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Investigating Technological Complexity in the Design of small-scale, off-grid Photovoltaic Systems in Rural Tanzania

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PIA HENOCH
JESSIKA STEEN ENGLUND

Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
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PIA HENOCH & JESSIKA STEEN ENGLUND

Department of Energy and Environment
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone + 46 (0)31-772 1000

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ABSTRACT

In this Master's thesis the phenomenon of technological complexity in the design of small-scale, off-grid photovoltaic (PV) systems in rural Tanzania is studied. Interviews were carried out with technicians, PV company employees (PCEs) and energy sector stakeholders (ESNs) during a nine-week field study in Dar es Salaam and the Ruvuma Region. Sites with small-scale, off-grid PV systems in Ruvuma Region were also visited and studied during this period.

The concept of technological complexity is developed and investigated through literature studies, interviews, site visits and by the analysis of the result. The concept of technological complexity is studied and analyzed at two system levels; first, the technical system level, where the hardware and software of the PV system design is in focus; and secondly the stakeholder system level, where the stakeholders, who design, implement, use, operate and maintain the PV system are studied.

The result shows that the all three stakeholder groups emphasize seven main considerations, related to the two system levels, to take into account when designing small-scale, off-grid PV systems. At a technical system level, four main considerations are identified; 1) choices of technology and components; 2) system sizing; 3) protection of the system and in particular the battery; and 4) quality in components and installations. At a stakeholder system level, three main considerations are identified; 1) affordability; 2) education, capacity building and awareness raising; and 3) user friendliness, maintenance and responsibility.

One of the main considerations at a technical system level is the choice of technology and components. During the study, two design approaches were identified to diverge from the typical choices of technology and components in a standard PV system design. One approach is to use locally assembled components, instead of OEM (original equipment manufacturer) components. The other approach is to integrate a remote monitoring- and controlling system (RMCS) in the PV system design.

The benefits and drawbacks of the two approaches are analysed in relation to the seven main considerations. Further, the level of technological complexity of the two approaches is analysed by comparing them to a standard PV system. Locally assembled components are shown to have a low level of complexity at a technical system level, while the same is high for PV systems with RMCS. It is found that a low level of complexity at a technical system level can lead to a high level of complexity at a stakeholder system level, and vice versa. It is also found that the complexity level is different depending on which stakeholder perspective is taken on – user-, local technician- or company perspective.

It is found that the concept of technological complexity can serve as a tool to analyze the potential for technology transfer, as well as when designing PV systems.

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ABBREVIATIONS AND ACRONYMS

A – ampere
AC – alternating current
BOS – balance of system
DAS – data acquisition system
DC – direct current
DOD – depth of discharge
ESN/s – energy sector stakeholder/s at national level
LAN – local area network
LED-lamp – light emitting diode lamp
LRTC – Lighting Rural Tanzania Competition
MEM – Ministry of Energy and Minerals of the United Republic of Tanzania
MDGs – Millennium Development Goals
MPPT – Maximum power point tracking
NGO/s – non-governmental organisation/s
PCE/s – PV company employee/s
PPP – point-to-point phone connection
PV – photovoltaic
PVSC – PV sensor cell
PWM – Pulse Width Modulation
RAM – rechargeable alkaline manganese
REA – Rural Energy Agency
REB – Rural Energy Board
REF – Rural Energy Fund
RES – renewable energy systems
RMC – remote monitoring and controlling
RMCS – remote monitoring and controlling system
RMS – remote monitoring system
SC – solar controller
SHS – solar home system/s
Sida – Swedish International Development Agency
SLI battery – starting, lighting and ignition battery
SOC – state of charge
TAREA – Tanzania Renewable Energy Association
TZS – Tanzanian Shillings
UN – United Nations
USD – US dollars
V – volt
VAT – value-added tax
VETA – Vocational Education and Training Authority
W – watt
W_p – watt peak
WB – World Bank

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1 INTRODUCTION

Access to modern energy services is an important component in strategies that can improve people's living conditions by helping to promote social equality, economic growth, improved health care and environmental sustainability (United Nations Development Programme, 2005). Access to electricity is of great importance for different parts of the society, such as hospitals/health care, schools, expansion of businesses and single households (Johnson & Lambe, 2009). In year 2000, the eight Millennium Development Goals (MDGs) were set forth by the United Nations (UN), and endorsed by 192 nations with the aim to reduce poverty in the world (United Nations Development Programme, 2013). Energy services are not the main target of the MDGs, however it can be argued that countries cannot meet the MDGs without energy services of adequate quality and quantity (Modi, et al. 2006).

At least 1.6 billion people in the world do not have access to electricity; people living in rural areas are especially deprived in this aspect. About 4-5 % of the rural population in Tanzania have access to electricity through the national grid and the grid is unlikely to be expanded at a large scale in the foreseeable future. The return of investment for expanding the electricity grid in rural areas would be low because of the investment needed, spread-out, low-density population, under developed infrastructure and low ability-to-pay in rural areas. Hence, to enable the expansion of electrification in rural areas, off-grid alternatives can play an essential role (Ahlborg, 2012). Off-grid electrification can provide a solution for low-demand users at a lower cost, compared to grid extension (Reiche, et al., 2000).

One of the off-grid technologies identified to have a large potential in Africa, since many years, is photovoltaic (PV) technology (Bugaje, 1999). Over the past years the PV market has grown rapidly in Tanzania, and in 2009 it was estimated that 0.6-1 % of rural households were using solar energy as their main electricity source (Ondraczek, 2013).

1.1 Introducing new technology in developing countries

In the rural energy literature several ideas are presented on how to provide rural populations in East Africa with off-grid electricity and about which technologies could be long-lived and appropriate (International Energy Agency 2012a; Ahlborg, 2012; Murphy, et al., 2009; Muntasser et al. 2000; Karekezi and Kithyoma 2002).

Wilkins (2002) describes technology transfer as an important tool to bring renewable energy technologies to developing countries. She emphasises the importance of building knowledge locally and articulates some barriers to this much-needed transfer. Transfer of new technology to, and within developing countries can be understood through different viewpoints. Various stakeholders, such as private companies, the government, donor organisations and non-governmental organisations (NGOs) have different goals. This affects the approaches used in practice when it comes to electrification of rural areas in developing countries. From the private companies' viewpoint the goal is often to sell their own products and find new customers. The role of the governments should be to find solutions that benefit society as a whole, and support technology that can contribute to raising the rural population's standard of living. Donor organisation and NGOs can have a broad spectrum of goals often applying a top-down approach, where the donor identifies the needs of the beneficiary and implements what seems appropriate to the donor. This top-down approach does not always meet the needs of the beneficiary in a desirable way (Wilkins, 2002).

1.2 The impact of choice of PV system design

The topic of this Master's thesis was formulated in the context of technology transfer, and different approaches regarding PV system design. The question was raised if there exist PV systems with varying technical designs in rural Tanzania, or if there only exist PV systems with a similar standard design. If there are different types of designs; what levels of complexity do the different designs result in, and how does the design affect the stakeholders close to the PV system? How do different PV system designs affect the longevity of PV systems in rural areas?

From an engineer's point of view the question is raised if there are any special design choices or approaches, as regards technology, which could result in more appropriate PV systems in a rural context in developing countries. In a standard off-grid, small-scale PV systems the main components are the PV panel, battery, charge controller, balance of system (BOS) components and sometimes an inverter. The definition of a standard PV system design, and components from original equipment manufacturers (OEM), are further described in chapter 4. From an engineer's perspective a standardised PV system with its basic components can probably be considered as rather simple to design, implement and maintain, given that the basic knowledge and understanding is integrated (Wenham, et al., 2007). However, seen from the rural end-user's perspective in developing countries, a PV system can be seen as a high-tech system to use and maintain. Hence, what appears simple to one actor, might not be simple to another actor. Since the designer and the user of a PV system perceive the complexity of the system differently this might affect the operation phase of the system. An explorative approach has been applied throughout this study to address how the complexity of the technology used in a PV system, in interaction with surrounding stakeholders, could have an impact on the long-term operation of a PV system.

