strong supply orientation, meaning that the technological artefacts were often supplied free to the users, or at an attractive price. Technology transfer was focused on supplying technological artefact while little consideration was given to the appropriateness of the technology in a specific context (Wilkins 2002). The strengths of this approach were that large numbers of technical artefacts could be distributed effectively and that the disseminators could partly control the dissemination efforts. The weaknesses on the other hand were greater. Constraints on technology transfer were not identified, leading to large numbers of the technical artefacts supplied becoming non-operational after some time. See e.g. the national biogas programmes in India (Gustavsson 2000). Apart from mismanagement of resource allocation, and the need for control structures to administer the resources channelled, the most serious problem was that the targeted users of the artefacts did not experience the incentives for using it as intended by the implementers.

The experiences accumulated from many top-down projects on technology transfer, led to a reaction where the local context and people were put in focus, and the ambition was to include – and base actions on – the needs of the people concerned and these became referred to as *bottom-up strategies* (Black 1999). Participation and co-operation became key issues and novel actors were enrolled in the dissemination efforts. Thus Non-Governmental Organisations (NGO) came to be important actors in the technology transfer, and resources were also channelled directly to them. The bottom-up strategies were also characterised by gender issues becoming increasingly important. Instead of looking at technology transfer as supplying technical artefacts that could fit anywhere, the introduction was based on assessment of local needs, proper training of recipients, and local cooperation. Technologies should fill a local need, and the technical artefacts could even sometimes be built with local resources using local skills, and fit into local tradition and culture. The context where the technology should be used was put first, and a wide range of *appropriate technologies* were proposed. The people who would become users should decide what types of technologies they needed (Dudley 1993). Strengths of this approach are the involvement of the people concerned, and the resulting stronger sense of local acceptance. The challenge was to scale up the projects while maintaining the close contact with the local setting and the needs of the people. But both the top-down and the bottom-up approaches were based on the rationale that outside agencies should be key actors in technology transfer and that external funds supplied either through donors or state agencies were central to technology oriented projects.

This was partly changed in the late 1980s, as when more market-oriented approaches to technology transfer were introduced and promoted by both multilateral and bilateral donors as a consequence of the discourse in development economics (Williamson 1993; Biot *et al.* 1995; McCarthy *et al.* 2004). This went hand-in-hand with the formulation of projects that used local companies as the vehicle for implementation (Halpern *et al.* 2001). This development strategy is today often referred to as the *neo-liberal* approach to development (Peet *et al.* 1999; Peck *et al.* 2002; McCarthy *et al.* 2004). Here the diffusion of the technologies is handled by private companies that earn a profit from selling and introducing technologies to users. The market-oriented approach, according to its adherents, would result in efficient implementation and use of resources. The companies would have a vested interest in the successful operation of the technical systems deployed, and the diffusion of technology is administered through commercial channels.

In reality these three approaches still work side-by-side in the real world. The need for control of a technology transfer, means that top-down approaches are still in place, and must be so, for example, to control corruption. There are also projects that due to the complexity of the technology or the size of a project presuppose a top-down approach. The bottom-up approach is now seen as a necessity in projects and government policies aiming at, for example, rural development. The bottom-up approach can assure people's participation in the technology transfer.

Delivery mechanisms of solar technology

Solar systems can be made available to users in several ways, and the various approaches are usually referred to as delivery mechanisms. While the strategies for development are linked to policies and economic and environmental realities, the delivery mechanisms are tools to create a situation where people and/or institutions can afford, or get access to solar technology. The driving force behind an intervention and the use of a specific delivery mechanism is based on the assumption that access to solar energy services will improve people's lives and bring development benefits. In a paper by Hankins and Banks 2004, delivery mechanism for the introduction of solar technology are presented. They propose that there are four basic delivery models (Hankins *et al.* 2004): i) commercial led models, ii) multi-stakeholder model including credits, iii) utility models and iv) grant-based models. Below a short presentation of these will be given, as one of the models has a bearing on the delivery model chosen by the Government of Zambia in their dissemination effort on SHS introduction and is the core of the empirical data presented in the thesis.

Commercially led models, over-the-counter purchases

In this model, manufacturers and suppliers compete and establish a market. In its purest form there should be little involvement from government, international donors or other funders. But in many cases there are several activities taking place that support a growing market. Training, development of quality standards, research, and efforts to increase awareness of the potentials of the technology are examples of such support. Users will purchase equipment directly from suppliers, and typically there are no or only basic service agreements included in the purchase.

There is little control practised apart from the market forces in these cases, and this is the closest thing to spontaneous diffusion we can find among the different delivery models. The inputs in terms of resources to uphold the diffusion process are relatively small. The three other models described below usually have an expansion mechanism that tries to initiate and support a more spontaneous diffusion. A commercially driven diffusion of solar technology is susceptible to market distortions such as subsidies in other sectors or activities that compete with the solar market, or development programmes including free provision of solar services.

In the cases where a market for solar energy exists, this has often been preceded by several years of other activities within the solar sector which were not directly driven by the market forces. Kenya is often brought forward as an example of an existing market-led diffusion of solar technology in Africa, but one must keep in mind that this stage was preceded by several years of induced diffusion efforts starting in the 1980s (Hankins 2000).

Multi-stakeholder models, typically involving consumer credits

The multi-stakeholder model is similar to a market-driven model in the sense that the users will purchase the equipment, and suppliers and entrepreneurs can act to supply the hardware. The main difference is that a credit scheme is initiated that supports users with credit for the purchase of the equipment. Typically the credit is given to a supplier of the hardware that is part of the project. The repayments are then made by the user. The model includes a possibility to control the diffusion process in terms of quality standards, as the financing institution can prescribe what the supplier should do. The quality of the transfer process could thus be assured. This model has been utilised in a number of places, for example Zimbabwe (Mulugetta *et al.* 2000; Afrane-Okese *et al.* 2003).

Subsidies play a vital role in the possibility to make electric energy services available to people and institutions that do not have access to the electric grid (Banks 1998; Halpern *et al.* 2001). Within this delivery model there are a number of possibilities to reduce the capital cost of the technology. Making the loans interest free or subsidising the hardware are such options. In the long run these support measures should be phased out and a transition to a more commercially led diffusion should take place.

The maintenance of the hardware, including replacement of batteries will be a responsibility of the users. This requires the existence of an infrastructure to deliver service, maintenance facilities, and spare parts. Solar projects applying this model will have to ensure that these components are also in place. A problem is the long time frames needed for support. The technical life of a solar panel is today in the range of 15-20 years, but most support programmes are planned for shorter time periods, e.g. 5-years. The users will be the owners of the solar systems, and should therefore have a vested interest in the proper maintenance and management of the system and its use. All solar systems will require a certain amount of routine maintenance to function properly, and as users are responsible for this, such knowledge about maintenance must therefore be transferred to the users in this model.

Utility models, typically fee-for-service

The utility model uses institutions or companies to supply energy services to clients in a geographic area. These areas can be large or relatively small. In South Africa this model has been applied with companies serving relatively large areas that can include up to 50 000 customers. But smaller areas are more common, and examples are found in Togo (Martinot *et al.* 2001) and Zambia (this study). In this delivery mechanism the users will pay for the service that they get access to, rather than getting access to the hardware. This is similar to how the ordinary electric sector functions. People purchase electricity, but do not become owners of the grid or transmission lines. Instead they receive electric power in their sockets. One difference is found in the units that the fees are based on. In the electric grids these are based on electric units used, while for the solar services people pay for the days they have access to the service. As the unit for payment is normally based on daily access, the monthly fee can easily be mistaken for rent. But there no transfer of ownership, or down payments are included in the service fee. The service fee should cover running costs of the utility and repayments of the credit given through the project.

A project applying this mechanism will identify bodies that can act as utilities. Loans will be offered to the utilities along with other support such as technical training for employees. The loans will be used to purchase solar systems that will then be installed at the locations where the utilities have their clients. The project management of the development intervention will interact with the utilities and not directly with the clients of the utilities. Contracts between the utility and the body for managing the solar diffusion project will control the agreements and condition upon which the utility can act. Various subsidies can be provided to increase the attractiveness of the service at the user level, but this will always go via the utility. For example, by arranging interest-free loans the repayment costs will be lower for the utility, and thus hopefully they will be able to have a lower monthly fee.

Typically the service offered by the utilities will not have any competition in the areas they operate. One alternative would be to make purchases over-the-counter, but this requires substantial investments. Fee levels are thus not tied to competition but rather to the experience of the market potential and of the knowledge of running and financial costs. The energy regulation body in the country can act to ensure that fee levels are kept at an acceptable level.

One of the main advantages of this mechanism is that much of maintenance of the systems is made by people working at the utility company, who can thus be trained for this task. The utility has a vested interest in keeping the systems in operation, as this is what they get paid for, and the users will pay the fee and use the system.

Grant-based models, typically used by institutions

Grant-based mechanisms are typically found with institutions, but will also include communities benefiting from the system. The strength of the grant approach is that there is a very large possibility for control, and target groups can be selected and approached by the implementing agency. In all three of the above approaches there is no full control in this respect. The challenge in the grant based system is to ensure sustainability in the functioning of the system. As there is little or no effort from the beneficiaries to acquire the system, it is believed that there is little vested interest in the proper operation and maintenance of the system. The reasons why this type of model fails are combinations of many factors e.g. lack of own financial input in the system, lack of technical knowledge on operation and maintenance, and lack of resources to cover the running costs. In a grant-based solar project, the implementing body can arrange support for maintenance and technical training, wither for free or to be paid for by the beneficiaries. But one of the reasons for choosing this approach is that it facilitates quick establishment. As there are no repayments of the investments in hardware, the approach will become relatively costly, but when focusing on institutions and other central functions in society it can be seen as part of the development of the services offered in the rural sector. The option is normally to operate a generator set, or establish an extension of the grid which in the end will become more costly.

4 The Zambia PV-ESCO project, a pilot project

Projects are not isolated, but are the results of historical events and the surroundings and people linked to the project. The impacts of a project will not end when the project period is completed (Blomberg 1998). The Zambia PV-ESCO project is, as will be shown, an example supporting this assertion.

4.1 Zambia and the Power sector

The energy sector in Zambia is dominated by biomass-based fuels in the form of firewood and charcoal (see Appendix 1). Biomass constitutes about 80% of the total energy consumption, electricity 11%, and petroleum products 8% (DOE 2000). Three quarters of the total energy is used in the household sector, and here the dominance of biomass fuels is very strong. This is partly a result of the lack of access to alternative sources such as electricity, but also that people consider charcoal a good source of energy for cooking. There is some use of kerosene in the household sector; no LPG is used. The mining sector uses more than half of the electricity, followed by households at almost 20%.

Overall about 20% of the households are electrified, but in rural areas the access levels are in the range of 2%. This figure has not changed to any great extent during the last 30 years (Mihalyi 1977; MEWD 1994; CSO 2004a). In the mid 70s it was assessed that about 16% of the households in Zambia had access to electricity, and of these 95% were located in a zone along the railroad between Livingstone in the South to the Northern end of the Copperbelt (Mihalyi 1977). These percentages should be considered in the light of the population growth that has taken place in Zambia. In 1975 the population of Zambia was 4.8 million, and it had increased to 7.4 million in 1990 and 9.9 million in 2000 (Mihalyi 1977; CSO 2003)[7]. The percentages should thus be seen in the light of the fact that although new customers are receiving electricity, and rural electrification programmes are going on, the population growth is higher.

The total installed electric power generation in Zambia is about 1 700 MW (World Bank 2006; Zesco 2006). More than 94% of this capacity is generated by hydro power plants, and the rest is generated by gas turbines, diesel and thermal power plants. The bulk of the installed capacity was made in the 70s and since then there has been little increase in the in nations capacity. Today, with an increased use of electricity there power shortages have started to occur (Wines 2007).

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[7] About 65% of the population lived in rural areas in 2000, which is a slight increase compared to 61% in 1990 and 60% in 1980 (CSO 2003).

It is estimated that Zambia could install about 4 000 MW more hydropower in the country (DOE 1998); the environmental and social impacts this would have are not presented. One of the driving forces behind increasing the capacity would be to sell power to the neighbouring countries. Zambia is part of the Southern Africa Power Pool (SAPP) and has been a net-exporter of electric power for many years. As the power system is based on a few large production facilities, any technical problems at these will have a significant effect on the generation of electricity.

There are also a number of isolated grids in Zambia where diesel generators or mini-hydropower plants are operated. In addition to these larger distributed generation systems, there are growing numbers of solar home systems. The Zambia PV ESCO project, which has been the main solar programme run by the Department of Energy, Government of Republic of Zambia (DOE), has supported the diffusion of 404 SHS:s that are operated mostly in rural, un-electrified areas.

The energy policy of Zambia (MEWD 1994), adopted in 1994, is focused on supply, rather than end-uses. Social issues such as reaching the poor, facilitating a development process in remote areas, and facing gender issues are not taken into consideration. Since the policy was adopted, a number of new institutions have been created that are supposed to work with various tasks within the energy sector. For example a rural electrification fund was established in 1995 and is supposed to be used to support rural electrification projects. This fund is financed through a 3% levy on power sales. The newly established Rural Electrification Authority (REA)[8] is responsible for planning and implementing rural electrification schemes. The Office for the Promotion of Private Power Investment (OPPPI) works to stimulate private investment in the power sector, and the Energy Regulation Board (ERB) is working with regulation of the energy sector. Sweden has a long history of bi-lateral support to energy sector programmes in Zambia. Sida, for example, have supported Zesco and the ERB with technical assistance, and have recently also supported the creation of REA (Sida 2003, 2006). Revision of the National Energy Policy as well as developing a plan for how to increase access to electricity in rural areas are presently underway.

4.2 The Zambia PV-ESCO project and the study area

Rural electrification through the introduction of solar home systems was found in many parts of Sub-Saharan Africa at the end of the 1990s. One of these was the Zambia PV-ESCO project, which was implemented by the DOE, and funded by

[8] REA is sometimes referred to as Rural electrification Agency, I have used Rural Electrification Authority as used in, for example, GRZ (2006)

Sida, Sweden. The project started in 1999 and was ended in December 2005. The continued management and coordination is presently part of the work of DOE.

The overall objective of the Zambia PV-ESCO project was to develop models through which rural people can get access to sustainable energy services (Nordström *et al.* 2001). The project was initiated in 1999, but had been discussed at the DOE and with international consultants, mainly at the Stockholm Environment Institute (SEI), since 1996[9]. The project would support the establishment of four local energy service companies (ESCO:s) in the Eastern Province (a utility mechanism). These companies would operate a number of solar energy systems on a *fee for service* basis at the homes of clients in the four areas. The SHS would be installed by the ESCO:s in the houses and act as a distributed generation energy source. Clients would pay a fee to the ESCO:s for the services of the system. This fee is not based on energy units, but on access to solar electric services during a certain period. The users are thus free to use the system as much or as little as they want during the period for which they have paid the service fee. Each ESCO would be granted a loan to enable procurement of the solar energy systems with a repayment period of 20 years. Another feature of the ESCO approach in Zambia was to have a battery replacement fund to which the ESCO:s should pay a monthly instalment. This fund would be used to replace the batteries when their technical life had expired. In the project plans the batteries were expected to last about 3-5 years.

When the project had received funding[10] from Sida and the implementation phase was about to commence, a number of changes in the project design took place. In the original setup the credits to purchase hardware would have been supplied to the ESCO:s from what is often referred to as a revolving fund. This would have created a possibility to design systems based on customers' various needs, and to have the ESCO:s establish direct links to the suppliers. For formal reasons the procurement of hardware had to be done through government procurement, and to make this as smooth as possible a "one size fits all" design was adopted. The specifications for the solar energy system to be procured were based on experience from other projects, and from a baseline study performed in 1998 (Ellegård *et al.* 2001). The government procurement process resulted in a slower rate of progress than expected in acquiring the hardware, and the initial time plan had to be revised. As a result two of the ESCO:s received only two demonstration systems each for two years, but the

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[9] SEI, and the staff later involved in managing the Zambia PV-ESCO project have a long track record working together with the DOE.

[10] The budget for the project period 1999 to 2005 (extended period) was 13.2 million SEK (1.7 million USD, exchange rate 7.7 SEK/USD) (Sida 2003).

companies were fully staffed and had also started to enlist potential clients. Quite a few people soon began wondering whether this was only talk or something that was actually going to happen, as no solar energy systems ever arrived. Few of these potential client dropped off, as the obligations connected with enlisting as a future client were very light. To enlist one only had to purchase and submit the application form (at a cost of between ZMK 2 000-10 000, USD 0.75-2.5). No other costs were involved. Another important reason was that the ESCO:s were maintaining ongoing interaction with the clients, and representatives of DOE and international consultants came on occasional visits to report on the progress. The visits by the DOE officials and the consultants to the locations became important for the ESCO:s in upholding their status in the eyes of prospective clients and also the communities in general.

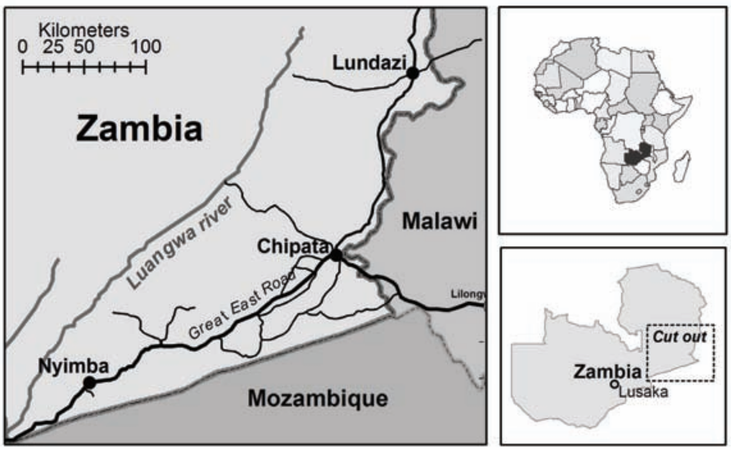

Figure 4: Location of the three different ESCO:s

The original plan was to establish four ESCO:s in the Eastern Province of Zambia, and these companies were to be spread geographically in order not to compete with each other. The number of ESCO:s was later changed to three. The selection of the ESCO:s was based on a number of criteria such as adequate financial resources, being a registered company with accepted accounting procedures, and not having a poor track record on financial matters. The level of interest shown by businesses in the province in becoming part of the project was great. In the end, one ESCO was established in Nyimba, Nyimba Energy Service Company (NESCO), one in Chipata (CHESCO), and one in Lundazi, Lundazi Energy Service Company (LESCO) (Figure 4). The company in Nyimba had its roots in a farmers union organisation.

The Lundazi company had been involved in harvest sales, and the company in Chipata in waste management.

The first ESCO to receive its solar energy system was NESCO where the first installations were made in May 2000. The winning bidder for the procurement in Nyimba, the Lusaka based firm Electrical Maintenance Limited (EML), had signed a contract with the DOE to deliver and install the hardware specified in the bidding document. The installations were to be made at locations specified by NESCO. At this point 100 clients had been localised and the installations were performed in four batches. To train the NESCO technicians in how to make future installations, they were supposed to take part in the installation work together with EML workers.

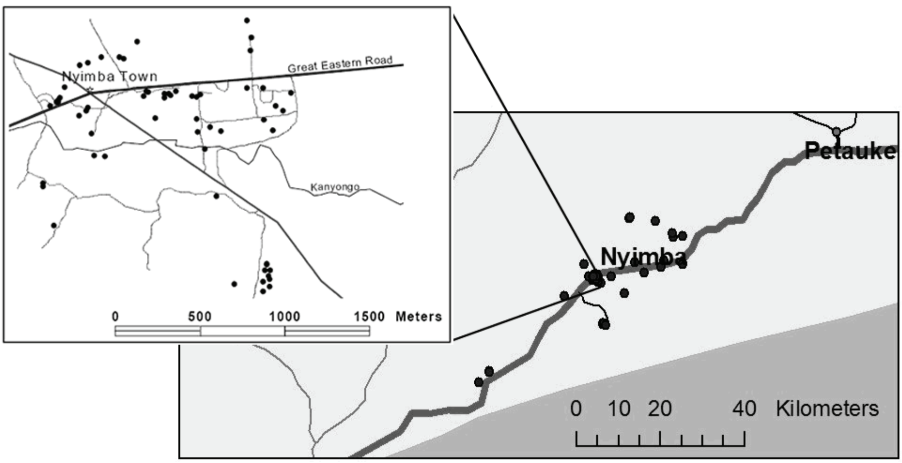

Figure 5: Nyimba area and cut out showing the town area. NESCO installations are represented by dots. Total number of installations is 100

The second round of procurements started with new rounds of bidding to decide on the companies to deliver equipment to Lundazi and Chipata. In Chipata it was decided by the project team and CHESCO to procure a system that would include a pre-payment function. A pre-payment function would make the SHS automatically shut down when the paid number of days came to an end. There are several different types of technical solutions to implement such a function in the SHS. One possibility is to have disposable cards that recharge the system with a certain number of days for use. Another option is to have a token that will be recharged in a computer interface. The specification given in the bidding documents only stated that the SHS should be equipped with a pre-payment function. All the ESCO managers considered pre-payment to be a good technical feature of the system.

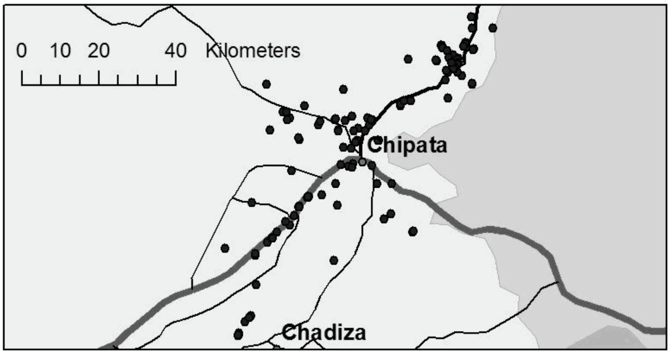

Figure 6: Chipata area. CHESCO installations are represented with dots. Total number of installations is 152

The winning bidder in Chipata was Siemens Zambia, and they based their pre-payment function on a token used for identification and recharging the system. This solution required a computer to be installed in the CHESCO office which was equipped with special software and an interface to charge the tokens. This solution is centralised in the sense that the token will have to be brought to the recharging station, while with disposable cards, sales stations could have been established closer to the clients who normally live around the district capital.

The same company that performed the installations in Nyimba, EML, was awarded the contract for the installations in Lundazi. The systems offered were similar to those installed in Nyimba.

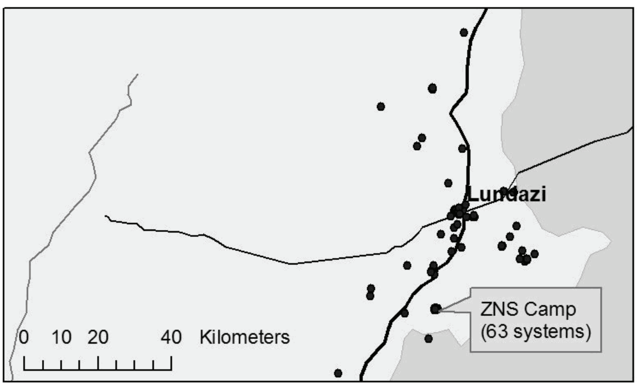

Figure 7: Lundazi area, LESCO installations are represented by dots. Total number of installations is 152

The contractor doing the installations in Lundazi was able to draw on experiences from Nyimba and could plan and administer the work efficiently. In Chipata, on the other hand, the winning bidder used a local company to do the installations, and deliveries of the systems were slow. As CHESCO was not the buyer, communication had to take place between the project managers of the Zambia PV-ESCO project and the suppliers, and this was very slow. After the completion of installations at each location, the sites were inspected by representatives of the Energy Regulation Board (ERB), together with people from the project team. A list of complaints about the installations was compiled, and the installers were asked to correct these in order to receive the last payments.

One of the problems in operating distributed generation energy systems such as SHS, is that in order to ensure operation and maintenance (O&M), the installations should not be located too far from each other. Positioning the systems in clusters will make monthly inspections less time consuming, as the time spent on travel to each location will be reduced. It is also possible for customers to send monthly payments with fellow clients, and thus reduce their travel time. CHESCO and LESCO have arranged for motorized transport, while Nyimba has managed to service its systems using bicycles and busses. Comparing the three ESCO:s in terms of distances between the systems shows that there are relatively large differences. In Table 1 an index of the distances as 'spread of the systems' are presented.

ESCO	**Index of spread***
Nyimba Energy Service Company (NESCO)	0.078
Lundazi Energy Service Company (LESCO)	0.116
Chipata Energy Service Company (CHESCO)	0.181

Index of spread (Is) was calculated through $I_s = \sqrt{\frac{\text{variance}(x_{coord}) + \text{variance}(y_{coord})}{2}}$

Table 1: Index showing the spread of systems compared between the ESCO:s

Nyimba shows the lowest result in terms of spread of its systems, while the systems in Chipata had the highest value for standard deviation. In Nyimba most of the systems are found in the town or in its close vicinity (Figure 5). In Nyimba there is no grid electricity, and consequently there are many customers close to the office[11]. The opposite is the case for CHESCO where all systems, more or less, are found outside Chipata. Systems are found in three directions: along the road to Lusaka, along the

[11] Nyimba has received a grid extension in September 2005 (Chambwa 2005). This will probably mean that many of the installations made in Nyimba will have to be relocated as the clients opt for a grid connection.

road to Lundazi, and towards the Mkuzi national animal reserve. In Lundazi, LESCO was able to place 63 SHS in a Zambian National Service (ZNS) camp. The people stationed in the camp got the solar service fee deducted from their salaries. To LESCO this meant that the systems could be serviced without spending too much time on transportation.

One of the central components in the Zambia PV-ESCO project was to train technicians and managers in the ESCO:s on O&M issues, installations, and accounting. Training of technicians took place at the University of Zambia (UNZA), and Mr Herbert Wade, a solar pioneer with long experience of training and managing ESCO projects, was together with Mr Themba Munyani from Zimbabwe for a brief period employed by the project (Ellegård *et al.* 2001). The training received by the ESCO technicians and managers included recommendations on the routines for maintenance of the solar energy systems. The recommendations included a monthly visit to each of the systems installed, which should include ocular inspection of the installations and equipment, and inspection of the battery including measuring specific gravity in the battery cells. Records should be kept of these inspections. Broken lamps should be replaced at the clients' own expense.

Technical backstopping in the project was made through occasional visits by the international consultant working with technical aspects of solar energy systems, and the technicians from UNZA (University of Zambia). Relatively shortly after the first installations, the technical maintenance work began to run on routine. Transportation soon came to be of central importance. During the rainy season many of the dirt roads became impossible to travel on and thus monthly inspections were not made. Even though the training had included practical exercises, difficulties were experienced in routine maintenance. For example, batteries were topped up with battery acid, instead of distilled water for a period of time. The instructions from the suppliers were minimal, and the training documentation from UNZA was of a general character, and the technicians considered it difficult to apply these instructions in the field.

In 1999 a workshop was held where the fee levels were discussed among the project group and the ESCO managers. A tentative fee level was presented, which was to cover the running costs for the ESCO:s as well as an indicated repayment. This came to ZMK 20 000 (8 USD) in 1999. The project team made clear to the ESCO managers the importance of adjusting fee levels according to the inflation rates. A yearly increase in the range of 15%-20% in order to adjust for inflation would be necessary, otherwise the repayments could not be kept up. The ESCO:s operate under a license issued by the ERB. Drastic changes in the monthly fees must be subject to negotiations and proposals can be rejected by the regulation board. The ESCO:s have so far not had any problems in this respect.

Another challenge was related to the repayment and the revolving fund. The repayment period of 20 years had been discussed, and the managers and Zambians in the project group considered this period to be very long. If the period for repayments was reduced, and the repayment level retained, this would result in high monthly instalments. These discussions led to a decision where the repayment period was reduced to 10 years at the same time as the repayment levels were kept fixed. As a result, the project will give about 50% of the hardware costs in subsidy.

At the time of the first installations all ESCO:s had a waiting list of potential clients who could not receive a solar energy system in the first phase of the project. Three years later the waiting lists were in the range of 200-300 clients per ESCO. The number of systems served by each of the ESCO:s is relatively small. Each ESCO would manage to handle perhaps 300 systems without expanding the number of technicians or office workers. This way the costs of O&M per system could be reduced and business conditions would become more favourable. As the project was delayed, a second phase was discussed shortly after the last installations had been made in Lundazi and Chipata. But the signing of the contracts for repayments and transfer of ownership from DOE to the ESCO:s was set as a prerequisite for being granted access to funds for new systems. As this process was part of Government procedures, the contracts had to be scrutinized by several departments.

Apart from the Zambia PV-ESCO project, there is one additional solar programme, run by the Ministry of Education, found in the same area. This project supplies solar energy systems to teachers (individuals) at a subsidised cost (consumer credit mechanism). The payments for these systems are made as a deduction from their salaries over a period of three years, after which the system will be their property. The supply of systems seems to have been limited, and information on this project has been difficult to come by.

5 Methodological considerations

Case studies are useful when studying a contemporary phenomenon where the researcher is working in a complex context with little control over the events (Yin 2003). They give the researcher the possibility to go into greater depth on one special case, using a range of different research methods, and to triangulate the results. The case study presented in this thesis is based on data collected from clients using the energy services from solar energy systems promoted through the Zambia PV-ESCO project.

The research has been carried out independently of the Zambia PV-ESCO project, with funding from Sida/Sarec, Stiftelsen Lars Hiertas Minne, Stiftelsen J Gust Richerts minne (twice), Ångpanneföreningens forskningsstiftelse and two travel grants from Göteborg University. Towards the end of each fieldwork period, the Zambia PV-ESCO project group in Zambia was briefed about the research, and results of my studies have been presented to the PV-ESCO project group in Sweden.

5.1 Methods used

The data for this thesis was collected using different research methods (Table 2).

Year	Month	Methods	Description
2001	May	Interviews	Interviews with stakeholders in solar business, the managers and technicians of the different ESCO:s, and representatives from DOE
	June-July	Survey	Nyimba clients and neighbours, Chipata and Lundazi potential clients
2002	June-July	Survey	Chipata and Lundazi clients and neighbours
2003	February	Battery tests, load loggings, interviews	Initiation of test programmes. Training of assistants and running of pre-tests. Calibration of equipment and computers. Setting up of school test results collection.
2003	Jan-Dec	Load loggings, collection of school results	Load loggings, school results preliminary study (Zambian assistant collecting the information and sending to Sweden via e-mail)
2005	February	Battery tests, load logging, interviews	Lundazi. Follow-up fieldwork. Setting up of battery tests and instructing assistant on procedures to complete a second round of tests. Instructing assistant in collection of Third Term Results. Interviews with headmasters and teachers in rural schools.

Table 2: Summary of fieldwork and methods used.

The first two periods of fieldwork were used to collect information on background data concerning livelihoods and housing, energy usage including cooking, and the clients' views on the services received from the solar-energy system and how these have changed their daily lives. The results indicated that the load on the systems was in many cases higher than had been anticipated. A study of the actual energy use was performed along with controlled battery tests to examine the technical dimensions of the SHS use. In conjunction with this, a study focusing on the effects SHS in individual households had on school results was performed.

Surveys

The two surveys carried out targeted all the clients of the ESCO:s. The closest neighbour to each client was selected as a reference group. *Closest neighbour* was defined as the house nearest the client along the road by which the field worker arrived, see Figure 8.

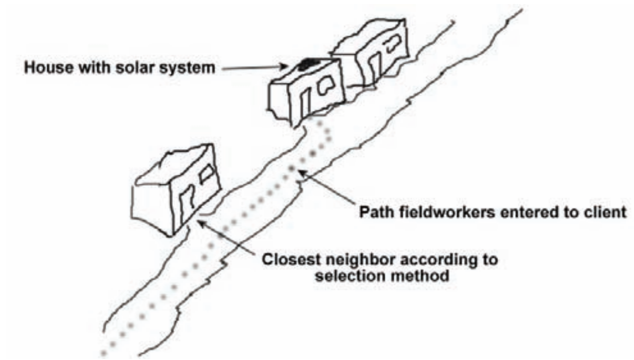

Figure 8: Selection of reference clients

The two surveys (2001 and 2002) were based on a questionnaire where only slight changes were made between the years. The questionnaire was based on information received during a number of interviews conducted in May 2001.