1.3 Different approaches when implementing PV technology

An example of a PV system design with a more innovative design that has served as inspiration when developing the topic for this study is a project called "SharedSolar", developed by the Modi Research Group at the Earth Institute, Columbia University. This project is interesting since the SharedSolar concept adds several aspects to the standardised PV system. SharedSolar has introduced more advanced hardware and software to the PV system, such as shared electrical metering and account management technology which combines four technologies; stand-alone PV or diesel-PV hybrid, pay-as-you-go payment system (by mobile phone, scratch cards or internet), remote metering and a web-based management system (SharedSolar, 2013). This example of design can be considered to be rather "hi-tech" and more technically complex, compared to a standard PV system.

An example of “lo-tech” PV system design, with a lower technical complexity compared to a standard PV system, is when local inhabitants assemble the PV system components themselves. In Barefoot College’s solar projects the approach is to train grandmothers in rural villages to become solar engineers and teach them how to build PV systems. The idea is that the local knowledge and skills should be empowered in first hand, before hiring competence from outside the area to perform PV installations (Barefoot College, 2013).

SharedSolar and Barefoot College are two examples of different approaches to PV systems designs, with varying technical complexity, with the goal to bring electricity and PV systems into developing countries. But what type of technology would be more appropriate to increase the electrification rate in the context of rural Tanzania – “hi-tech” or “lo-tech”?

1.4 Introduction of technological complexity and two system levels

A definition of “technological complexity”, relevant to this area of research, is developed in this Master’s thesis to be able to address the interaction between stakeholders and the PV system. The topic of interest is how the design of a PV system can have an effect on this interaction. Existing concepts concerning technology and complexity have been used to investigate what importance technological complexity might have in this specific context. The concept of technological complexity developed is analysed at two system levels; first at the “technical system level”; and secondly at the “stakeholder system level”. The “technical system level” refers to the physical PV system, including hardware with potentially integrated software. The “stakeholder system level” comprises the whole system studied, including the surrounding stakeholders and their relations to the technical system. A key issue studied is if there are any special choices made, or approaches used, by different stakeholders when designing PV systems, which are mentioned as arguments for easier planning, installation, operation and maintenance of the PV system. Furthermore, it is studied what effect these design choices/approaches may have at the two system levels. Firstly, how technologically complex the PV system becomes, in terms of hardware and software. Secondly, what impact different types of design might have on the complexity at a stakeholder system level.

1.5 The importance of a stakeholder approach

Desk and empirical evaluations including experience from introduction of PV systems and new technologies in developing countries emphasize the importance of the participation of local people when an off-grid energy system is integrated. Many donor projects have failed after some years due to, among other things, failure to integrate the local stakeholders, users and technicians, on site in the process of designing, implementing and operating the electrical system (Mulugetta, et al., 2000; International Energy Agency 2012a; Murphy, 2001). Furthermore, the literature highlights that the level of competence and knowledge required to operate and maintain a PV system should not be underestimated, so that users/technicians on site can be able to understand, repair and handle the maintenance of the system (Wilkins, 2002; Ulsrud, et al., 2010; Murphy, 2001; Kivaisi 2000), if it is assumed that the technology requires management on site rather than remotely. Furthermore, there are many challenges in the institutional and organisational structure. In the long-term perspective it is necessary that the PV market grows (Muntasser, et al., 2000; Mulugetta, et al., 2000).

The stakeholders who interact with the PV system influence the functionality of the PV system. Hence a stakeholder approach is needed to assess the consequences of certain design choices in a PV system. The stakeholder perspective is in this Master's thesis addressed by studying the "stakeholder system level".

Stakeholders linked to the PV system considered in this study are PV companies, PV shops/dealers, local technicians and owners/end-users. These are the stakeholders closest to the technical system in the rural area, who are the ones often involved in the design, installation, maintenance and usage of the PV system. Also employees at universities, governmental institutions and donor organisations are considered as stakeholders in this study, since they can play an important role in both planning-, designing, implementing and operation phases of PV systems. Furthermore these stakeholders are often involved when it comes to different donor funded projects and local capacity building, including for example training programs of rural technicians.

1.6 Aim

This Master's thesis aims to analyse what are the main considerations, choices and approaches of different stakeholders who influence the design of off-grid, small-scale, photovoltaic (PV) systems. The question of particular interest is if these design choices are linked to the level of technological complexity at a technical- and stakeholder system level. Further, the relevance of the concept of technological complexity is also addressed in the context of PV system design and technology transfer.

We introduce the work with our definition of technological complexity in chapter 2, where the research questions are also presented. We define technological complexity as a concept concerning both the technical system level and the stakeholder system level. A conceptual model and definition of technological complexity is developed, which is used to analyse different stakeholders' approaches and choices of design in relation to technological complexity. Stakeholders are the actors expected to design, promote, invest in, implement, maintain and use the PV system. The stakeholder groups of particular interest for this study are; PV technicians, PV company employees (PCEs) and energy sector stakeholders on national level (ESNs), since these have an experience of, and can influence, the design of PV systems.

1.7 Delimitations of the study

The research questions in this Master's thesis focus on off-grid, small-scale, PV systems, with special emphasis on SHS, in the sizes below 0.5 kW_p maximum PV effect. The research questions focus on the technical design of PV systems in rural Tanzania, and its consequences. The interviews conducted have been limited to interviews with actors working in the area of renewable energy and PV technology in Dar es Salaam, the economic main city of Tanzania, and PV technicians in Ruvuma region in southern Tanzania.

Environmental aspects have not been taken into consideration. Neither have social effects such as productive use, gender aspects or social welfare connected to access of electricity been studied. One underlying assumption in the context of this Master's thesis has been that the stakeholders around the PV system have the goal that the technical system should be functional and deliver reliable electricity for its users during the planned lifetime of the system.

There is extensive literature written on barriers and success factors on how to provide rural electricity in rural areas in developing countries. This Master's thesis is only in limited aspects relating to the barriers and success factors connected to how to make PV systems in rural parts of East Africa operate successfully. Instead, focus is put on design choices and if and how technological complexity has an impact in this specific context. When addressing the question of technology transfer, the analysis is also restricted to the context of rural Tanzania.

1.8 Structure of the report

This thesis has ten chapters. The research topic is introduced in chapter 1. In chapter 2 the two system levels and the concept of technological complexity, relating to systems theory, are defined. The research questions are also presented in chapter 2. Chapter 3 describes the methods used for the thesis. Chapter 4 describes relevant technical aspects relating to the topic of small-scale, off-grid PV systems in terms of hardware and software. This is the base for what is referred to as the "technical system level". Chapter 5 summarizes literature especially relevant for the research topic, concerning design of PV systems and technology transfer in developing countries. This is the base for what is referred to as the "stakeholder system level". Chapter 6 continues with a description of the Tanzanian PV market and stakeholders relevant to the study. In chapter 7 the results of the interviews and observations at site visits of PV systems are presented, and an analysis is given in the light of the research questions. Recommendations for future studies are given in chapter 8. Finally the conclusions from the study are presented in chapter 9.

2 THE CONCEPT OF TECHNOLOGICAL COMPLEXITY AT TECHNICAL- AND STAKEHOLDER SYSTEM LEVEL

In this chapter theory regarding systems and technology is presented, with the aim to put the photovoltaic (PV) system into a context. Two different system levels – technical- and stakeholder system level – relevant to the study are described. The concept of technological complexity developed is also introduced and defined. A conceptual model created as a base for the exploration of the concept of technological complexity is presented. Finally, the research questions of the study undertaken are put forward.