During the fieldwork in May 2001 I had discussed the upcoming surveys with the individual ESCO:s, asking for their permission and hoping to secure their support in finding field workers. None of the managers had any objections. The criteria for field workers were that they should be graduates of secondary school and have worked as enumerators in the 2000 national census, thus having experience of working with surveys and questionnaires. The recruited field workers all spoke the local languages and were instructed to communicate in the local language whenever necessary to complete the questionnaire. The fieldworker would then translate the answers into English and write them down. Each survey started with a training session with the field workers. Each fieldworker was also accompanied by a technician from the ESCO. The technician showed the fieldworker where clients were located, and was instructed to introduce the field worker as a person working on a University research project to the person in the household, shop, or institution. The technician was then to leave the fieldworker with the respondent to complete the questionnaire. The fieldworker began the sessions by informing the respondents about the aim of the survey and providing assurances that their answers would not be possible to trace back to them. Each questionnaire took about 30 minutes to complete. In those cases where the client was not a household, specific questions directed towards the other types of clients with a SHS were added to the questionnaire. In cases where the client was a shop with an attached household at the back, the household version of the questionnaire was used.

Most of the answers in the questionnaires could be inputted directly into the SPSS statistical software. But this was not possible with the open-ended questions. Here the following procedure was used. First, the answers given by the respondents to the open-ended questions were summarised by the fieldworker and written down on the questionnaire. This was necessary as the answers given by the respondents were often quite elaborate. The next step was to make an even more condensed summary of the text lines supplied by the enumerators. Finally each summarised open-ended question was analysed for common factors by which the open-ended questions could be categorised. These factors were then put into the statistical software. When the enumeration had been conducted in the local language, the answers were translated into English by the field workers.

The geographic location of each client interviewed was determined with a waypoint (geographic position) which the technicians did with a GPS (Global Positioning System). The waypoint identifier was put on the questionnaire. The waypoints were then transferred to ArcView software and the questionnaire database linked to each location. Maps were digitised for the area using paper maps (1:50 000) and GPS track loggings. The spatial data was useful in the analysis of some of the aspects of SHS use. For example ownership of TV:s among neighbours was explained by these households being found in and around a school that operated a generator for a period of time during the evenings (Gustavsson *et al.* 2004). The data on the location of each SHS operated by the ESCO:s made it possible to show the differences between the different ESCO:s in terms of transportation needs.

Interviews, discussion, and observation

Interviews have been used as a method throughout this project. Interviews can be divided into two categories: i) formal interviews where questions and themes were prepared in advance (so called semi-structured interview, see Holme *et al.* 1986; Denscombe 1998; Mikkelsen 2005), and ii) informal interviews or discussions. In the case of the formal interviews the respondent was informed that he or she was taking part in an interview that was part of a research project at a Swedish University. Notes were taken which were then transcribed and analysed. Most of the formal interviews could be done without the help of an interpreter. As each interview becomes unique with the semi-structured approach, the information was not used for any generalisations. In the preparation and design of the questionnaires, information from these semi-structured interviews was used.

Informal interviews and discussions with clients, neighbours, and other stakeholders were held on many occasions during the fieldwork. Notes were made directly after the interview. Direct observation was another source of information (see for example Mikkelsen 2005). I spent time in the offices of the ESCO:s, where I could observe the daily routines of the ESCO and ways of communicating with clients and people coming to the offices. I could often talk with the people coming and going at the office, and they were often willing to talk about the work of the ESCO:s, solar technology, and the situation in the communities.

Controlled battery tests and load loggings

The results of the surveys (Gustavsson 2004; Gustavsson *et al.* 2004) indicated that the load on the systems was higher than the systems' specifications. There had also been blackouts that were possibly caused by the regulators switching off the system when the battery voltage, i.e. the SOC, became too low.

A number of tests were designed to investigate the technical performance of the system. These tests included the following:

- Measuring the solar irradiation: this was done in order to assess the potential energy available
- Controlled battery tests: to learn more about how much capacity the batteries had lost during a one year operation period
- Load loggings: to measure the use of energy by different appliances

The tests were planned to be implemented in Nyimba, but as there was no grid electricity available to charge the batteries during the battery tests, the test location was switched to Lundazi.

A number of parameters had to be considered in the design of the methods and equipment used in these tests. The tests were supposed to take place over a long period of time, hence assistants would have to use a laptop computer to collect the information and send the collected data to Sweden. The assistants required training in both handling the equipment and basic problem shooting. The equipment used in the field had to be easy to handle.

During the field work the test rig for controlled battery tests was constructed and tested (Figure 9). Data loggers with a suitable software interface were found. These had an 8-bit resolution which meant that the resolution in testing the battery was 0.06V. The increased level of precision which could have been achieved with more advanced equipment was considered secondary to having robust test equipment. A test manual prescribing how routine testing was to be performed was written. One of the technicians at LESCO was assigned and trained to perform the battery tests.

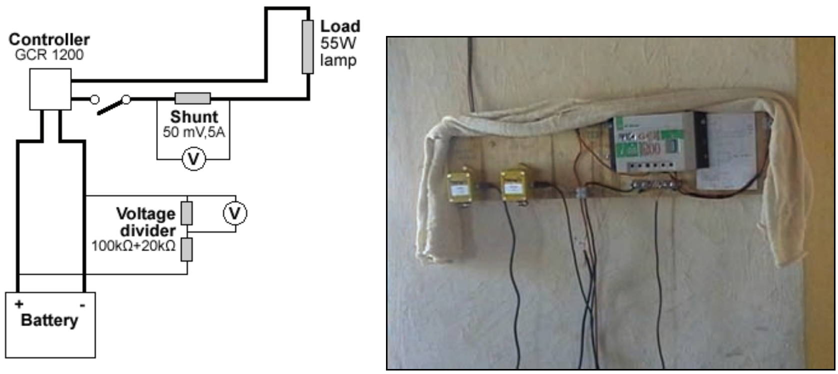

Figure 9: Battery test rig, picture to right shows data logger shunts and the regulator

A laptop computer possible to run on 12 V DC was used to collect the data files from the field and the battery test logs. The data files from the loggers were compressed to zip format and sent to Sweden via email.

Load loggings were made on three systems with different loads. The selection of the systems to be included in these tests was made using the survey results from 2002. The clients were divided into three groups based on the number of electric appliances connected to the SHS. One group was comprised of *low energy users* having lamps and a radio cassette player connected to the system. One group was *medium energy users* having lamps, radio cassette player, and a TV, and the last group was called *high energy users* where lamps, radio cassette player, TV, and a VCR (video cassette recorder) were found.

There are two different approaches found in the literature on how to study energy use patterns and charge currents. The first is to measure the energy used, either by logging the current or keeping track of the energy used with an energy meter. These types of studies are found in, for example, Jacobson (2004), Nieuwenhout *et al.* (2001b) and Reinders *et al.* (1999). This is the method used in this thesis. A second approach that provides a rougher estimate of the energy used is to collect information on how much the appliances have been used from the SHS users, and based on this deduce the amount of energy used. This approach can be found in, for example, Morante and Zilles (2001), and van der Plas *et al.* (1998).

Shunts, a well defined resistance where the voltage drop together with the resistance gives a value of the current, were used to measure the currents. Voltage drops caused by the shunts were max 50 mV. Voltage dividers were utilised to measure the voltage over the batteries, as these were outside the range of the loggers used. The clients were informed about the tests and did not object; the setup for load testing is presented in Figure 10.

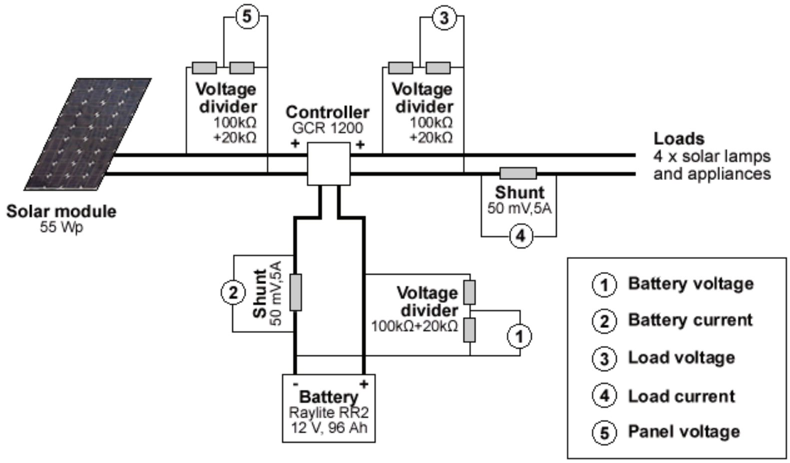

Figure 10: Setup of the load measurements of the Solar Home System in medium user household.

A solar irradiation meter was placed on the roof of the LESCO office in Lundazi (12°17'47.00"S 33°10'39.83"E). The irradiation meter was connected to a data logger which enabled us to collect a long-term series of the solar irradiation. This irradiation meter was based on a linear photoelectric element, and readings were downloaded from the data logger and emailed to Sweden.

Figure 11: Irradiation meter on the roof of the LESCO office.

5.2 Discussion of the selection of methods and their implementation

The surveys were carried out using local field workers who were responsible for completing the questionnaires based on the respondents' answers. A total of 12 field workers were used during the surveys in 2001 and 2002. The written answers given in the questionnaires had to be kept relatively short, which made it important for the field workers to be skilful at summarising the answers. Using field workers also involves a certain degree of uncertainty in terms individual differences in how the answers were summarised. In the analysis of the open-ended answers given in the questionnaires, a process of simplification was required. As has been presented, this was done in a number of steps. This process was very time consuming, but as the answers to these questions were not known at the time of designing the questionnaire, using open-ended questions was the most feasible solution.

The case study has been carried out in a complex setting where most of the variables cannot be separated from their context, and influence from other variables cannot be ruled out. For example, the study on educational benefits of solar technology has a socio-economic dimension that will have consequences for the opportunity to study. The clients who have received SHS from the ESCO:s are a privileged group in the rural setting. For example this group has a high rate of household members with formal incomes. It is likely that their children have greater opportunities to attend school and also have strong encouragement at home to do homework and to complete school.

In the presentation of results, the *household* is the unit used for presenting data on how domestic users utilize the SHS. In this context *household* represents people living under the same roof, which means that household members do not necessarily have to be family or kin. A common misconception about *households* is that they only consist of nuclear families and that there is equal control over resources between the household members (Moser 1989; Ilkkaracan *et al.* 1994). One example is that women are more likely than men to use their resources for the well-being of the family (Bruce *et al.* 1988; Agarwal 1995). The questionnaire was designed with the complexity of intra-household relations in mind, and separate sections were included to investigate the different roles of women, men, and children. The answers to the questionnaire are treated on a household level and the impacts are described as such. There is, to my knowledge, no study that was conducted using the level of the individual as the unit for analysis. The approach used in this study is in many respects typical of the studies performed within the field.

Battery tests, solar irradiation metering and load loggings were done according to the presented methods. The equipment had to be chosen according to budgetary considerations and the possibilities available at the test locations. The 8bit resolution of the data loggers had to be taken into consideration when analysing the data, i.e. remembering the precision in terms of significant figures. The procedures used for downloading data from the loggers and sending it to Sweden worked satisfactorily[12].

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[12] The computer was struck with computer virus during the period when we worked on the dataloggings. There was an anti-virus software installed, but the virus update files could not be downloaded due to slow connections with the Internet. As a result there are some gaps in the dataloggings.

6 Integrating solar electric services in people's lives

The five articles included in the thesis (Gustavsson 2004; Gustavsson *et al.* 2004; Gustavsson *et al.* 2005; Gustavsson 2007a, 2007b) describe and analyse impacts of the use of solar home systems on people's lives, and other users' daily operation of their businesses or other activities. The three subject areas presented in section 1.1 will be discussed in more detail:

1. *The technical dimension of the use of Solar Home Systems:* In this section, a closer look will be taken at the technical side of solar technology use, and some aspects of the black box that concerns the transformation of the inputs to outputs are examined. Examination of the solar energy systems in terms of limitations and possibilities to use energy gives a better understanding of the experiences the users have of the system. A discussion on the possibilities to improve the technical performance of the systems can be based on this information.
2. *The impacts of Solar Home Systems on daily routines and lives:* The outputs from the SHS will make possible a number of activities that were previously difficult or impossible to do. The solar energy system will provide good lighting, but what are people doing with this improved availability of lighting? The possibilities that arise through improved lighting are not only restricted to reading and writing, but also include the possibility to carry out domestic work in the evening, watch TV, and work at home. There are also considerations about the inputs that the users will have to perform in terms of accessing the technology, i.e. paying the monthly bill.
3. *Consequences of access to solar energy services on institutions and communities:* A wider perspective is applied in this subject area. Providing the opportunity for people to access solar technology is an alternative path for rural electrification. Rural electrification and the services provided through government channels can improve the often weak position that rural areas have in comparison with urban areas.

Each theme is discussed in more detail after the initial presentation of the typical customers of the ESCO:s.

6.1 Presentation of the typical customers of the ESCO:s and their context

There are 404 solar energy systems operated by the three ESCO:s[13]. 84% of them are in households, and the second largest group of clients, 7%, are shops. In 4% of the cases the system was found in a household and shop. 5% of the clients are schools, guest houses, and health and medical centres.

Households

The clients of ESCO:s are a relatively homogenous group sharing a number of characteristics, and there are only small differences between the client groups in Lundazi, Chipata, and Lundazi. In Nyimba most of the clients are found in the town centre, while the clients of CHESCO and LESCO are mostly found outside the towns. The houses where solar energy systems have been installed are, in more than 80% of the cases, built of concrete or burned brick walls, and in more than 90% the roof is made of asbestos or iron sheets. This is different from the typical house in the Eastern province which, according to the national census in 2000 (CSO 2004a), was a pole and dagga/mud construction (66%) with a thatched roof (86%). The members of households with a solar energy system had lived in the house 4 years (median), and the neighbours for 3 years (median). Most of the houses consisted of 5 rooms (median), which was the same figure for both clients and neighbours. The typical household consists of 6 persons (median), 3 adults and 3 children. About 10% of the households are female headed.

In almost 90% of the households with a solar home system, one or more persons had a formal income. Generally the households are also involved in farming activities. The main occupation in the three areas is agriculture (CSO 2004b). That a large number of households have members with formal incomes shows that the group is better off in these rural areas. The neighbour group has a slightly lower proportion of members with formal incomes in their household, 80%.

The occupations of the household members shed some light on the housing situation. Occupations other than farming are teacher, policeman/woman, health worker, and other civil servants. Such employments are often associated with an offer to rent or receive housing in the proximity of the workplace. In many cases, the housing pattern surrounding a workplace such as a school or health station is best described as a camp. A school compound will thus not only contain the buildings for classrooms and administration, but also include teachers' houses. This explains why the neighbours of the clients with a SHS display such similarities to each other, while they are not typical of the inhabitants in the Eastern Province generally. There

[13] Numbers here are for 2001 and 2002 and there has not been any drastic changes to these.

is a constant shifting of the employees within the province, which explains the short length of time people have occupied the houses where they are staying.

There are differences between members of the households in terms of what types of chores and activities they are involved in. For example women and children have the main responsibility for preparing food (in 90% of the cases) and doing dishes (in 95% of the cases). According to the survey results men are responsible for 'borrowing money', and decisions in economic matters tend to be made by men, though the difference is not as pronounced. While there are significant differences in certain activities, there are a number of activities in which all members of the household are involved to the same extent. The best example of this is listening to radio, which, in 90% in the households, all the members did to the same extent[14]. Reading is also an activity that is shared among the household members with a slight tilt towards children being those doing it most. The respondents were asked about household members' capabilities in terms of reading and writing. The results indicated high levels of literacy: 90% of the adult men, and 80% of the adult women in the sample. The 2000 census in Zambia showed a literacy rate in the Eastern Province of 48%, and a national average for rural adult women of 46%, and for rural men 68% (CSO 2003). Once again the special status the solar energy clients possess as a group is apparent, this time in their high literacy rates.

Other solar electric services users

The other main client group is shops. Many of the shops consist of both shop and living quarters, and the solar energy system can serve both. Shops can thus be illuminated during the evenings, extending their opening hours. They can also use a radio to attract customers. There are a number of schools, health centres, guesthouse/hotels, and other institutions that have contracts with the ESCO:s. In a few cases solar energy systems are used in small industries (for example milling stations). Here the electric services were used for lighting to enable work in the evenings.

In most cases where the contract holder is not a household, a local person has arranged for the shop or institution to sign the contract with the ESCO. Consequently the ESCO:s usually have good channels of communication with their clients. The monthly fee for commercial or domestic use is the same.

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[14] No questions were included on gender differences in the use of TV:s. The reason was mainly that not all households have a TV, while radios are found in more or less every household, also those without a solar energy system.

Energy use among the clients

A small solar photovoltaic system like those discussed here cannot supply energy for routine cooking. In the study, charcoal and fuel wood are the main energy sources for cooking. Most households used different types of fuels with one principal energy source. Cooking fuel was bought from resellers at the market, locally or at the door. Fuel wood was in many cases collected in the surrounding areas.

All the clients and neighbours used dry cell batteries to some extent. When a household receives access to solar electric services they can operate e.g. a radio cassette player thus using fewer batteries. Neighbours and potential clients have to spend money to buy dry cell batteries. Candles and kerosene/paraffin lamps were the typical light source found. Car batteries charged in town were not frequently found in the study area. In Table 3, a comparison of the costs of different energy services and different clients are presented.

	Cooking	Light incl solar	Electric services for appliances	Expenses for energy services total
Clients	14 100 (3.2)	30 100 (6.8)	7 700 (1.8)	51 900 (11.8)
Potential clients	13 400 (3.0)	18 300 (4.2)	21 000 (4.8)	52 700 (12.0)
Neighbours	13 200 (3.0)	10 800 (2.5)	9 800 (2.2)	33 800 (7.7)

Table 3: Monthly expenses for energy services, ZMK (2002 money value, USD within brackets) (Gustavsson 2004)

When a household receives access to solar services, the money spent on dry cell batteries and fuel for light is diverted to pay the monthly fee. In monetary term, this access to solar services did not make any difference, i.e. the households did not save any money by switching from batteries to solar services. The solar services on the other hand allowed for the more frequent use of radios and cassette players and improved lighting.

6.2 The technical dimension of the use of Solar Home Systems

A solar energy system only has a limited capacity, while the load is prone to increase when the users find that they have access to a more continuous electricity supply than before, and thus start adding more electric appliances. If this happens, it will affect the battery life time negatively, and the users will experience black-outs as the safety functions of the system will disconnect the load side.

The solar energy system's capacity can be expanded by adding more solar panels, but as was discussed earlier the increased cost is the main barrier for spontaneous diffusion of the technology. When planning for the introduction of SHS, feasibility assessments are undertaken. Here the willingness to pay for energy services is one factor considered. In the Zambia PV-ESCO project, a feasibility study was undertaken in 1998 (Ellegård *et al.* 2001). The system considered was based on a 50Wp solar module providing power for four lamps and the possibility to connect appliances. The components were chosen in such a way that a second solar panel could be attached to the system without changing regulators, wiring, and battery.

There are a number of parameters that will affect the use and performance of the SHS. Four of these parameters are discussed here.

Solar irradiation in Lundazi

The quantum flow of solar irradiation is converted in the solar panel to electricity. The strength of the irradiation varies around the globe, and thus certain locations have more conducive conditions for solar power than others. The African continent has favourable conditions for using solar panels for electricity generation in general (Figure 12).

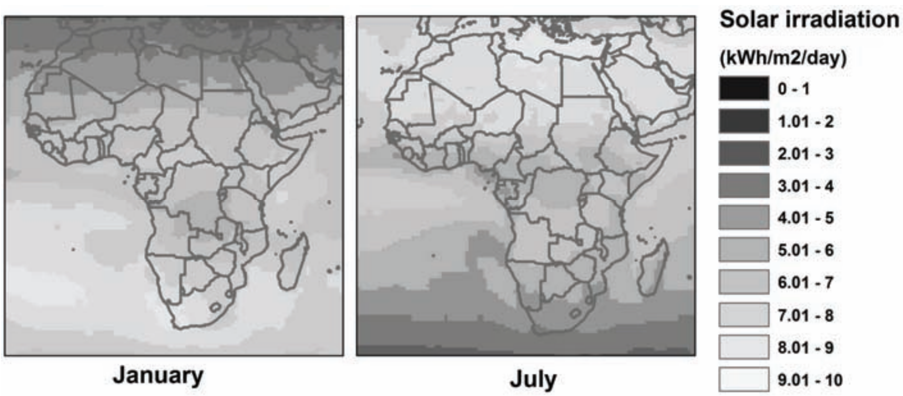

Figure 12: Solar irradiation in Africa, January and July. Monthly averaged (July 1983 - June 1993) insolation incident on a horizontal surface (kWh/m²/day)[15]

These continental maps do not account for local and regional variations that can be found in the incident irradiation. In Figure 13, the solar irradiation over one year has been measured at one of the sites of this investigation (Lundazi). Here both the variations between days as well as between seasons are seen.

[15] Global data was downloaded from Nasa (2005) and transferred to ArcView, where a raster was generated using the values for each point in the dataset. Similar tools as the one found at the NASA site can be found at for example PV-GIS at sunbird.jrc.it/pvgis/pv/

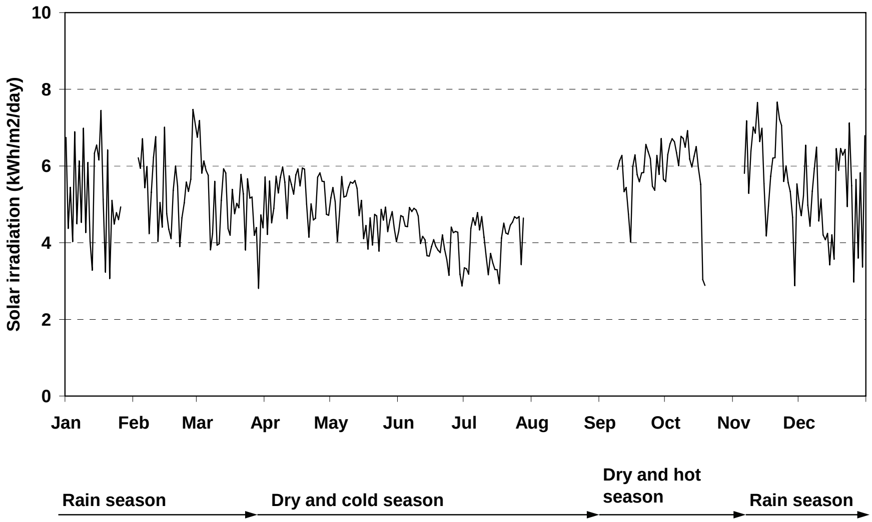

Figure 13: Changes in solar irradiation readings measured Lundazi, 2003 and 2004

According to such irradiation readings, the months when one can assess that the SHS will be operated with the lowest charge are June and July. Only in a few cases were longer periods of low irradiation, caused by cloud cover, present (Gustavsson 2007a). The user surveys were undertaken in June and July which is the time of the lowest incident irradiation.

Charge of the solar module, energy available in the system

The variables of 'solar irradiation' and 'module size' are parameters that will affect the daily charge of the system. Keeping the module out of the shade, and cleaning the glass to prevent a dust film are necessary maintenance. Apart from this, these two parameters are relatively fixed and difficult to alter.

The effect rating of the panel will yield an indication of the amount of incident irradiation that can be converted in the solar panel. A solar panel has a factory rating, which is set under controlled conditions. This means that moving from a place with strong irradiation to one with lower irradiation results in less energy being delivered from the same solar panel. The efficiency rates of the module will eventually decrease, but this will only happen after 10-20 years, and then within a range of 10% of the rated Wp.

In Figure 14 the daily charge from a system is seen plotted over a period of five months[16].

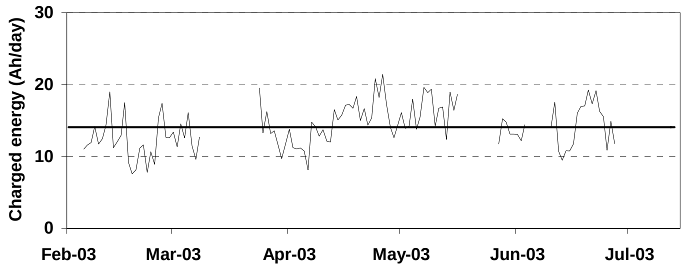

Figure 14: Charge energy from 50Wp solar panel in Lundazi, average charge 14 Ah/day (Gustavsson 2007a)

The collected data on the charge energy from the solar panel shows that there are few periods of very low charge. For example, there are no periods when more than four days of less than 10 Ah/day are recorded. Taking the solar irradiation loggings into consideration, it can be assumed that there is little likelihood that there should be any major differences in terms of long periods of low charge during the other month of the year. From the measurements, one can calculate the daily average energy input. During the period covered, this was 14 Ah/day. This figure represents an estimate of the limitation of energy use of the system each day.

Sizing of batteries, a challenge in terms of not too large or too small

The battery will store energy generated in the solar module during the day. This energy will be available when a load is put on the system. The size of the battery will only affect the energy storage capacity, but not increase its capacity seen over a longer period of time. One factor that needs to be considered in choosing the battery capacity is how many days it should be possible to operate the system without any charge. This is often referred to as the number of days of autonomy. According to design manuals, there should be around 3 days of autonomy in the Zambian region (Derrick *et al.* 1991; Spiers *et al.* 1998; Stapleton *et al.* 2002).

A large battery will cost more than a smaller one. Perhaps more important is that an overly large battery can deteriorate faster than a small one due to operational conditions. The solar energy systems found in development projects are usually equipped

[16] The diagram is based on an integration of the currents logged in the negative cable connected to the module. Readings were made at an interval of 5 minutes.

with a regulator that will cut power if the State of Charge (SOC) falls below a certain level (normally around 30-40%). In the Lundazi case, where battery tests were performed, the regulator cut the loads at 11.7 V, corresponding to an open circuit voltage of 12.1-12.2 V. This open circuit voltage gives a rough estimate of the SOC, which in this case is about 40% (First National Batteries 2003). Operating the battery on a low SOC with shallow charge cycles will harm the battery and the life time will be reduced. The processes involved in this deterioration are sulphation, stratification of battery acid, corrosion, and erosion (Spiers *et al.* 1998; Mattera *et al.* 2003; Potteau *et al.* 2003; Sauer 2003). A battery has, from a technical point of view, exceeded its lifespan when its storage capacity is less than 80% of its rated capacity (Spiers *et al.* 1996; PVPS 1999).

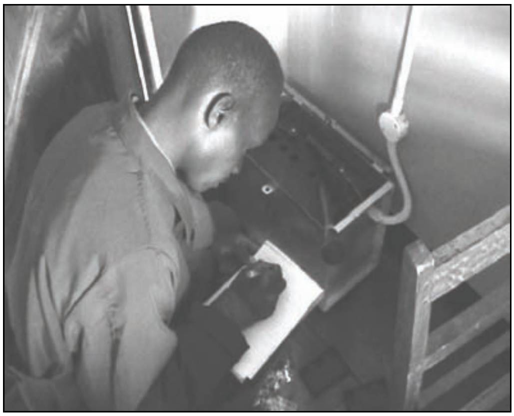

Figure 15: CHESCO technician checking the battery specific gravity

Results from the battery study at LESCO (Gustavsson *et al.* 2005) show that all of the batteries tested (13 randomly picked out of 152) had, during the 3 years of operation, lost more than 80% of their capacity compared to two new reference batteries of the same type[17]. As the batteries had excess capacity, this reduction in capacity will not necessarily be experienced by the users. The problems that were seen were rather linked to damaged cells, which would result in sudden drops of the battery voltage. The batteries found in the Zambia PV-ESCO project are rated about 100 Ah and are a bit large considering the panel rating. The use of such large batteries was a decision based on a future possible expansion of the SHS by adding extra solar panels without replacing the battery or the regulator.

[17] A follow up of these batteries was made in February 2005 and all the batteries tested in the 2003 battery test had been replaced or were broken.

The research performed in this case study suggests that even though there are technical safety functions in a solar energy system to prevent low SOC in the batteries, these will not ensure a long lifespan for the battery.

Appliances, loads and charge

A technology is needed to convert the electric power in the SHS to the energy service wanted. By using energy-efficient technology, the same energy service can be obtained by using less energy. In the case of lighting, a fluorescent lamp will deliver the same amount of light as an incandescent lamp, but use less energy[18].

The typical appliances found in a solar home system are lamps, small radios and radio cassette players, small black-and-white TV:s, and video cassette recorders (VCR). All these appliances are available in low effect rated versions suitable to connect to a 12 V DC system. Refrigerators and colour TV:s require relatively large solar energy systems to be operated, and for cooking, solar PV technology is not suited at all. In Table 4 a comparison between different appliances is found based on their rated power and also estimated price.

	Item	Rated power	Price (USD)
Solar appliances	Fluorescent solar lamp	7-11 W	5
	Small radio	>10 W	~10
	Radio cassette player	10-17 W	~15-90
	Black and white TV (12VDC, 14'')	13-17 W	~50
	VCR (12VDC)	13-17 W	120-150
Not suitable for solar application	Refrigerator (12VDC)*	>8-20 Ah/day	na
	Colour TV (12 VDC)	~40W	~150-250
	Ordinary lamp (incandescent)	40-100 W	
	Cooker	800 W	na

** Refrigerators used for special purposes such as keeping vaccines are well known, but for domestic use fridges are considered not suitable with small solar energy systems. The refrigerator uses a certain amount of energy per day as the compressor or other technology will be turned off and on thus the use of Ah/day rather than W.*

Table 4: Rough values of rated power for typical (solar) appliances. Prices were collected in Chipata, Lundazi, and Nyimba in 2002 and converted to USD. For comparison a candle is about USD 0.15-0.25

[18] In recent years LED (light emitting diodes) technology has entered the solar scene. LED lamps are more efficient than fluorescent lamps. In the Zambia PV-ESCO projects, LEDs are not found. The technical life of a LED lamp is typically much longer than for fluorescent lamps and given the experience with broken lamps this is an important advantage. The cost is, however, higher for a good LED lamp for use in a solar application, but considering a solar systems whole life time LED lamps will eventually be competitive from a economic point of view (Foster *et al.* 2005).

Most clients used other appliances than just the lamps that came with the system, see Figure 16.

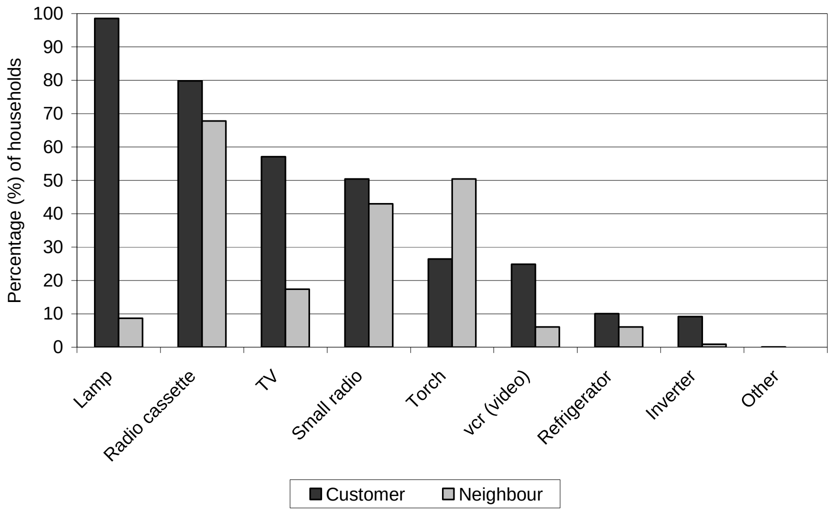

Figure 16: Percentage of households with specific appliances in their households

Apart from lamps, cassette players were the most frequently found appliances among both clients and neighbours. Cassette players can be operated on dry cell batteries, and in many of the households the cost of dry-cells could amount to a substantial sum every month (see Table 3). TV:s are the second most common appliance used in the households with solar energy systems, but are found in a number of households without solar services as well. Some of these households have TV:s because they have previously lived in areas with access to grid electricity and brought the TV:s with them. The experience of having lived in areas with access to grid electricity was common among both clients and neighbours, thus knowledge of what electric services entail was available to the clients. This is reflected in the most common reaction to the shortcomings of the solar energy system being that it was too weak, expressed in terms of *"the systems should be 220 V"*, i.e. it should be possible to operate fridges and colour TV:s.