2.1 Theory of technology and systems

A technology can be described as consisting of two aspects; hardware and software. The hardware aspect means the tool that embodies the technology as a physical object or material. The software aspect is the tool's information or knowledge base (Rogers, 2003). In the case of the technology; small-scale, off-grid PV systems, the components like the PV panels, batteries, charge controller, inverter and other balance of system (BOS) components constitute the hardware aspect. The software aspect can be described as consisting of two main parts. One part is the knowledge needed to develop and use the technology, and the organisation of the actors surrounding the system. The second part of the software is integrated as software programs in the hardware – e.g. in the charge controller and the inverter. If a remote monitoring- and control system (RMCS) or a remote monitoring system (RMS) is used, there is a software programme integrated into it, which also would contribute to the software aspect.

The word 'system' derives from the Greek 'synhistanai', which means 'to place together'. A system means an integrated whole, whose essential properties arise from the relationships between its parts. To understand things systemically means to put things into a context to understand their relationships. When a systems approach is taken on, the properties of the parts can only be understood by understanding the organisation of the whole (Capra, 1997). A PV system is both a technological system with hardware and software, and a small part of a larger system. In the larger system, different stakeholders like user and technician constitute other parts of the system. "In the systems view, we realize that the objects themselves are networks of relationships, embedded in larger networks." (Capra,1997) This leads us to two identified system levels. Depending on where the boundaries are set the PV system can be studied on two different system levels. One level is the technical system level, where the relationships between the PV system's different hardware- and software components decide the properties of the system. When zooming out, a larger system level; the stakeholder system level can be seen. At the stakeholder system level, the relationships between, the PV system, technician, user, etc. have an impact on the properties of the PV system itself. This is illustrated in figure 1. As described earlier, the software aspect is in this study divided into two separate parts. Firstly; the software programs integrated in the PV system itself on the technical system level. Secondly; the software in terms of knowledge and organisation of the surrounding stakeholders, on the stakeholder level.

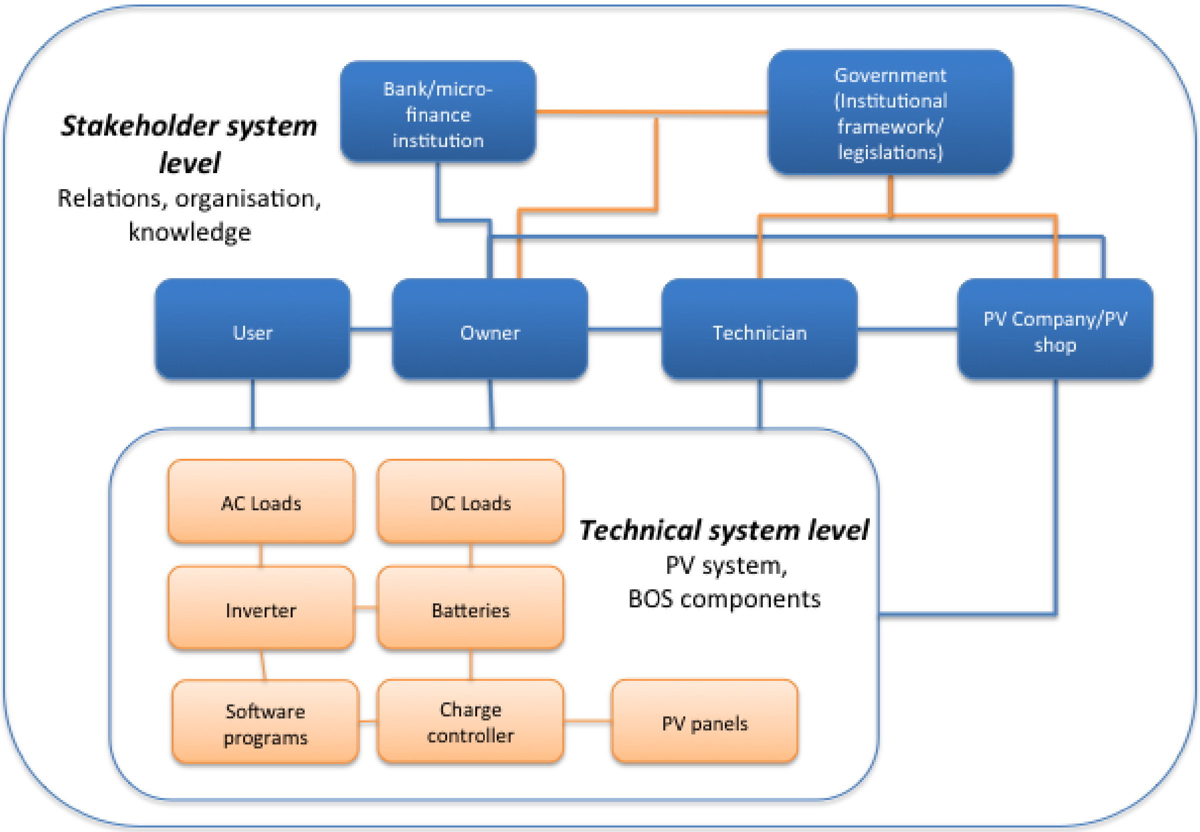


Figure 1: A PV system is a part of a larger stakeholder system, at the same time as it is built by smaller parts and is defined as a system of its own. This figure is an example of what it can look like.

It is assumed that the function of a PV system is to deliver electricity of sufficient quality and quantity during its estimated lifetime. It is not only the hardware- and software components of the PV system that decide if the PV system can deliver electricity as expected. How the PV system is designed affects the demand for knowledge and organisation on the larger stakeholder system level. This fact raises the question if any specific design choices are made by different stakeholders working with implementation of PV systems in rural Tanzania, in order to reach a more long-term and reliable electricity supply from the system. The two system levels described is a tool when analysing this question. In this context the concept of technological complexity is introduced.

2.2 Defining Technological Complexity

There is no unique definition of "complexity". One definition of complexity science is "the study of the phenomena which emerge from a collection of interacting objects" (Johnson, 2009). Hence complexity relates to systems theory. Generally, the more interacting objects, the more complex the system becomes.

In relation to technology diffusion, complexity can be understood as the degree to which an innovation is perceived as relatively difficult to understand and use. Complexity is a characteristic, together with others, that can help to explain the rate of adoption of a technology. Hence, if the users perceive the level of complexity as low, this can be translated to user-friendliness. Rogers (2003) suggests the generalisation: "The complexity of an innovation, as perceived by members of a social system, is negatively related to its rate of adoption." (Rogers, 2003) This definition of complexity, where a perceived low level of complexity is translated to user-friendliness, is relevant when taking the perspective of the users or technicians of the PV system. The wish for user-friendly PV systems that are simple to install, use and maintain, is probably the case for most users and technicians.

The concept of "technological complexity" is in this Master's thesis investigated at both the technical system level and the stakeholder system level. It is studied how the design of a PV system, at the technical system level, can comprise a certain level of technological complexity, which in turn can affect the level of technological complexity at the stakeholder system level, and vice-versa. Furthermore it is studied if there is a connection between the level of technological complexity on the two different system levels and the implementation and long-term operation of the PV system. This is illustrated in a conceptual model created, see figure 2. The model was fully developed first after the gathering of material for the study had been completed.