Figure 17: The interior of a house with appliances operated with solar electricity.

Most of the households that have acquired a TV after receiving the solar energy system had opted for a 12 V DC type. Inverters used to convert the 12 V DC to 220 V AC are well known to people, but relatively few inverters were actually found connected to the systems. The training that the technicians and managers underwent through the Zambia PV ESCO project included the advice that inverters should be avoided if possible. All three ESCO:s have discouraged the use of inverters. The restrictions against connecting inverters to the systems are one reason for this development; another reason is that 12 V TV:s are easy to buy and less expensive than 220 V appliances. The main reason for not connecting inverters is to avoid the use of 220 V equipment with an effect rating too high for a small solar energy system. In addition, inverters are preferably connected to the battery poles, and hence the charge regulator with its low-charge safety function will be bypassed.

In order to examine the use of electricity in the households, the clients were divided into three groups with different combinations of appliances. One group was those households that had lamps and a radio cassette player. Another user group was households that also had a TV. A third user group was those households that had a VCR as well. Each appliance has a power rating defining the maximum energy it will use at a specific point in time (see Table 4). The load patterns in these three groups of users are presented in Figure 18 [19].

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[19] The diagram is based on an integration of the currents logged in the negative cable connected to the regulator's load side. Readings were made at intervals of 5 minutes.

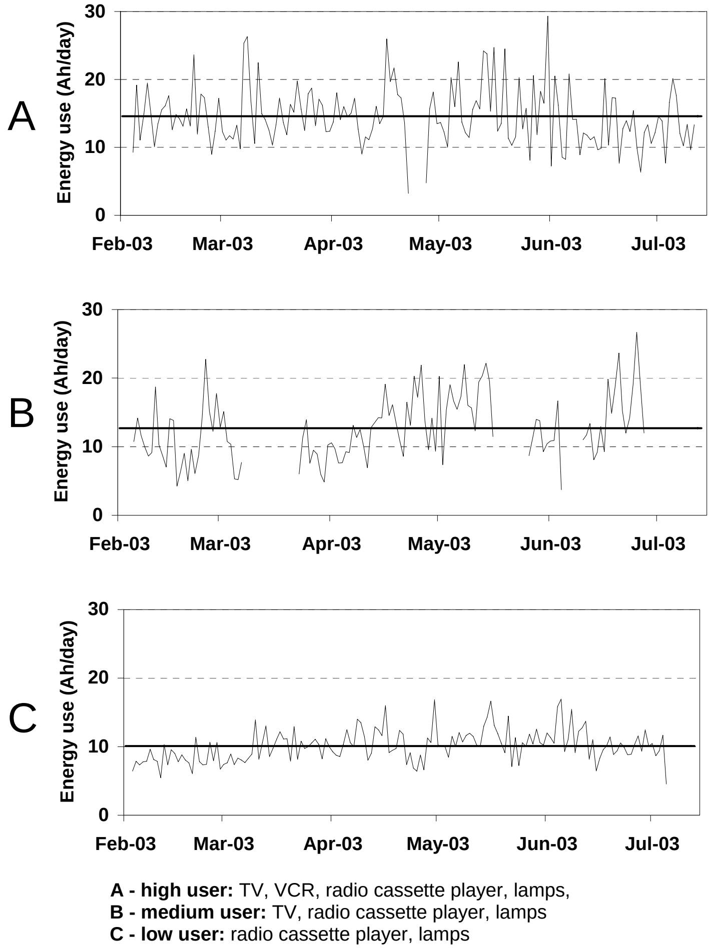
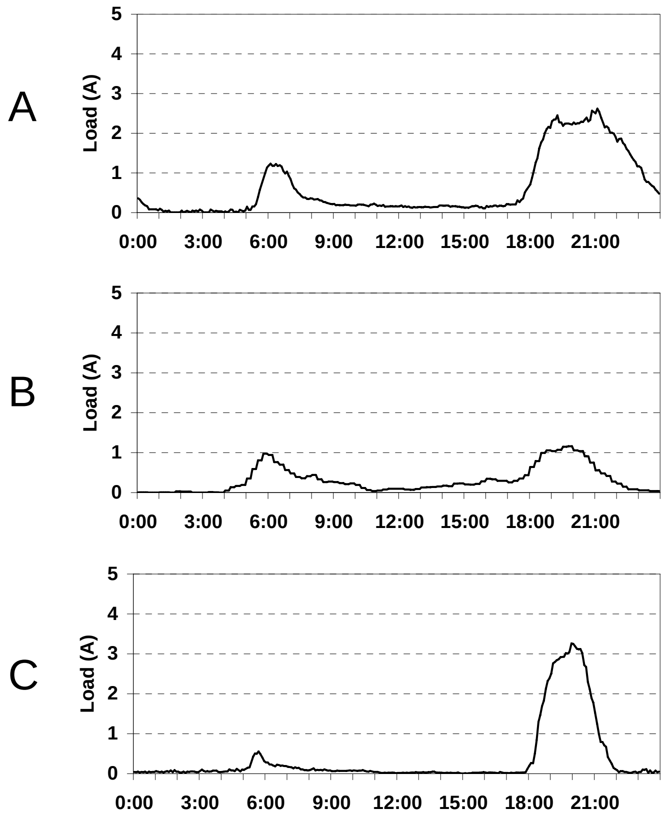


Figure 18: Loads on systems, three user groups (Gustavsson 2007a)

In the high usage household the average use reaches 14.5 Ah per day, while the low user has an average use of 10.0 Ah. The load is put on the systems during mornings and evenings (Figure 19). In the morning the load is lower because only lighting and perhaps a radio cassette player are used. This load continues for about 1-2 hours. In the evening the load includes lamps, radio cassette player, and TV and VCR if these appliances are found.



A - high user: TV, VCR, radio cassette player, lamps,
B - medium user: TV, radio cassette player, lamps
C - low user: radio cassette player, lamps

Figure 19: Average loads on the system for high, medium and low users (Gustavsson 2007a).

Using the system with all the appliances (lamps, a cassette player, a VCR and a TV) will result in a daily energy use that is almost equal to the energy input from the solar module. The system will probably be operated in such a way that the SOC will be in the range of 50%, rather than 80% and above. This was verified in specific gravity readings collected by the technicians during monthly inspections[20]. Operat-

[20] Specific gravity will only give a very crude measurement of the charge of the battery. Stratification of battery acid will, for example, affect the reliability of these measurements. But the values nevertheless give an indication of the status.

ing the battery on a low SOC and with shallow charge cycles is harmful to the battery as discussed previously.

One of the assumptions in the Zambia PV-ESCO project was that already prior to the project a certain level of knowledge was present in the communities about how to repair 12 V electric systems. For example battery chargers are locally produced in Lundazi and Chipata, and there are people who can repair radios, for example. But specific knowledge on operation and maintenance (O&M) of solar energy systems had to be transferred, as the users had very little or no experience of such systems prior to the project. Many of the answers given by respondents in the studies in Lundazi and Chipata in 2001 reflected the view that people did not really know what to expect from the systems and how to operate them. Training of technicians in O&M (including trouble-shooting and repairs) was part of the set up in the Zambia PV-ESCO programme, while dissemination of information to users was done by the ESCO:s. The information to the clients on how to operate and manage the SHS was provided at the time of installation. Each client would receive oral information on the proper way to use the system and what appliances they could connect. Along with this, a short set of written instructions was also provided. The instructions are straightforward and include such recommendations as that lights should be switched off when there is no one in the room, that the system should not be excessively used, and that 220 V appliances are not possible to run on the system.

The users are now accumulating knowledge on the operation of the systems. They are interested in learning more, and for many more, knowledge about the function of the system is desired (Perskaja-Wisén 2004). An example of this learning process is how the users assess how much power is left in the system, i.e. the SOC of the battery. Clients said that they could assess the charge of the batteries by looking at the brightness of the lamps. Another indicator was that the size of the TV image would shrink if the battery voltage went down. To assess the SOC of the battery, the indicator on the charge regulator, or the indicator on the battery can be used, but these indicators are found inside the battery box which is supposed to be locked, so this is not feasible.

Changing the loads will change the system

In the Zambia PV-ESCO case, one type of system is expected to suit all customers, but it is clear that many of the clients are exceeding the design parameters for the systems they currently have. The typical users in the Zambia PV-ESCO case are relatively well-off, and many are able to purchase a TV and a VCR. The results from the study show that people have bought such appliances after they have received the SHS. This is also supported in interviews with the ESCO managers and technicians.

The results from the studies performed show that the loads increase as people have more electric appliances.

There are a number of approaches that could solve the problem related to the load and charge issue. One would be to add more charge effect through adding more panels. Adjusting the capacity of the systems is relatively easy, through augmenting solar panel effect by, for example, 25 Wp. The batteries and regulators will cope with this increase. This would create a system with a higher daily charge. If the use is kept stable at present levels it should result in a slight over-capacity in the system, and it should operate in accordance with the preferred model. An increase in the power of the solar module would result in a need for the ESCO to charge a higher monthly fee.

Another option would be to adjust the points for the cutting and reconnection of power. At present these are the factory set-point. Adjusting the reconnection set-point to connect only after reaching for example 12.5 V open circuit voltage (corresponding to ~75% SOC) instead of 12.1 V open circuit voltage (corresponding to ~40% SOC) would ensure that the battery would get a better charge after reaching lowest permitted charge. On the other hand, this would result in longer periods without service from the system. In the example above, the power cut would last about three days based on the charge loggings made in Lundazi. Longer periods of power cuts could lead to the customers trying to bypass regulators and consequently affecting the security system of the battery. A smaller battery would decrease the time needed to reach the adjusted set-point.

Another option is to improve the transfer of knowledge to the users in order for them to better understand the limitations of the system and operate it in better accordance with the specifications. Uphoff (1991) argues that one often underestimates the technical knowledge of local people (the users) in development assisted projects. The Zambia PV-ESCO project shows that the programme was designed to provide technical training to the ESCO:s. The systems have been kept operational and routine maintenance has been carried out. Training of users is the responsibility of the ESCO:s, and the training could be improved. 90% of the clients report in the surveys that they have received information. The results from load loggings and battery tests show, on the other hand, that the information to the users could be improved. Here the challenge lies in making the users aware of the limitations of the system. For example if the system is used extensively during one period it should be allowed to regain full charge of the battery for some days. At present such information is mainly transferred from the technicians at the time of installation, and there is also a written (one-page) information sheet of dos and don'ts. Clients will often ask the ESCO staff in the office or in the field about ways to increase the power or connect appliances, but also about ways to perform maintenance on their own.

6.3 The impacts of Solar Home Systems on daily routines and lives

The possibility to use electric appliances operated on 12 V DC in the households, institutions or shops will facilitate a number of activities that were difficult or not possible earlier. Lamps will give brighter illumination, enabling people to, for example, read and write in the evenings. Radio and television can supply information and entertainment. As presented in section 6.2 most households have appliances other than the lamps in their houses, and the trend is to get more appliances once the power to operate them is available.

The main output from the solar energy system is the energy services received from the SHS. The user will have to pay a monthly fee to get access to the outputs, and this fee constitutes the main input. The customers are not required to do any daily maintenance on the systems.

The monetary side of SHS – monthly fees and income-generating activities

There are two main inputs of money that the client will have to provide in order to get access to the solar electric services. One is an installation cost and the other is the monthly fee paid for the services. The installation cost will be all items and work needed to install electric wiring in the house, such as electric wires, switches, sockets, conduit pipes, and costs for labour and transportation. The installation cost is dependent on the ESCO, but is about ZMK 250 000 (USD 60) and will not be repaid when the contract is ended.

The monthly fee was set to ZMK 20 000 (USD 8) in 1999, but the actual fee started at 25 000 (USD 9) in 2000. The fee has subsequently been raised on a number of occasions putting it in the range of ZMK 45 000 (USD 9) in 2005. The monthly fee had then increased by 80% in ZMK terms, but converted to dollars there is instead a tendency that the value of the monthly fee is decreasing (Ellegård *et al.* 2004)[21]. Keeping fees adjusted to the inflation in Zambia has been an essential task of the ESCO managers and is part of the yearly updates of economic audits. If the monthly fees are not adjusted the repayment of the credit taken for the hardware, and possibility to purchase exchange batteries, would be reduced. Respondents are well aware that prices for commodities such as dry cell batteries, candles, and

[21] Appendix 2 includes diagrams of 12 month inflation rates (2000-2006) and also a Consumer Price Index for Zambia 1990-2006 based on information from the Zambia Central Statistics Office (CSO 2006). Costs and prices have been adjusted according to these data.

paraffin steadily increased over the years, while they claim that they do not understand why this happened. The increases in fees that have taken place have not resulted in any significant cancellation of contracts.

Applicants to the ESCO:s who the managers have reason to believe will have difficulties paying the monthly fees are less likely to get a system installed. The ESCO:s are local companies with managers knowledgeable about the financial situations of applicants. The issue of how to avoid defaulting clients was considered, both by the Zambia PV ESCO project team as well as the ESCO managers, before the first installations were made. The issue of defaulting clients became a minor one as experiences from the ESCO:s were accumulated. People paid their bills, sometimes a bit late, but they paid. Most households, 80%, considered that the fee they paid for the service was *"reasonable"*. At the same time, 37% reported having had problems paying the fee on one or more occasions, but there are few defaulting clients.

The typical household with a solar energy system has at least one formal income, which is similar to several other solar electrification experiences (see for example Nieuwenhout *et al.* 1999; Wamukonya *et al.* 1999; Jacobson 2004; Ranniger 2004a). People with formal incomes have relatively regular and secure livelihoods if compared to people relying on incomes from small scale farming. In recent years a discussion on the value of supporting solar projects with international donor money when the target groups are middle income has been started (Karekezi *et al.* 2002; Villavicencio 2002). One argument is that it will not benefit the rural poor. But as the project manager of the Zambia PV-ESCO project stated:

> *"the Zambia PV-ESCO project is not a poverty alleviation project"*.

The present group of clients has the means to improve their living standards, but cannot get access to the electric energy services because they live in rural or remote areas. Once the possibility to get access to solar technology is there, by paying a monthly service fee, it will not impose any major problems or risk taking to the users/household, as it is possible for them to end the contract if their income situation changes.

Most clients want to buy the system they have instead of keeping the service contract. Included in the questionnaires was a set of questions on how much the respondent would be willing to pay to become the owners of the systems. The sum considered by the respondents was generally low, and about 10% of the customers mentioned sums above ZMK 2 000 000 (USD 450 in 2002). This should be contrasted with the actual cost for the system ranging from 900 to 1 000 USD depending on location. In the Eastern Province, privately owned solar energy systems are found, but these are not very common. These systems are typically based on low-cost solar panels with a lower effect than those found in the Zambia PV-ESCO project. The reasons more systems are not found are lack of knowledge about how to get a system and that they are considered too costly. According to a compilation of costs for solar home systems in a selection of countries made by Moner-Girona *et al.* (2006) Zambia stands out as one of the most expensive countries in which to buy a solar home system. Transaction costs and various taxes on the equipment explain the differences in prices found.

One of the arguments for introducing solar technology in rural areas is that it will create income-generating activities. In the case study, about 13% of the respondents in the household group answered that they had considered starting some activity as a result of having access to solar power. Of these the most common activity contemplated was to start a small business or shop (35%), followed by initiating or changing farming activities, including starting milling (28%). A number of the activities that were considered are not possible with the available solar energy systems, as their power output is too small. Typical activities sorting under this category are welding and ice making.

Most of the activities considered are related to the opportunities given by improved lighting, for example giving night classes, starting a shop (that can be open during the evenings) and organising video shows. Teachers reported that they were able to prepare classes and make corrections during the evening as a consequence of the improved lighting. Some of them had considered giving night classes. Power for the radio attracted some people to the shop, but radios were also found in shops without solar power. Shop owners reported increased sales as shops could be kept open for longer hours, but the actual monetary increase could not be assessed. From the surveys, as well as in interviews with shop keepers, the impression was that the shop gained social importance as it became a meeting point. Even though this might not result in a direct economic gain, it improved the position of the shop and owner socially.

During these first years of operation the ESCO:s have re-located about 5-10% of the systems on a yearly basis. Reasons are clients moving from the area, changing family conditions, and non-payment of the monthly fee. 88% of the respondents say they are satisfied with the services they receive from the systems. The 12% that are not satisfied would like to have a larger system, and in some cases more light points. In addition, clients know that if they terminate their contract, they will have difficulties receiving another system if they decide to re-apply. The reasons are a long waiting list and no new credits having been released through the Zambia PV-ESCO project to facilitate additional purchases of systems. The ESCO:s themselves have not worked pro-actively to create funds to purchase new systems. There are without doubt several reasons behind this, but one central factor, according to my view, is that a continuous dialogue has taken place between the managers and the people managing the Zambia PV-ESCO project where the issue of release of new credits has been a topic. Being promised the release of new funds in the (near) future, the managers have seen this as the easy way to expand and acted accordingly. No credits have been released due to delays and lengthy formal procedures in finalising the transfer of ownership agreement between the DOE and the ESCO:s. The ESCO:s have generally been swift to act, and been able to respond to new options given them, which is one of the strengths of the market-oriented approach. The Zambia PV-ESCO project has, however, been less prone to match this swiftness, as many of the tasks involve negotiations and the involvement of outsiders in the decisions.

Activities and possibilities provided by access to solar electric services

In the Zambian case studied, the main benefit is related to the improved lighting that comes with the SHS. The respondents also saw the possibility to connect TV-sets and radio cassette players as positive, but valued the benefit that came through the improved lighting conditions as more important. In other studies from SSA the improved possibilities to access entertainment in the form of TV and music are presented as the main benefit of the SHS (Nieuwenhout *et al.* 1999; Jacobson 2004).

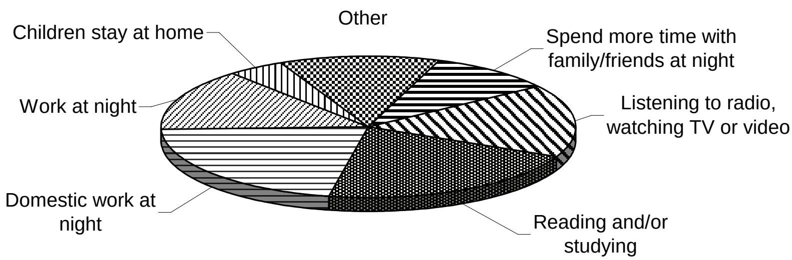


Figure 20: Changes in daily routines as a consequence of access to SHS

Changes in daily routines as a consequence of the access to solar services were expressed by 75% of the households. Examples of such changes were doing dishes and other domestic work, reading and writing, knitting, and studying during the dark hours (morning and evening) (Figure 20). Reading, writing, and studying were, for example, not expressed as just being an activity for children going to school, but rather as general activities of both men and women in the households. Examples of what people read were *"the bible"* or *"religious leaflets"*. Along with reading and studying, extending working hours into the evenings for both domestic and professional work was presented by the respondents as an example of changes they had made in their daily routines as a consequence of the access to solar electric services. About 25% also said that they now could enjoy and spend time watching TV and listing to radio.

Jacobson (2004) discusses intra-household dynamics in connection with who makes the decisions and how when it comes to the use the solar home systems. In his study of solar energy systems in Kenya, he found that certain energy services were prioritised over others. The solar energy systems that Jacobson (2004) studied in Kenya normally had a relatively low effect, less than 40 Wp in the module, and were often acquired as the users wanted to have the possibility to watch TV. Saving energy for TV through limiting the possibility to use lamps was found. In the Zambian case-study, there were examples of decision making in terms of using power from the SHS. For example:

> *"we stop using the system when the picture in the TV becomes too small, or the lamps will go out"*

But who made this decision in the household is not known. In the Zambian case, all systems have a 50 Wp module, and 4 lamps come with the installation. The results from the load loggings show that if the households only run a cassette player and lamps on the system for a couple of hours each day, the energy supplied through the system will be sufficient. Introducing a TV will result in a higher energy demand, but the systems are still able to cope with this if the TV is not utilised for too long hours. When the amount of time that the appliances are acting as loads is increased, the system will start to cut power and thus stop delivering energy services, such as light, until the battery has recovered charge.

Solar electric services and educational benefits in the households

The rationale behind introducing a new technology is based on a number of expected impacts. In the case of introducing solar technology, the possibility for children to spend more time studying is often put forward (Foley 1992; Andersson *et al.* 1999; Foley 2000; ESMAP 2002; Wilkins 2002; UN-Energy 2005). The results from the Zambian case study showed positive aspects of SHS introduction related to education. *Education* consisted of formal education as well as information and learning processes taking place as a result of exposure to TV, other media, books, and other texts.

In the households with school-aged children (5-12 years) children studied at night in more than 80% of the cases, while the same figure for children in neighbouring households was 53%. Many respondents said that the children had changed their study routines, and now with the improved lighting spent more time reading and writing. In addition, the children in households with solar services are more exposed to news and radio broadcasts, as TV and radios are more frequent.

The user surveys showed that the respondents had experienced an improvement of children's school marks. This result was, however, not verified through checking the children's actual report sheets. To try to triangulate these claims, quantitative data on the results from third term tests were collected from one school. Each pupil was paired randomly with a classmate of the same sex without solar at home. Answers for a total number of 32 student-pairs were collected. In 2001 the students had just received the systems, and in 2002 they had had them for one year (Figure 21).

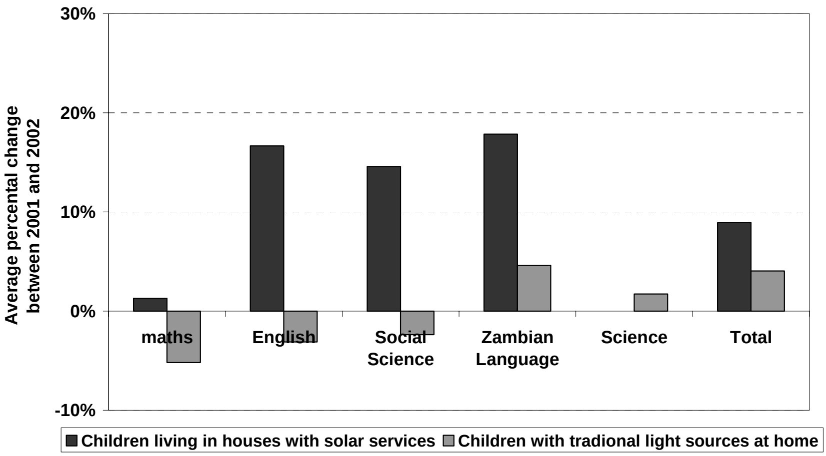


Figure 21: Average percent change in children's third term test results between 2001 and 2002 (Ngonga Lundazi)

The third term results did not show any statistically significant difference in terms of improved results between the students with and without SHS at home. At the same time, the results indicates that the average student with solar at home had increased his or her results more than the classmate without solar at home. English is the subject which shows the largest gap in the average improvements between the students with and without solar at home. A factor that may influence this improvement is the increased exposure to the English language that children with TV and radios at home will have. The national broadcast of both TV and radio are often in English. Another indication from the third term results was that girls stood out as the group with strongest improvements, compared with boys. During the daytime many are involved in domestic chores and have difficulties finding time to study. Boys, on the other hand, have somewhat more freedom in this sense.

6.4 Consequences of access to solar energy services on institutions and communities

Access to grid electricity is generally very restricted in rural areas of Zambia. Distribution lines are only extended outside the town centre when there is considered to be a sufficient density of households/clients. The process by which the distribution lines are extended to cover more of the areas around the towns, is generally slow. In comparison SHS are not dependant on basic infrastructure, and the fact that they – within the power range they represent – can supply energy to appliances that can supply basic energy services, SHS can represent an alternative to grid electrification in rural areas. People in the areas where the ESCO:s are operating are aware that it is not likely that their rural area will be electrified in the near future. In an interview with Chief Ndake in Nyimba he argued that:

> *"the Boma should have hydro [grid electricity] while outside the town solar is a good alternative."*

Access to grid electricity in the towns would mean that people in the area would have access to services that supply more power than SHS can generate at present.[22]

When the expected load is limited, i.e. only some basic energy services can be supplied, distributed electricity generation will be an attractive way to solve the immediate energy requirements. Solar power can supply the energy requirements for a household in areas where the grid is not expected to arrive within the next 10 or 20 years. I argue that, even though it only supplies limited power, introduction of solar technology must be seen as a component of infrastructure development. Infrastructure refers to an underlying system that supports and organizes a society. The energy system infrastructure consists of the generation, transmission, and distribution facilities. In addition to these, the institutional setup of organisation is included. Distributed generation, such as SHS, becomes an element in this system that will not be interconnected to the large system. At the same time, these distributed generation facilities will be part of the system that provides important energy services for the functioning of society.

Chiparamba is a community about 25 km west of Chipata, which consists of about 200 households with some shops, a health clinic, and other institutions. In 2004, a Minor Field Study (MFS) was carried out in Chiparamba that looked at how people/clients had opted for either solar or the electric services provided in the electric grid (Hedin 2004). Chiparamba was electrified with financial support from the Rural Electrification fund some years prior to this study, and at the time of the study

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[22] Nyimba did not have any grid electricity at the time of the interview, but today there is an extension line from Petauke to the town.

there were 24 grid customers. CHESCO operates 15 SHS in this community. Two reasons given for the low number of grid customers were the unreliability of the services received from the grid and the long waiting time between applying for a connection and receiving it. The reliability of the energy services from a solar energy system was held up as a positive feature of the solar technology, despite the fact that the electricity tariff for small households will normally result in a lower bill than the monthly fee paid for the solar electric services (Gustavsson 2004).

The drawbacks of solar are that it targets mainly middle and higher income groups in the rural setting, and the low power generated. Reaching the poor is not seen in the ESCO project as a goal in itself. This because the ESCO:s seek customers with a steady income who can afford to pay the monthly fee. At the same time, grid electricity will not reach the poor either, unless it is more or less totally subsidised.

A number of schools, offices, and health clinics are found among the clients of the ESCO:s. The schools with a contract with one of the ESCO:s will get a more powerful light source that enables the school to provide night classes and special teaching for students. In a number of these schools the power from the solar energy system was used to operate a cassette player during weekly dances with the students and to play instructional audio tapes in class. One of the problems is that the luminance at the place for reading was low due to the ceilings in classrooms being higher than in ordinary houses. There are no TV:s or computers operated in these schools with solar power. At the health stations the improvement of the lighting was the main advantage brought up in the interviews. Vaccine refrigerators were not found, but could be operated on the system if an appropriate size of refrigerator was used.

Some schools and health centres in the areas where the ESCO:s are operating have been supplied with solar technologies through other channels. Unfortunately, it is not uncommon to find relatively large solar energy systems that are not used due to various technical problems. Examples were found in all three areas where the ESCO:s are active. The experience is that when the technology starts malfunctioning, there are no maintenance routines or knowledge about where to turn to get the systems repaired. At this point, when the system is not used and the interest in the technical artefacts from those benefiting from them is low, the chance of permanent damage or theft increases.

In those cases where a contract had been signed between the ESCO and an institution the systems have been kept operational, and servicing has been performed on regular basis. The systems have also been used in the daily work, and the services supplied have been appreciated. Payments of the monthly fee have been organised in two ways. Either they are managed locally through funds like the PTA (Parent Teacher Association) or more central institutions, like the Zambia National Service headquarters in Lusaka. In the cases where local funds are used, it is easy for the ESCO to maintain a close relationship with the client and the persons who control and manage the monthly service fee. When the fees are raised and new contracts need to be signed this can be communicated in person. When linking up with centralised payments for the fees there is much more bureaucracy involved. When re-signing contracts, these have to be sent to a central location.

In Lundazi a ZNS camp was fully electrified through the installation of 63 SHS in the servicemen's houses, the officers' mess, and offices. The payments were managed from the ZNS headquarters in Lusaka. What was first seen as an efficient clustering of SHS later became problematical. First the payments were paid without problems as long as the first contract was valid, but when a new contract was to be signed the fee had to be adjusted for inflation, which created problems, as it became a central issue handled in Lusaka. As there were 63 systems that were paid through one source, the delayed payments quickly added up to large amounts. The communication between LESCO, a small rural company, and the ZNS officers in Lusaka was slow and subject to a lot of bureaucracy. In addition, the users in the camp did not view themselves as the clients of the ESCO:s as the systems installed in the houses came with the post. The installations at the camp were continuously tampered with; for example the battery boxes were made accessible and direct connections to the battery were common.

7 Discussion – The role of Solar Home Systems in Rural electrification

The introduction of solar home systems will affect people's lives in many different ways, and will also have implications on many different levels in the society. The electricity generated in the solar panel can deliver energy services that create new opportunities that will have implications for their livelihood systems, both positive and negative. Apart from more direct benefits, such as improved lighting, safety, longer working days, the SHS system also introduces the need of understanding the technology and to have knowledge of operation and maintenance. Introducing solar systems into the livelihoods of people, and providing solar energy services to institutions, creates new situations for the people to act on. These actions are not dictated by the technology, but neither are they unconnected to it, as the technical systems have built-in restrictions in terms of, for example, the cost of access and the amount of energy available. The results of the study in the Eastern Province show both the strengths of the use of technology as a facilitator of development, as well as its weaknesses.

The main argument put forth in this thesis is that there is more to solar technology than the electricity generated in the solar panel. The solar energy services are what generate the impacts seen. But there are also other impacts brought about by the need to support and regulate the technology. The discussion here is based on the four service functions presented in the conceptual framework (Figure 2), and illustrates the connections and linkages between these functions. A discussion based on the project set-up will also be made.

Provisioning Energy services

This study showed that many of the activities that have been enabled through access to solar electric services are domestic chores, or chores that earlier were done at other times during the day. These changes were shown not to generate much direct income. To argue that the project led to a *vast* numbers of new income generating activities to provide income to the households is not a valid conclusion, as more commonly energy services are used for leisure or *cultural energy services*. The reasons are, among other things, to be found in the category of households that are targeted by the ESCO:s.

In some households, however, the energy services were used for productive uses and income generation. Some respondents in the surveys also report that they have considered starting some income generating activity linked the access to solar electric services, examples were giving private teaching or opening a shop. It is due to the improved lighting that these options are considered. There is a possibility to make use of the dark hours. Shops report longer opening hours. Whether this yields increased sales is not known, and even here the result in terms of net-income of the household is not known. The opportunities provided by the solar services in terms of, for example, watching movies or sitting and listening to the radio during the day can have negative economic consequences.

The limited power supplied by a solar energy system restricts the possibilities for what the energy services can be used for. Users mentioned the possibility to refrigerate drinks and produce ice as an option for income; another was to have a barber shop and operate various hairdressing machines. Operating machines that produce heat or cold will require relatively large quantities of energy in most cases. This requires larger panels in order to balance the energy requirements in the system, with ensuing cost increase. But a hair clipper with a power rating in the range of 10-30 W should be possible to operate on a solar system depending on the daily use. This is not perhaps an obvious appliance to operate on a solar system, but hair clipping is an electric service that could render an economic income. A suitable machine would have to meet with the demands set by the equipment, e.g. operating on 12 V DC. The problem was that the knowledge of the actual possibilities through the electricity supplied from the SHS is not explicit to the users, or the ESCO:s. The training, part of the support function, has been focusing on the basics of technical training, management and economics. Advanced courses have been given on technical issues, but courses on improving the ESCO business, options to offer clients new energy services and creating new markets has not been given.

Comparing the expenditures that the potential clients had prior to receiving SHS and after, show that the money allocated to energy services was almost the same (Table 3). The results suggest that there is an improvement in the quality of the energy services received for the same amount of money. The households will, however, not be able to save money by cutting down on these SHS expenses, which would be possible if using dry cell batteries and candles to supply energy services. So even though the solar services are rather expensive compared to the power purchased from the national grid, it is still cost efficient for the households that have opted for solar power. The introduction of SHS does not bring about a total change in energy use in most cases. Considering the type of expenses displayed by households with solar systems clients still use dry cell batteries and candles to some extent. Some of these costs would be possible to cut utilising solar electricity. There could be a need to alter the voltage to be able to power, for example, a small radio. Consideration has to be taken to avoid efficiency drops. The ESCO:s have a role to play here. They could offer their advice to customers on how to make the most of the services that the solar system can provide. This requires knowledge, willingness to perform this task, as well as the customers accepting that the ESCO:s carry out this task. During the study period some ESCO:s had informal activities in line with this, mostly taking place during the monthly visits by the technician.