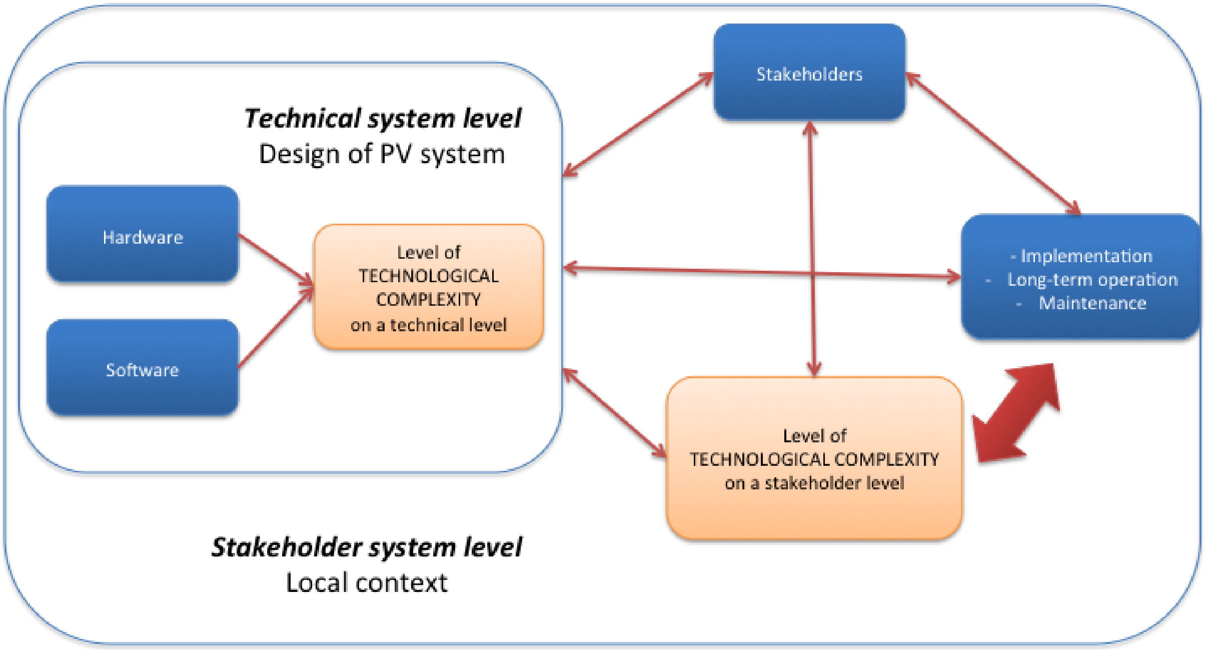


Figure 2: Conceptual model of the assumed relation between the level of technological complexity and implementation and long-term operation. The level of technological complexity is a result of the PV system design.

The specific design choices made by stakeholders, like PV technicians or system designers at PV companies, result in a final PV system design with a certain level of technological complexity at a technical system level. ***The level of technological complexity at a technical system level, regarding hardware and software, is in this Master's thesis defined by***;

- The number of PV system components integrated in the PV system – the more components, the higher level of technological complexity.

- To what degree electronic components and software are integrated in the PV system components – the more electronic components and software, the higher level of technological complexity.
- The non-human requirements on the workshop/factory/manufacturing process of the components in the PV system – the higher requirements, the higher level of technological complexity.

Design choices made at the technical system level result in specific demands on the stakeholder system level. ***Factors that can affect the level of technological complexity at a stakeholder system level are in this Master's thesis defined as:***

- The requirements of knowledge to design, manufacture, install, maintain and use the PV system and its components – the higher requirements, the higher level of technological complexity.
- The availability of electronic components for the PV components, and spare parts for the PV system – the lower availability, the higher level of technological complexity.

By using the definition above it is possible to compare and analyse different kinds of PV systems designs and their level of technological complexity to a "standard PV system design". The standard PV system design is further described in chapter 4. What is here defined as "level of technological complexity" will hereafter be referred to as "level of complexity".

It is interesting to study the relations between the level of complexity at the two system levels, and the implementation and long-term performance for small-scale, off-grid PV systems in rural areas. Adopting a systems view, the characteristics of a PV system – like user friendliness, size, flexibility, reliability etc. – will have an impact on the relations between the different actors on a stakeholder level. Also the introduced concept of technological complexity can be seen as a characteristic. If the relations at a stakeholder system level change, according to a varying level of complexity at a technical system level, this will in turn have an impact on all the different actors on a stakeholder system level, including the PV system itself. Considering the systems view adopted, the intention with this Master's thesis is to identify what potential impacts the level of complexity at the two system levels presented could have on a PV system during its whole lifetime. However, it can be presumed that this impact is not static, but goes both ways. Stakeholders' earlier experiences or expectations, and the local context, might as well cause a specific PV system design. This relation is also given attention in this study. The division of the two system levels can be seen in figure 1, and the conceptual model can be seen in figure 2.

2.3 Research questions

With the background of the introduction of the concept of technological complexity the research questions are presented below:

- How do stakeholders motivate their main considerations when designing off-grid, small-scale PV systems (stand alone PV systems and SHS) in rural Tanzania, considering the whole lifetime of a PV system, when looking at planning-, installation- and operation phase – including maintenance?

- What variations in PV system design, compared to a standard PV system, are observed or described by the stakeholders, and how do these design variations differ in their level of technological complexity at a technical- and stakeholder system level?

- How is the concept of technological complexity in this context perceived by different stakeholders?

- How do the stakeholders' main considerations and design of the PV system have an impact on the level of technological complexity? How could the concept of technological complexity be useful in the process of designing PV systems?

- Is the concept of technological complexity relevant in the context of technology transfer, and how does technological complexity affect the process of technology transfer?

3 METHOD

In this chapter the methods used for the study are described. The study consisted in three main parts; a preparatory literature review, field studies and final analysis of the data. The work was equally divided between the two authors throughout the whole work process. Before the field studies were carried out, a performance checklist for solar home systems (SHS) and an interview guide were also developed. The study was of explorative nature, with the aim to provide details within an area of research where a limited amount of information exists. A qualitative approach was undertaken and interviews and observations were used as main tools.

3.1 Preparatory research

The first step was to create a background and understanding of the prerequisites for implementation of small-scale off-grid electric systems in rural areas in East Africa, and especially Tanzania. This was done through a literature review, which served as a base for the elaborated research questions and the development of a checklist and an interview guide. The checklist was created based on information about PV system design, installation and maintenance. It was used when visiting PV systems in field and can be found in Appendix II. An extensive interview guide was also formulated, based on the literature review and the research questions. It was used mainly during the interviews, but also to some extent during the site visits, and can be found in Appendix I.

3.2 Selection of PV systems to visit

In Tanzania "snowball sampling" (Handcock and Gile 2011) was used as a method to find information about potential respondents and off-grid systems that could be visited. During each interview the respondent was asked for contacts to other relevant respondents and information about systems that could be of interest for the study. The basic criteria for systems, to be part of interest for the study, were that they should be small-scale, off-grid electrical systems in rural areas with as similar contextual circumstances as possible. The goal was to visit systems that had been operating successfully for more than five years. Further, the wish was to visit different types of systems, where the design had resulted in different levels of technological complexity in terms of hardware and/or software. "Operating successfully" implies that the system is generating electricity with the expected quality and quantity. "Similar contextual circumstances" implies that the electrical systems are placed in rural areas in Tanzania, and that the owners/users of the systems have similar living conditions and level of income. Furthermore, the wish was that the electrical systems should have an economically sustainable management, and preferably would have been initiated based on local initiative or entrepreneurship.

Contact was established with three local PV technicians working in the same rural area in Ruvuma Region. The contact was established by the help from one of the respondents, working at a PV company in Dar es Salaam. The respondent had been working together with these technicians in a successful partnership. When arriving in Ruvuma Region contact was established with a fourth technician, who was also working in the same area. Knowing the criteria for the systems that could be of interest for the study, the respondent selected a few PV systems, together with the technicians.

3.3 Visits at PV systems and discussions with the PV technicians

Site visits were paid to ten different PV system installations in the Ruvuma region in Southern Tanzania. The technicians who had chosen the PV systems, together with the respondent from Dar es Salaam, were also guiding the site visits. Close to Mbinga town, three visits in private homes, one visit at a school and one visit at a dispensary were made. Close to Songea town, 95 kilometres from Mbinga town, three visits at private homes and two visits at schools were made. Two of the four technicians showed their shops, where they were selling and repairing electronic components and PV systems. One of the technicians who owned a shop also showed how to assemble locally assembled inverters.