Regulating Energy services

From an engineering perspective, a solar energy system can be viewed as an input-output device where the transformation of solar irradiation to electricity takes place inside a black-box (the black box is discussed in for example Sigaut 1994; Sismondo 2004). The contents of the black-box and the processes taking place inside do not need to be known to the users of the technology, but at the same time the use of the system will have consequences for the life-span of the technical components that comprise the technical system inside the black-box. As was noted in this study, the battery is not fully protected against damage by the technical functions provided in the regulator. The capacity of the battery was therefore reduced drastically in three years time. As battery costs will become one of the most costly expenses of a SHS over the full period of use, there are reasons to try to improve the life-span of the battery. One possibility, based on the findings in the Eastern Province, is to add an indicator of the battery charge status that could be placed outside the battery box. The information conveyed by the indicator should be easy for the user to understand and act on. The indicator would make it possible for users to learn more about some of the system variables inside the black-box that determine the functioning of the technical system.

A photovoltaic system contains a number of expensive components. Even though the solar modules have exhibited a reduced price per Wp since the 70s (Gustavsson 2007a)[23], the cost is still high considering the expenditures for other items in the rural areas. In addition to these initial capital costs, the battery will have to be replaced after some years, and there are costs for maintenance and replacement of faulty components, such as lamp fittings or lamps. The costs can also be high because proponents of the technology often argues that the quality of the system should be high, thus often more costly components are proposed, rather than low-cost alternatives. The trade-off between quality and costs can be a problem if poor people are to be targeted. With high quality the cost will increase excluding people from accessing the technology. In the Zambia PV-ESCO project there has not been

[23] The cost per installed Wp describes a typical experience curve (de Moor *et al.* 2003; Moner-Girona *et al.* 2006). The conclusion drawn is that with decreased costs poor people will eventually be able to afford to access it. The panel is, however, only one of the components in the system, and the battery will from a life-cycle perspective comprise a substantial part of the total cost of the system.

any low-price alternative to the 50 Wp systems installed. It would, for example, be possible to deliver only electric light services to several households by not connecting any appliances other than lamps. As improved lighting was by many clients seen as the most important benefit of the system, this would possibly be an attractive alternative energy service. The monthly fee would then be split up between the households, which could enable households with less income to benefit from the electricity services. One example was found outside Lundazi where a Peace Corps volunteer had installed one of her lamps in a neighbouring house so that those living there could enjoy the light. She was, however, the one paying the monthly fee. Sharing a limited energy source between many users will create a new set of challenges in terms of managing this limited resource and creating a system of usage that is sustainable. With a selection of components that will deliver energy services with low energy utilisation, training of the users, and positioning of lamps in spots that are useful to the users an alternative solution to an asked for energy service could be brought about. The target group for this cheaper type of services is households with low incomes. If this is going to be implemented there needs to be initiatives taken already in the funding and credit mechanism giving incentives for the ESCO:s to approach other targets groups than the middle and high income groups in the rural setting.

The solar home system represents a new technology introduced to the users, and knowledge and skills are needed to operate and maintain it. The ESCO:s have been offered training courses for their staff in both technical issues and management. These courses have been highly appreciated by the people attending the courses and the ESCO managers. The technical training, provided by UNZA, included both lectures and practical training. The lectures provided a background of formal knowledge about how to design, operate, and maintain a solar energy system. The training provided both theoretical and practical skills as well as practical aspects of O&M, and preparation the work in the field. Judging from the status of the solar energy systems the transfer of knowledge to the ESCO:s seems to have been working relatively well. At the same time further training is needed on various aspects, both technical and business oriented. Training courses cost money and the costs have to be covered somehow. The Zambia PV-ESCO project has arranged courses funded through the project funding. A problem has been that that knowledge and skills attained is personal, and when people leave the ESCO, or there is a change in personal policy of the ESCO, there is a loss of know-how in the company. The ESCO:s can handle some of the personal losses, but my experience was that this was a difficult task as even the more senior technicians were uncertain on certain more technical issues and routines. The first course given through the Zambia PV-ESCO project included hiring one international expert within the solar electrification arena, Mr H. Wade, and he gave the participants insights and knowledge from his years of working with solar electrification in rural areas.

Cultural Energy services

Those households that have received solar electric services in their homes have had what would best be described as a general improvement in their living standard. This general improvement is part of the human capital of the livelihood assets, and is expressed in *"a more modern way of life"*. One client living in a school camp outside Nyimba said that *"today it is like living in the town"*. In the same camp, another person without solar said that *"now he will sit and listen to music the whole day, I can hear it from my house"*. This man also said that he would have liked to sign a contract with the ESCO himself, and listen to his own music, but there were no systems available. Another impact of solar electric power on human capital is the improved conditions for studying. Children in households with SHS have much better lighting than can be obtained from candles. They can also use light more freely, as the access to the service is not dependant on energy units but rather on time. Once the fee has been paid, the service can be used freely. Even the adults in households with solar electric services reported reading and writing more than their neighbours did. In addition, people have the opportunity to access information from TV to a greater extent in households with SHS.

Training and informing the users/clients in how they are supposed to use, operate, and maintain the SHS has been made a task for the ESCO:s. Normally the technicians have demonstrated for the clients how to use the system at the time of installation. Along with this oral presentation, a short written list of dos and don'ts has been handed out. The clients are not supposed to perform any direct maintenance such as cleaning the modules or checking battery acid, but they are involved in what can be labelled preventive maintenance (Lorenzo 1997). This maintenance is done to keep the system in good working order, and effects are often difficult to observe as there is no direct feedback on the effect of the maintenance. Examples of preventive maintenance are removing dust from the glass surface of the solar module or operating the system in such a way that the battery gets occasional high SOC. Cleaning the solar module is done by the ESCO technicians, while maintenance in terms of occasionally fully charging the battery is something that is done by the clients. Both these actions will improve the output of the system over time, but the results of the actions are not directly visible. This suggests that clients should be identified as being involved in maintenance in fee-for-service projects and not only be considered users. Thus the transfer of knowledge to the clients should require more attention in the project design and set-up.[24]

The people working for the ESCO:s have also benefited from the work with supply of energy services. The employees receive a salary and have had the opportunity to attend training courses. The technicians working in the ESCO:s have, through the training courses, increased their knowledge of electrical installation and maintenance, and are now attractive for other jobs in the energy sector. The ESCO:s are playing a role as energy suppliers in the area where they are operating. The people working with the ESCO have created a position in society for themselves. It seems that some of the employees are improving their social networks as a consequence of their employment.

Schools, health clinics, and other institutions that have a contract with an ESCO can offer new services to the people and customers that they are serving. The most visible change is they can offer energy services in the evening and during the hours of darkness. One school in Lundazi had, for example, organised night classes and students preparing for their final exams could come and practise in the evenings. Classrooms were also occasionally used for community activities. This makes people to access education and take part in community decision making. It is not dependent on whether or not the household can afford a separate service fee to the ESCO.

The technology does not dictate what will happen once an institution such as a school receives solar energy services. In the Zambian case study, all of these institutions had actively sought to sign a contract with the ESCO. This suggests that considerations had been made as to what the solar services would be used for, and how this could benefit the school or institution. Again the outcome of the access to solar electric services is not determined in advance. The institution will have to act on the new situation. A solar energy system at a school might lead to the headmaster's office being equipped with electric light, which can improve his/her working conditions, or it can provide opportunities for evening classes.

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[24] This view can be contrasted with Kenya where solar energy systems are purchased over the counter and little attention is given to transfer of knowledge (Hankins 2002). The systems are functional, and people are willing to purchase and maintain them. But there is one point that I would like to make here. With privately owned systems, the users themselves will have to pay to replace components that do not work, while in the ESCO setup the users only purchase the service, and the ESCO will have to replace components. If the ESCO can get the users to carry out preventive maintenance, they can improve the operation of the systems and possibly also prolong the lifetime of some of the components, which will have positive economic benefits for them.

Supporting Energy services

I think it is fair to say that the three ESCO:s found in the Eastern Province of Zambia would not have been established if it had not been for the initiatives taken by the Department of Zambia and the funding made available by Sida. The funding and support given to the ESCO:s has showed that it is possible to supply households, institutions and shops with solar electric services. But at the same time, this experience has showed that operating a development strategy with a utility model for introduction of solar energy services will be lined with decisions and structures that are more commonly associated with top-down and grant-based implementation models. For example the need to carry out official procurement, instead of letting the ESCO:s have control of it, created a situation where the hardware came in from outside to the areas where it would be installed. The access to loans has been regulated by routines in the DOE and Sida, rather than the needs set by the ESCO:s. The ESCO:s have operated according to how they have experienced the situation. One of the major setbacks has been the problem of initiating a process of expansion in the number of systems operated by the companies. One reason for this was that the ESCO:s have known that new loans were going to be allocated through the project, which would mean a quicker means of expansion than using money generated from the business. As release of new loans took long, due to administrative and bureaucratic reasons, there has not been much expansion. Using companies for implementation requires that the structures supporting the development process, typically the project management, can live up to the dynamics and rather quick decision making that are found in companies and among users. The case study displays the problems foreseeing the pitfalls related to existing structures and routines outside the control of the project.

The companies that have been established through the project have proved themselves able to provide maintenance of the solar systems and make a profit from the solar energy business. These companies have gained experience and knowledge on installation, operation, maintenance and repair of solar systems, which can be used in continued efforts to popularise solar energy as a distributed energy source in rural Zambia. The bottleneck seems to be the lack of funds to these projects. Even though there are many people willing to pay the service fee, there is need for subsidies and support to support the process of diffusing solar technology, at least during the initial phases of the introduction. Subsidies and other incentives are important tools to provide mechanisms to reach the weaker sections in society. It is tempting to draw the conclusion that this study has showed that electrifying schools and health clinics can be successfully done through the establishment and support of local ESCO:s. But the institutions investigated in this study are a special group where most of them have arranged the payment of the monthly fee with local money, rather than centralised funds. This shows that a local initiative to get access to solar electric services has taken place, and possibly also consideration of how these services can be used. But it is also a system of paying the monthly fee that is attractive to the ESCO. The ESCO has a local representative who is possible to reach and negotiate with when the fees are raised rather than becoming one among several in a centralised administration. The Zambia PV-ESCO project shows that it is possible to include schools and institutions in the client group, but to transfer it to other parts of Zambia or to scale it up requires consideration of securing payments and that the users can find uses for the energy services supplied.

Households are the most important customer group in the Zambia PV-ESCO project. As the households are local and are able and willing to pay their bills, they will form a basis for creating a business from supply of solar services. Only serving schools and health clinics would mean more travelling, as these are spread throughout the area, and it would also mean, based on the experiences from the Eastern province, a risk for more erratic payments. Thus the utility approach of only electrifying rural institutions cannot work without consideration given to how a basis for the business operation should be formed, as well as securing safe payments. The conclusion would be that a solid base of household clients is needed to secure a steady income with institutions as a special group of users.

The ESCO technicians have been trained to undertake maintenance and basic repairs. This was necessary as there have been technical problems and faults with the components in the systems. Some of the problems experienced could then be remedied. The training given to the technicians made them competent to handle relatively advanced service and maintenance. But when the SHS is to be commercialised training on maintenance and repair costs has to be paid by the customers through their service fees unless a scheme offering this support can be put in place as part of supporting for example rural electrification.

Training solar technicians that are not part of the ESCO:s, and offer this type of training as part of the solar project, could be one strategy to diffuse knowledge of how to sell, install and maintain solar technology to other actors than the ESCO:s. Since solar systems are available over the counter, people that have acquired the solar training could venture into the solar business and thus support the process of diffusing solar technology through commercially led models parallel to the ESCO mechanism. Presently there are activities taking place in Zambia to form a body that would act to support rural electrification, REA. This body could take the responsibility for coordinating activities within the solar sector and actively collect information and knowledge on experiences of disseminating solar PV-technology for electrification.

7.1 Assessment of the experiences of the development intervention

The Zambia PV-ESCO project is one of several solar photovoltaic projects that have been implemented in Africa. In a synthesis report on solar expansion in Africa, Hankins and Bank (2004) list a number of issues which they link to delivery mechanisms. In their presentation they put forth strengths and weaknesses of different delivery mechanisms. Below I will briefly use the issues they describe and relate them to the findings in this thesis.

The set-up process of the Zambia PV-ESCO project came at a time when several activities were taking place in Zambia concerning the deregulation of the power sector. There was an Energy Regulation Board that had the role of regulating fees and the official status of local energy companies. A technical standard for solar equipment was developed (ZBS 2000). There was also political interest in the issue of applying solar technology to rural electrification, as rural electrification was an area where little had happened during the 1990s. The existing projects were often beset with problems. Solar technology was seen as a solution to rural electrification, and applying a more market-oriented delivery mechanism was the way forward. The three ESCO:s which were proposed to be in charge of the new operation were therefore all located to rural areas. They had somewhat different backgrounds but they all saw a potential in the business that was presented for them through the Zambia PV-project administrators. For the ESCO:s to start working in the field they were dependant on loans and also training, both planned to be provided in the project.

The loans had been provided by Sida and Government of Republic of Zambia (GRZ) was responsible for handling these funds. This resulted in that procurement of equipment must be made through official channels. This created a number of problems. The plan had originally been to let the ESCO:s make their own decisions on system components based on a set of technical standards and have direct connections with different suppliers. Some of the anticipated results of this plan were: improved knowledge about equipment, establishing links between suppliers and ESCO:s, the possibility to have different specifications of systems with different clients, finally it should be more cost effective. The procurement that finally took place became time consuming and led to delays. It meant that all the systems became one size fits all, which in one sense can be deemed rational, but it could not adjust to the requirements of the client. The procurement that took place did not result in any drastic cut in prices per system.

The initial plan had been to let the ESCO:s have a high rate of repayment of the loans given. The fee paid by customers should cover running costs of the ESCO and also the repayment of the loan. The ESCO:s would get a three year deferment of repayment of instalments. The suggested 20 years was too long according to the

ESCO:s. Less time would mean higher instalments, and this led to a compromise of 10 years and a repayment level of 50% of loans given. The solar systems were still the property of GRZ and finding ways to transfer ownership became administratively problematic. As long as repayment has not started the monthly fee has basically covered running costs of the ESCO:s, and it seems likely that the ESCO:s have made a profit despite the low number of systems operated.

The project has been successful in reaching customers. The ESCO:s did not have problems finding customers. Once the solar systems were arriving there were clients who had applied and been selected. These customers were mainly households and most had a formal income in the household. A small number of farmers became customers. For the ESCO:s there was no need to select low income households that risked defaulting on the monthly fee. Some farmers would possibly have had the resources to pay for the service, but their income is not steady throughout the year. There was no incentives for the ESCO:s to target clients from weaker sections of the society and nor have there been any problems finding clients willing and able to pay the monthly fee. Soon after all the systems had been installed, a waiting list of potential clients was found in each of the ESCO:s.

Part of the managers' training was related to expand the activities. A few new systems added yearly would increase the income for the company and secure that the ESCO:s could continue their operation. It was, however, known to the ESCO managers that loans for hardware were in the pipeline, which would be a quick way to expand and therefore other ways of expanding the projects were not pursued. I believe this was major reason why the ESCO:s did not venture into new purchases.

Each year the fee should be adjusted to inflation. The ESCO:s were doing this at intervals. ERB had to approve such changes in fees. Increasing fees lead to reactions and complaints but most coped with the increased fees. Clients were aware that if they ended the contract they would not be able to find any alternative to the solar services.

The ESCO has proved that they are able to provide energy services in the areas where they operate but they operate their businesses in areas where there is no electric grid. As a result another solar project would mean a strong competitor to the ESCO:s business and clients would possibly turn to the one providing the most profitable conditions. One important factor valuing in this evaluation would be future ownership of the hardware. Clients often brought up the ownership issue as a comment in the surveys; they did not want to loose the energy services that they had gained. In the ESCO set up, clients are only paying a service fee and if they wanted to become full owners of the systems they would have to pay the full cost of it.

Included in the project set-up were a number of training activities to ensure good maintenance procedures. The training was appreciated by the technicians and gave UNZA an opportunity to take an active part in the projects. Despite the opportunity this meant for staff at UNZA, in terms of taking on own research and developing practical experience of solar technology very little such activities has been done apart from the planned (and paid) activities given through the project. Finding ways to offer solar training to people and companies outside the PV-ESCO project would have been one option to both strengthen the group of people involved in solar technology research at UNZA, as well as work for making more people knowledgeable about the potential of solar technology and how to utilise it in practice.