The local technician/s who were to guide a site visit made contact with the owners of the PV system before the visits. At the sites the technicians showed the PV system and answered to several questions about the system from the interview guide. At eight out of ten sites the guiding technician was the same person who had also installed the PV system. At eight out of ten site visits it was also possible to talk to the owner/person responsible for the system. Some of the owners did not speak English and for these cases the guiding technician/s were interpreting the conversations between the authors and the interviewees.

Together with the interview guide a checklist was used to perform a status check of the PV system, to be able to have informed discussions with both technicians and owners. Longer interviews were not carried out with users or owners. The information gathered from the users or owners at the site visits rather worked as a complement to what the technicians were saying and the authors' understanding of the situation of the PV system. A multimeter was used to check the battery voltage as a part of the status check. Each visit lasted for approximately two-three hours.

3.4 Interview guide and selection of interview topics

An interview guide was created during the preparatory research, based on the literature review. The interview guide was developed to conduct qualitative, semi-structured interviews with different types of stakeholders interacting with, or influencing the design of, PV systems. The considered stakeholders were employees at PV companies, scholars at universities, employees at non-governmental and governmental organisations, PV technicians and users. Hence, the interview guide was developed to suit both stakeholders with a broad and general knowledge, and stakeholders with more practical knowledge. The extensive interview guide was divided in groups of questions regarding the topics; design of the electrical system; implementation phase; operational phase (including suitability, availability, quality, infrastructure, reliability, maintenance and reparation); economic situation; education; and the perception of the concept of technological complexity. The interview guide can be found in Appendix I.

Semi-structured interviews with open-ended questions have the benefit of giving the possibility of highly flexible discussions around the questions in the interview guide. In this way the interviews can be adjusted to the stakeholders' personal backgrounds and new angels on the topic of research can be brought into the light. In semi-structured interviews not all topics and questions are decided beforehand, and many of the questions are formulated during the interview. The aim with conducting semi-structured interviews with many open-ended questions was to open up for new angles related to the topics investigated, to allow the subject of study to develop. The questions in the interview guide were both wide-ranging and detailed, and different topics and questions were emphasized during different interviews depending on the background and experience of the respondent. The strength of the interview guide approach lies in that the interviews become fairly conversational and situational, and the researcher get a comprehensive material, where obvious logical gaps in the interview guide can be filled in during the interview. The drawback is that it can be difficult to compare the interviews, and it might be that all topics are not covered during some interviews (Mikkelsen, 2005).

3.5 Selection of respondents

The objective was to conduct interviews with a variety of stakeholders, who have different experiences from design, implementation and/or operation of small-scale, off-grid electrical systems in rural Tanzania. It was also a preference to get in contact with respondents who had experience from both donor- and market driven system implementations, since these projects usually have different stakeholder structures.

The supervisors of the Master's thesis provided the major part of the contact information to potential respondents in Tanzania. In Dar es Salaam interviews were conducted with two different stakeholder groups. The first group was named energy sector stakeholders on a national level (ESNs); scholars at technical universities, employees working for non-governmental organisation and governmental authorities. The second group was named PV company employees (PCEs); employees at companies selling SHS and/or SHS components. Furthermore, interviews were conducted with a third stakeholder group; PV technicians working in rural areas in Ruvuma Region. All the respondents from the two first stakeholder groups were found through the supervisors' network. Contact with four local PV technicians in Ruvuma Region was obtained through "snowball sampling" (Handcock and Gile 2011).

3.6 Conducting interviews

The interviews were conducted between the months of March and May in 2013. When conducting the interviews, one interviewer was responsible for asking the questions based on the interview guide and leading the interview. The other interviewer was taking notes and asking further questions if considered valuable. The interviews were recorded when the respondent approved with this and the interviews normally lasted between 1-2 hours. A conceptual model was used when the level of complexity and the causes and consequences of different design choices were discussed. The model can be seen in figure 3. The respondents were asked to make changes in the model, to show how different topics were linked according to their opinion.

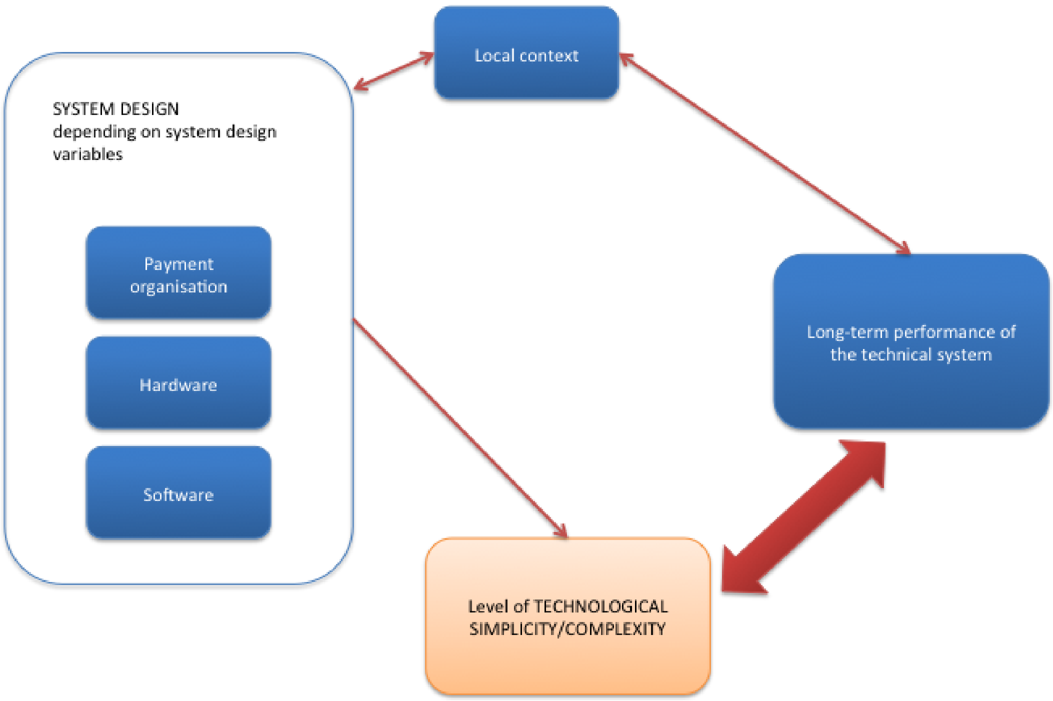


Figure 3: Initial conceptual model of technological complexity used during interviews.

The interviews conducted with PCEs and ESNs were most of the time a discussion on a more general level. Efforts were made to find examples of and/or approaches that could lead to successful small-scale, off-grid electrical systems in rural areas, with focus on PV systems. "Successful" was defined as an electrical system that has been operating and delivering electricity with expected quality and quantity during 5-10 years. Apart from the site visits also separate interviews, based on the interview guide, were made with the local PV technicians. The interviews with PV technicians were mainly focused on detailed questions regarding design choices, implementation and maintenance, using the visited PV systems as examples.

3.7 Presentation of the stakeholders interviewed

In total 23 interviews were carried out. 3 of these interviews were shorter, more of informative character and not as closely linked to the research topic, and are hence not included in the results. One respondent who worked with pico PV systems as a missionary was interviewed shortly. The major part of the result from interviews is based on interviews with 19 respondents categorised into three different stakeholder groups; 4 local PV technicians; 7 PV company employees (PCEs); and 8 respondents grouped as "energy sector stakeholders on a national level" (ESNs). The ESNs consisted of 5 scholars at universities, 1 employee working at a governmental institution, 1 employee working at a non-governmental organisation and 1 employee working with an international development partner.

In the following sections the 19 respondents closest linked to the results are presented within their stakeholder group.

3.7.1 Presentation of the PV technicians interviewed

The four technicians interviewed were all from the same area in Ruvuma Region, Tanzania and worked with installation and reparation/maintenance of SHS. Three of them were business partners with Company 3, working as consultants with installation and sales of the company's products. Two of these three technicians also had their own PV shops. The same three technicians knew English and the interviews were conducted without an interpreter. The fourth technician did not speak English and therefore one of the other technicians was interpreting during the site visits and the interview.

Technician 1: PV dealer and PV technician. He has his own PV shop since 2007. Before dealing with PV systems he used to work with electrical systems, but has not undergone an education specifically in electronics. He participated in several PV workshops and training sessions, organised by the Sida/MEM Solar PV project, among others, before he started to sell and install PV systems. He works as a consultant and performs PV installations for Company 3 on a regular basis. Technician 1 guided site visits at PV system installations at two schools.

Technician 2: PV technician since 2008. He works in a PV shop and helps customers to install PV systems. He has participated in trainings arranged by the Sida/MEM Solar PV Project, among others, to become a PV technician. He does not speak English and Technician 1 was interpreting when he was interviewed and guiding site visits. Technician 2 guided site visits at PV system installations at three families' homes.

Technician 3: PV technician working as a technician for a District Council. He started to learn about PV systems from another PV technician in 2004 and installed his first PV system at a school in 2007. He attended a three-day course in order to install PV systems at dispensaries as a consultant for Company 3 together with a group of technicians, and is main responsible for the maintenance of those PV systems. Technician 3 guided site visits at PV system installations at one school, one dispensary and at three families' homes.

Technician 4: PV technician, electronics technician and owner of an electronics shop. He sells and repairs electronic products and PV systems, and collaborates with Company 3. He is also assembling inverters with local material, that he sells and installs, and he has two students who work with him. Technician 4 showed how to assemble an inverter, but no site visits were made to PV systems that he had installed.

3.7.2 Presentation of the PV company employees (PCEs) interviewed

Seven respondents from six PV companies were interviewed. One of these companies, Company 6, does not install PV systems, but works exclusively with training, awareness raising and project management related to PV system installations. Only two of the companies, Company 3 and 6, are actively taking part in public procurements. This means that they can be hired to take part in larger works of public installations of PV systems that are financed by a donor and the government. It was through Company 3 that contact with the interviewed technicians in Ruvuma Region was established.

PCE 5 works for **Company 1**, which is based in UK, and has an office in Dar es Salaam, Tanzania. In Tanzania, Company 1 mainly works with distribution of PV system components, working with retailers around the country. They also carry out on- and off-grid PV system installations on request, but it is not their main focus.

PCE 6 works for **Company 2**, which is mainly a supplier of PV system components. Battery supply is a large part of their business. The company is based in Kenya and was established in Tanzania in 1966, with its main office in Dar es Salaam. When the company installs PV systems, those are mainly larger systems complementing grid electricity or power back-ups. The company do install off-grid systems in rural areas, but not on a large scale and those systems are mainly larger hybrid systems with a generator integrated. Company 2 does not have technicians working for them in rural areas on a larger scale.

PCE 7 works for **Company 3**, which was established in Dar es Salaam in 2001. The company supplies components for PV systems. Remote monitoring and –controlling (RMC) can be a part of their system design for larger PV systems. The company has made several installations of PV systems in rural areas – both for private persons and for institutions, and some of these installations have been funded by donors. Company 3 collaborates with local technicians contracted by the company to carry out technical assistance. These technicians also work as retailers for the company's products. Company 3 has put together a few examples of "system packages" for SHS of the sizes 30-360 W, where the sizing of the systems is already made, and there is a description for what loads the system can be used for. Many times those are the systems that their customers buy.

PCE 8 works with **Company 4**, which has been based in Dar es Salaam, with Dutch influences, since 2008. The company specializes in larger hybrid PV systems with RMC as a part of the system. The company distributes PV system components and carries out installations of larger PV systems – both hybrid- and off-grid systems. The hybrid systems operate on solar energy and a generator and/or electricity from he grid. The company has also carried out a few installations of smaller off-grid systems in rural areas for schools and hospitals. Most of these have been funded by a donor.

PCE 9 and **PCE 10** work for **Company 5**. The information regarding the design used by Company 5 was gathered through interviews, the company's website, as well as manuals provided by PCE 10. Interviews with PCEs 9 and 10 were conducted over e-mail and Skype. RMC is a part of the company's system design, and an important part of the business- and maintenance model of the company. The company is based in Germany, with an office in Arusha, Tanzania. The company started in 2010 as a pilot project, installing off-grid SHS in Arusha Region, and the first systems were installed in November 2011. The target group of the company is rural households. The company collaborates with local NGOs, international sponsors and mobile banking companies to provide customers with SHS in the sizes 30-200

W. The systems can be paid for in monthly instalments over a period of three years by a mobile banking service, and maintenance during three years is included in the deal.

PCE 11 works for **Company 6**, which is an international project developing consultant company, founded in Kenya in 1989. In Tanzania the company works with rural electrification and other areas connected to climate change. The Tanzanian office is based in Dar es Salaam, and in Tanzania the company is only working with donor-funded projects. Consultants are employed by the company to carry out training of local technicians and local PV component dealers, awareness raising and project management, among other things.

3.7.3 Presentation of the energy sector stakeholders on a national level (ESNs) interviewed

All of the eight ESNs have experience with renewable energy. Some of them have experience on a more theoretical level and some of them on a more practical level.

ESN 12 is a scholar and professor working at College of Engineering and Technology, University of Dar es Salaam. He has been working with off-grid electricity since 1995 and is also chairperson at Tanzania Renewable Energy Association (TAREA).

ESN 13 is a scholar and lecturer at University of Dar es Salaam Business School, focusing on the diffusion of renewable energy technologies.

ESN 14 is an engineer in renewable energy technologies, and works as executive secretary at TAREA in Dar es Salaam.

ESN 15 is an engineer working as energy administrator and first secretary at the Swedish Embassy in Dar es Salaam.

ESN 16 works as a projects officer at Rural Energy Agency (REA) in Dar es Salaam.

ESN 17 is a scholar, holding a Ph. D. in electrical power engineering. He works as senior lecturer at Arusha Technical College.

ESN18 is a scholar and assistant lecturer at University of Dar es Salaam, focusing on management and sustainable development.

ESN 19 is a scholar and professor working at University of Dar es Salaam. He has a long experience as consultant for PV system projects.

3.8 Method of analysis of the results

The observations made at the visited PV systems were compiled in an extensive table, covering technical details of the design, as well as topics like maintenance and payment. The table served as a basis for comparison and presentation of the result. The data from the interviews conducted with the three stakeholder groups PV technicians, PCEs and ESNs were analysed in the light of the research questions and the literature review. The method used for analysis was to summarize each interview made, and search through the interviews for topics relating to the research questions. These topics were labelled with codes and categorized.

An early version of a conceptual model showing the investigated relations between technological complexity, the technical system – hardware and software, as well as payment organisation – and the local context, including stakeholders, can be seen in figure 3. This model was shown to the respondents during the interviews, as a basis for discussion of the role of technological complexity. Due to the explorative nature of this study, the concept, and definition, of technological complexity and the two system levels; technical- and stakeholder system level, had not been fully developed when the interviews and site visits were carried out. Hence the analysis was partly focused on relating the material gathered not only to the research questions, but also to the two system levels and the concept of technological complexity.

A part of the analysis was to describe the level of technological complexity for different PV system designs observed. The notion of a "standard PV system design" was used to put the complexity level of a diverging PV system design in relation to the PV system design that was observed to be the most common.