Training of users have been the responsibility of the ESCO:s. The study indicated that users have received basic information on proper use of the systems. The study also shows that the clients have learnt from running and operating the systems and now utilise the systems accordingly. Preventive maintenance should be part of client training, but this has not been a prioritised issue. Maintenance has been considered to be the responsibility of the ESCO:s, and technical safety functions are expected to prevent the users from operating the systems in a (too) harmful way. The study shows that batteries are damaged, indicating that preventive maintenance could be improved. Clients reported that they were interested in learning more about the proper use of the system.

Theft of the solar module has occurred, but only rarely. The ESCO:s are well known in the communities, and the clients guard the systems almost as if they were their own. With increasing numbers of systems unguarded, e.g. installed in schools and other institutions, the risk of theft might increase. The ESCO carries the risk, but would ask the client about the circumstances.

The three ESCO:s have successfully operated and maintained 404 systems over a number of years, and managed to make repairs and replace batteries when needed. The people working in these companies are well aware that faulty systems do not render an income. Examples from the areas indicate that solar systems introduced through other projects have had problems with respect to long-term maintenance. The ESCO:s have tried to form service contracts with owners of private solar systems but the costs for this maintenance have often been considered to be too high by the solar system owner. Technicians from the ESCO:s have worked with the installation of other solar diffusion activities carried out in Zambia. Put together, the ESCO:s are a resource for future activities. The companies are, however, the result of a development intervention, and thereby also formed by the history and the structures of the project. Transferring the experiences from the Zambia PV-ESCO project to other projects will necessarily have to take this into consideration.

The four groups of delivery mechanisms, and also the development strategies presented in Section 3.1, are seldom found in their pure forms in practice. There is, for example, a need for control, regulation, and to evaluate the progress and effects of a project. Each project will have its own dynamics and history that have implications for the strategies and approaches used in the project set-up and implementation. In the case of projects where there is a technology component, there can be a number of factors that influence the choice of how the technology should be promoted. Many solar PV projects initiated in the 1990s were probably initiated because the technology was seen as the solution to a number of problems associated with rural poverty and development, and that there were good possibilities to implement projects through market channels. Today the situation is similar, but the driving force for the projects is now also to be found in the carbon emissions consciousness of Europe and North America. Giving people access to renewable energy sources can reduce carbon emissions and thus be an important weapon in the arsenal used against climate change. But the fact is, if the proposals put forward are not based on earlier experiences of technology transfer, the positive effects will be hard to achieve.

One way out of this problem is to start a development process by having a *pilot project* try out new structures and functions in the introduction process. It so happens that many of the projects concerned with rural electrification through distributed generation are termed pilot projects (Turkson *et al.* 2001). This expression implies that something is being tested or tried, and it can be seen as the next step after research and development of a certain artefact or approach. Learning from the experiences accumulated in such activities is a central aim. This would also suggest that evaluation and ongoing study of the activities should take a central role in such projects. It seems, however, that the follow-up activities, as well as ambitions to study the impacts in a systematic manner, are not prioritised. It is possibly safe to say that it is not the lack of interest or capacity on the part of the projects' administrators and implementers that makes these studies based on pilot projects rare, but rather reasons such as limited possibilities to include resources for research activities in the project setup and/or that the projects are not actually *pilots* in the first place.

The studies on which the data in this thesis is based raise a number of questions regarding the issue of what one can use a pilot project for, and how the learning process from a project is used. A typical project cycle for a development intervention starts in a project identification based on a problem or specific situation. This is undoubtedly the most crucial part of a development process. If it is based on theoretical frameworks and preconceived ideas, and there is a lack of proper identification of the prerequisites and constraints of a technology transfer, the chances of successfully implementing the project are already doubtful.

8 Concluding remarks

For the users, access to energy services is what matters; supply of this or that many energy units is not. The thesis has presented results on how users take advantage of access to solar electric services in various ways. These energy services will cover many basic energy needs where the most important was good light. It is widely accepted today to focus services, thus turning from a more technology supply approach to one that takes its point of departure in peoples' needs. Challenges are still to make these projects long-term sustainable. Market forces play important roles here. But, as have been seen in this study, structures of support are crucial also to the market in order to operate and plan their businesses. The conceptual framework presented in this thesis has proved useful in the analysis of a development project including a technology component. The framework has showed that these projects by necessity will include components of technical, socio-economic and management nature. It also turns the discussion to what the services are used for and the requirements set in order to access them.

The aim of this thesis was to investigate how the introduction of solar electric technology in rural areas in Zambia affects people's livelihoods and everyday lives. The impacts of access to these solar electric services could best be described as a general improvement of the households' living conditions. With access to improved lighting household chores, reading, and writing can be done during the evenings. TVs and radios could also be utilised more freely. While the services only to a certain degree were used for provision of new goods or income-generating activities, activities related to education, entertainment and socialising were stressed by the clients as the most important. These changes will mean a lot for a person living far from the electric grid, and many feel more a part of society and urban life than before they had access to these services. The Zambian energy policy speaks of solar energy as having a place in the national energy policy (MEWD 1994). One of the ambitions of the Zambian PV-ESCO project was to investigate the role that solar PV technology and small ESCO:s could play in the national energy policy (Nordström *et al.* 2001). In the Fifth National Development Plan (GRZ 2006) solar technology (together with other renewable energy technologies) is presented as able to play a role in the development and improvement of the infrastructure in rural areas.

The socio-economic situation of households that are clients of the ESCO:s in Zambia are similar to SHS users found in other African countries (Nieuwenhout *et al.* 1999; Wamukonya *et al.* 1999; Jacobson 2004; Ranniger 2004a). Experience shows that few poor and marginalised people have access to solar services in Africa, and this has been one of the strongest arguments against continued support for electrification through solar PV programmes (Karekezi *et al.* 2002; Villavicencio 2002; Wamukonya 2007). The problem here is that most rural electrification schemes will not reach the poor either. The connection fees are one barrier, and then the monthly bills have to be paid. The power sector is a commercial sector and the companies are supposed to make a profit. In the Zambia PV-ESCO project the managers of the ESCO:s are in a position to target easy customers who they know are able to pay, which in most cases will exclude small farmers. If there were not such long waiting lists of potential clients in the area, a higher degree of risk taking would surely take place in selecting the clients, and households with less secure incomes would also be considered. The ESCO:s are working with provision of energy services in the rural areas and make a profit/living from it. In this sense they are typical energy utilities and look for the best customers. In Zambia, with less than 5% of the rural population having access to electric power, there are many potential clients who can afford to pay both the installation and monthly fee. Similar situations will be found in other projects that have a market approach to introducing the technology, as the cost to access the technology will exclude those who do not have the money.

When allocating public money to a service that is not accessible to all, several questions will arise connected to equity and empowerment of the weaker sections in the society. Offering solar services to schools, health clinics and other public institutions is one way of reaching those that cannot afford paying for solar services in their homes. The Zambia PV-ESCO project has applied a market strategy for disseminating the solar energy systems. At the same time there are several components of control imposed on the companies by the implementers that are more typical of a top-down approach. In my view, it should be possible to include more groups of people found in the rural community as target groups. But, in order to do this, there will be a need, already at the project design stage, to include mechanisms to make them desired users/customers.

In most areas where the ESCO:s are operating they are the only providers of electric power. In some cases, like in Chiparamba, Lundazi town, and now recently in Nyimba town, they have competition from the electric utility Zesco. But it is not in the town/urban areas that the ESCO:s find their customers. The ESCO:s studied are serving areas covering a radius of about 40 km from their offices. Here, the solar energy systems have become a part of the rural energy infrastructure, and have proved their worth as a supplier of basic energy services to households. The limited power output from the solar system excludes several energy services, such as heating or cooling. One option is to use multiple energy sources and create a system where different power sources are used for different purposes. For example a rural mill, operated with an IC-engine, had lighting from a solar system and could thereby prolong its opening hours. Another example is a guest house where a genset was operated for some hours each day to cool drinks and show colour TV and videos, while solar was used for lighting in the rooms.

Supplying power to for example welding or workshops with solar PV technology would become very expensive. In rural centres the grid thus plays a vital role, like Chief Ndake in Nyimba pointed out – in the rural areas solar is good, but the grid is needed in the *Boma*. The services that can be bought from the ESCO can thus be seen as a complement to the electricity provided through the national grid. Jacobsson (2004) considers the use of spontaneously diffused solar technology in Kenya as a solution in a transition period between a situation where there is no electricity and when the grid has been extended. In many of the countries where access to electricity is very limited, as is the case in most SSA countries except South Africa, the option to get access to electric services through distributed generation will be an attractive solution for many people, as grid extensions are not realistic in the near future. The distributed generation, of which solar PV technology is an example, gives opportunities to supply electric energy services in areas that are not economically viable for grid extensions.

The ESCO:s have been able to create a business based on supplying solar electric services, but they have not expanded the number of systems they operate on their own account. One of the reasons, discussed earlier. relates to the expectations of new systems delivered through the PV-ESCO Project credit mechanism. These loans have included a certain degree of subsidisation. There are several examples related to the problems of creating a market and how subsidies can hamper such a process. In Zimbabwe, for example, an indigenous industry was to be established for the manufacture of solar equipment. During the course of the project this industry flourished, but since the project was completed it has more or less vanished (Mulugetta *et al.* 2000). South Africa had a commercial market for domestic solar systems prior to the national programme, and an estimated number of installed systems of 40-60 000. After launching the government concession programme the sales dropped significantly (Ranniger 2004a). Subsidies and provision of support for development interventions can distort the situation, and instead of supporting the popularisation and transition from an *induced* to a *spontaneous* diffusion process, be counterproductive.

The Zambia PV-ESCO project period has today been ended and responsibility for continuing activities with the ESCO:s has become part of the ongoing responsibilities of the DOE. The ESCO:s are still operating the solar system introduced and clients experience the energy services supplied from these systems every day. There are presently a number of activities taking place in Zambia that relate to the formulation of new policies and plans for the energy sector, including rural electrification and formulating how solar technology can be utilised in pursuing improved energy services in the rural areas. The experiences from the Zambia PV-ESCO project illustrate the need for coordination of activities relating to provision of energy services through distributed generation, and this coordination also includes sharing experiences. Many of the projects that include provision of solar technology are found in different sectors, for example the energy, educational, and health sectors. There seems to be very little exchange of experiences between them. The newly established REA will, hopefully, take on/play a role in achieving this coordination and sharing of experiences between initiatives for rural electrification, where both grid extension and distributed generation are considered side by side.

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Appendix

Appendix 1: Final energy consumption in 1999 by energy source and sector

	Petroleum products	Coal	Electricity	Firewood	Charcoal	Total	
Households	17.2		93.6	2 739.2	580.7	3 430.7	*74%*
Agriculture & forestry	15.1		11.3	109.5		135.9	*3%*
Mining	87.2	53.5	340.2	0.1	1.1	482.1	*11%*
Industry & commerce	42.9	21.3	19.5	250.4		334.1	*7%*
Government/services	4.5	6.2	37.4			48.1	*1%*
Transport	190.8		1.2			192.0	*4%*
Total	**357.7**	**81.0**	**503.2**	**3 099.2**	**581.8**	**4 622.9**	

Figure 22: Final energy use 1999 by energy source and sector (kilo tonne oil equivalent) (DOE 2000)

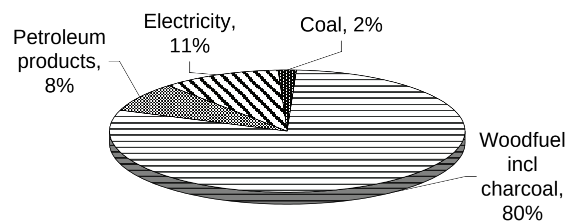

Figure 23: Final energy use 1999 by energy source (DOE 2000)

Appendix 2: 12-month Inflation rates in Zambia (2000-2005) and CPI 1990-2006

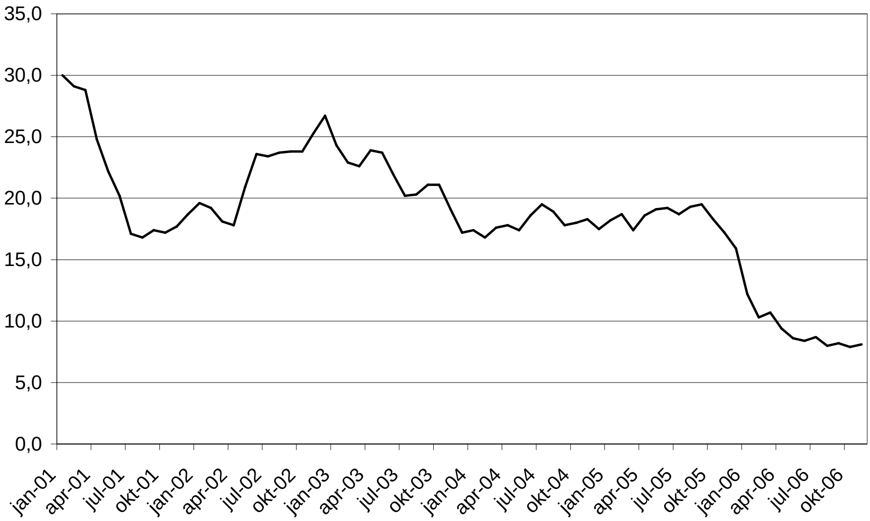

Figure 24: 12 month inflation rates in Zambia (CSO 2006)

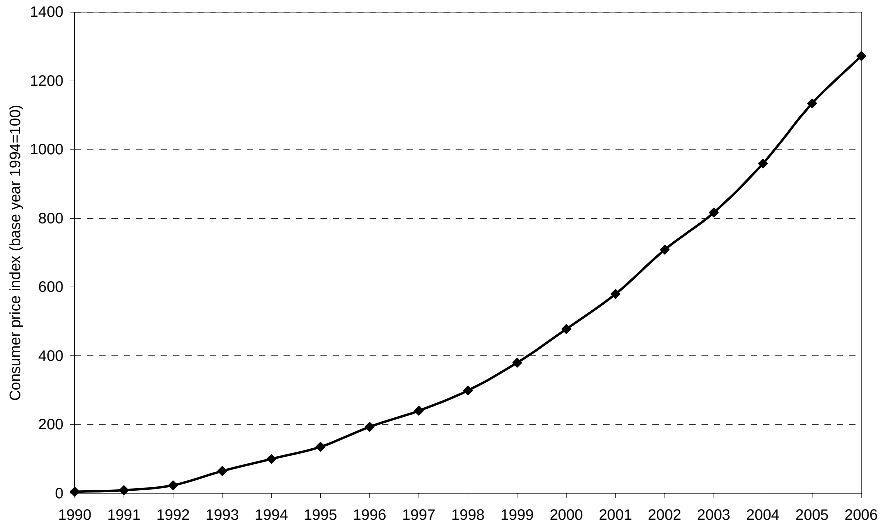

Figure 25: National Consumer Price Index (CPI) Zambia 1990-2006. 1994=100 (CSO 2006)

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24. Mathias Gustavsson *Solar Energy for a Brighter Life - A Case Study of Rural Electrification through Solar Photovoltaic Technology in the Eastern Province, Zambia*, 2008. (Doktorsavhandling)

The majority of people living in rural areas in Africa do not have access to electricity, which can supply a wide range of energy services, such as light, music, heat, and communication. Some of these energy services are already available to the people, but are supplied using another source of energy, such as biomass or petroleum products, but in some cases the services are dependant on electricity, such as telecommunications or television.

During the last 20 years solar photovoltaic technology has been used in Africa to provide rural people with electricity. This is an alternative to extending the electric grid, and is often referred to as distributed generation. But how will people's lives change when they get access to solar electricity, and what are the conditions for making this possible? This thesis concerns how a solar photovoltaic project, supported with international donor funds, has affected people and communities in the Eastern Province of Zambia.

Based on a case study of a solar PV-project in Zambia, an analysis of the impacts seen in people's daily lives is carried out. The thesis also examines how the implementation of the solar project will have an effect on the outcomes and results seen.

Mathias Gustavsson has previously studied diffusion of small scale biogas technology in India. With this study on solar technology in Zambia he focuses on a case where, instead of a top-down strategy for diffusion, a more market-driven implementation has been used.

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