3.9 Discussion of method

In this chapter topics related to the methods used, and other issues that could have influenced the results, are discussed.

Due to the explorative nature of this study, the scope was from the beginning not limited to photovoltaic (PV) systems. The study focused on all types of small-scale, off-grid electrical systems run by renewable energy resources. During the initial interviews with stakeholders operating in Dar es Salaam the broader scope was still used. The limitation to PV systems was not made until later during the study. Since the focus shifted slightly during the study, some information regarding PV systems could have been missed out during the initial interviews.

The concept of technological complexity was to some extent formulated before the field study, but was also developing alongside the work with interviews, as well as during the analysis stage. It would have been more appropriate to develop the concept as much as possible before the field study, and to carry out a pilot study on technological complexity in an environment more well-known to the authors, before the field study in Tanzania. To have a base line for what technological complexity could mean for PV systems in a Swedish context, would have facilitated the field study, as well as the analysis.

The concept of technological complexity was an attempt to create a concept that includes both the technical design of the PV system and the stakeholders' relation to the PV system. The two system levels – technical system level and stakeholder system level – were distinguished in order to clarify how the level of complexity could affect the system. However, gradually during the study it became clear that the concept of technological complexity was a confusing concept for many of the respondents. It might have been easier to only address "complexity" on the different system levels, instead of "technological complexity". But since the concept of technological complexity was developed during the whole study, this conclusion did not become clear until the end of the study.

The PV systems visited were not chosen by the authors, but by the PV technicians themselves, and were to some extent coordinated by PCE 7 at Company 3. Probably the technicians chose to show PV systems where they had a good relation with the customer, and where the operation of the system was rather smooth. The initial plan for this study; to visit PV systems with varying levels of complexity at a technical system level that had operated for at least five years, did not work out. Instead, the systems visited had a rather similar type of design. Since half of the visited PV systems were installed by technicians who partly worked as consultants for the one and same PV company, this could perhaps have been expected. Almost all of the visited PV systems had components of high quality and were properly installed. According to many of the interviewed respondents and literature, there are major challenges with low-quality products and improper installations of PV systems in Tanzania. Hence, the PV systems at the ten visited sites could probably not be considered as representative for the general design of SHS systems in rural Tanzania.

There are issues related to communication and translation that should be considered. A source of uncertainty in the result is misunderstandings due to miscommunications. In connection to the site visits, the guiding technicians acted as interpreters. For example, Technician 2 did not speak English, and Technician 1 translated both during site visits and the following interview with Technician 2. It is possible that Technician 1 added his own opinions into the translation. The results from the interviews with the users/owners during the site visits are very limited. The users/owners were not always at home when the visits were made. Furthermore, the short visits did not allow for actual observations of how the system was used and maintained. About half of the interviewed users/owners did not know English. In most cases the technician who guided and translated from Swahili to English between the users and the authors had also installed the system. This has probably had an effect on the results, since the guiding technicians might have put their own personal views into the translation.

At some occasions, when users/owners were asked about maintenance, they first answered that no maintenance was done. But when more detailed questions were asked, such as if they sometimes clean the PV panels, they sometimes changed and said that they do perform some maintenance. This could be a result of a different understanding of what the word 'maintenance' means to the users/owners, compared to the authors' understanding. However, it leads to uncertainty regarding what type of maintenance is actually carried out by the users/owners. The user is an important stakeholder in the context of this study, as the user is the one who have the most knowledge about the operational phase. However, the results obtained from this study in terms of interviews with users are not sufficient to fill that role. Therefore, the focus of this study has instead been put on other stakeholders.

A qualitative interview method with semi-structured, open-ended questions was applied in this study. A drawback with the method is that not all interview topics were covered during all interviews. This reduced the comparability of the interviews and affected also the method used to analyse the data. A concrete example of this is the topic of locally assembled components. It was introduced first at the last interviews made. It was covered in particular during interviews with two of the technicians, who had experience of assembling inverters, and only with a few of the PCEs and ESNs.

4 HARDWARE AND SOFTWARE INTEGRATED IN PV SYSTEMS – TECHNICAL SYSTEM LEVEL

In this chapter different types of off-grid photovoltaic (PV) systems, as well as hardware and software used in off-grid PV systems are described.

4.1 Off-grid, small-scale PV systems

PV cells can be used in a variety of off-grid applications, for example in hybrid PV systems, mini-grids, stand alone systems, solar home systems (SHS) and solar lanterns. Below, the most common types and a “standard PV system design” are presented.

4.1.1 Different sizes of PV systems

The smallest applications are called solar lanterns or pico solar PV systems, and are commonly in the size-range of 0,3 W_p up to 10 W_p. These applications are often including a small size PV panel, a battery with good energy storage potential, like lithium-ion, a charge controller and a light emitting diode lamp (LED-lamp). Typically the power kit can supply enough electricity for a couple of DC-lamps operating on direct current (DC), a music player, a radio, or to charge mobile phones. Since the pico solar PV systems are much cheaper than SHS they are affordable to a larger market segment in rural areas (International Energy Agency, 2012a).

For institutional and domestic applications SHS and stand alone systems are often used. SHS often have sizes in the range from 10 W_p up to 250 W_p. PV systems of larger size are often called stand alone systems. These can have an output power of up to 4 kW_p, and are often installed for larger institutions such as schools, hospitals or hotels (Rolland & Glania, 2011; International Energy Agency 2012a).

4.1.2 Standard PV system design

A SHS or a stand alone system often includes the main components; PV panel (or several PV panels constituting a PV array), battery and charge controller. The electricity output from the PV panel or -array to the charge controller and battery is of DC type with a low voltage. If the user wants to use loads requiring alternating current (AC) an inverter is needed to convert the low voltage of DC to a higher voltage of AC (Wenham, et al., 2007; Ross 2003).

In this Master’s thesis the components described above are included in the definition of a “standard PV system design”. The components are manufactured by original equipment manufacturers (OEM), and imported from outside of Tanzania in most cases. The software included in a standard PV system design is restricted to the software embedded in the inverter and charge controller. In figure 4 the most common components in a standard PV system design are presented.

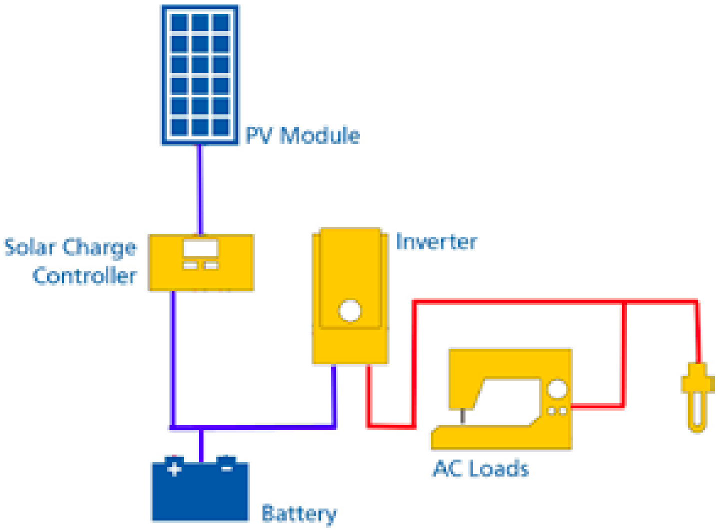


Figure 4: A standard design of a SHS with only AC loads (Rolland & Glania, 2011)

4.2 Hardware

In the following section, the hardware components commonly used in a PV system like; PV panel, batteries, charge controller and inverter, are described in detail.

4.2.1 PV panel

PV cells are manufactured from semiconductor materials, which means that these materials act as conductors when energy or heat is available, but as insulators at low temperatures (Wenham, et al., 2007). The PV cell enables photons from the sunlight to release electrons from the molecular lattice, creating freed electrons and "hole" pairs, which diffuse in an electric field to separate contacts, generating DC electricity. The photovoltaic effect described is illustrated in figure 5. Several PV cells are interconnected in a PV panel to create higher voltage and power capacity (International Energy Agency, 2011). The most commonly used technology is silicon-based PV cells, were the PV cell can be crystalline, multi-crystalline, polycrystalline, microcrystalline or amorphous. Another technology is the thin film technology (Wenham, et al., 2007).

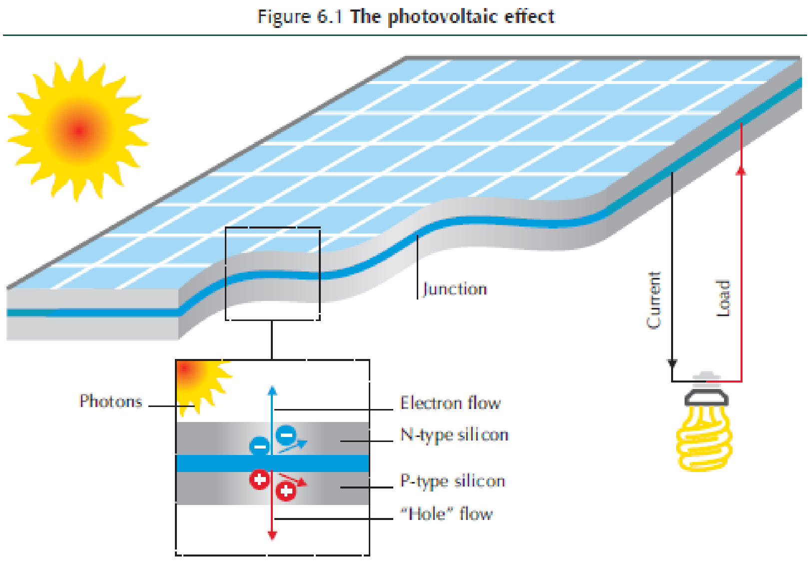


Figure 5: The photovoltaic effect (International Energy Agency, 2011).

4.2.2 Battery

Solar energy is intermittent, which means that the PV panel cannot generate electricity all the time. In an off-grid PV system, one or several rechargeable batteries is most of the time used to store the electricity from the PV panel as electrochemical energy, to be able to use electricity also when the sun is not shining. A battery consists of a number of battery cells. The battery cell is containing electrolyte, a positive electrode and a negative electrode. A voltage potential is created between the electrodes and the voltage of a lead-acid battery cell results from the chemical reaction inside it. During standard conditions the theoretical voltage is about 1.93 V in a single cell but in practise 2 V is used to represent the nominal voltage. The battery cells are serially connected to build up higher voltage in the battery – for example, a 12 V battery consists of 6 cells, which are connected in series. In SHS it is common to use batteries with a nominal voltage of 12 V. When several batteries are connected, either in parallel or in series, it is called a battery bank. In a battery bank of a larger stand alone system, with some kW_p of PV power, 12 V batteries can be connected in series to build up 24 V, 48 V or higher voltages in the PV system (International Energy Agency, 2003a; International Energy Agency, 1999).

There are several battery technologies for rechargeable batteries today, for example; lead-acid, nickel-metal-hybrid, nickel-cadmium, rechargeable alkaline manganese (RAM), lithium-ion and redox batteries (Wenham, et al., 2007). However, in stand alone PV systems and SHS today the most common batteries are lead-acid batteries due to availability and costs (International Energy Agency, 1999; Spiers, 2003; Potteau, et al., 2003). Furthermore, lead-acid batteries have relatively good energy storage density and can be considered as robust and reliable. Their disadvantage is mainly that they require a controlled charging- and discharging process if a large number of charge/discharge cycles is to be obtained (Ross, 2003).

Rechargeable lead-acid batteries can be divided into two main types. In literature these are referred to as wet/vented/flooded/open batteries and dry/valve regulated/sealed batteries. In wet batteries the electrolyte is a solution of water and sulphuric acid. The charging process does not need to be as stringent as for dry batteries, but the battery housing must be well ventilated to prevent the build-up of hydrogen gas (Wenham, et al., 2007). Since water is consumed during the charging/discharging process in a wet battery, the concentration of acid in the electrolyte is increasing over time. A too high concentration of acid in the electrolyte increases the corrosion of the electrodes, which decreases the battery lifetime. A reduced water/acid-solution level in the battery cell is also resulting in the electrodes being exposed to air, which over time can damage parts of the battery cells permanently. By using a good charge controller the loss of water in the wet battery can be minimised, but the water level in the batteries should be checked regularly and the battery cells have to be topped up with deionised/distilled water when needed (International Energy Agency, 1999).

In dry batteries the electrolyte is in solid state. Catalytic converters are used to convert evolved hydrogen and oxygen back into water and only in the case of excessive pressure in the battery gas is vented. Less maintenance is needed compared to wet batteries, since there is no need of refilling with distilled water, but dry batteries require a stringent charging control (Wenham, et al., 2007). Examples of dry batteries are the AGM- type, where the electrolyte is absorbed in a glass fibre matt, and the GEL-type, where the electrolyte exists in gel-form (Jossen, et al., 2004).

The batteries are often concerned as the weakest part in off-grid PV systems due to cost, lifetime and reliability (Potteau, et al., 2003). Irregular battery operation causes a number of degradation mechanisms, which affect the battery's lifetime, like for example; excessive gassing, corrosion, sulfation, loss of water and active mass. These degradation mechanisms will shorten the battery life time considerably, why it is important to use a proper charge controller (Yang, et al., 2006; Jossen, et al., 2004).

In off-grid PV systems the irregular usage of loads and the intermittent incoming of solar radiation towards the PV panels create a slow and irregular discharging- and charging process of the batteries. The battery used in off-grid PV systems often has to withstand deep discharging when the battery energy content is used to a larger extent, for example when there is no solar radiation during a couple of days and/or the loads are withdrawing energy from the battery to a larger extent. The state of charge (SOC) is representing the charge level of a battery. When the battery is fully charged to the nominal capacity, the SOC is 100 %. If the battery is fully discharged, the SOC is 0 %. Depth of discharge (DOD) is representing the opposite of SOC. DOD describes how deeply a battery is discharged; a 100 % DOD represents a battery which is discharged to 100 %. A discharge of more than 80 % DOD for a deep-cycle lead-acid battery and a discharge of more than 25 % DOD for a shallow-cycle lead-acid battery will dramatically shorten the lifetime of the battery (Wenham, et al. 2007). A lead-acid battery, manufactured to withstand deeper discharging, should preferable not have a daily discharged below 50 % SOC of its energy content (International Energy Agency, 1999).

Lead-acid batteries can be designed to withstand different depths of discharge, according to the intended application. Lead-acid batteries can also be manufactured in many different types depending on the sort of application. A SLI (starting, lighting and ignition) battery, for example starter batteries for cars, is manufactured to withstand very high loads during short periods of time, when the engine starts. These car batteries are designed to withstand quick, shallow discharge cycles and then get quickly fully loaded again (International Energy Agency, 1999). In PV systems it is preferable to use batteries that are manufactured to withstand deeper discharging, so called "solar batteries". However a SLI battery can work very well in a SHS, but only for a shorter period of time, in the range of 1-5 years. Since the SLI battery is not built to withstand deep discharge this results in a lower number of obtained charge/discharge cycles (International Energy Agency, 1999). In a long term perspective it is often more economically favourable to use batteries manufactured to withstand a deeper discharging and a larger number of charge/discharge cycles. However, local car batteries can be more preferable in solar home systems in rural areas in developing countries due to the lower price and the easier accessibility (Reinders, et al., 1999).

4.2.3 Charge controller

A charge controller is a component that controls and regulates the current and voltage between the PV panel, the battery and the loads. The charge controller is needed to protect the batteries by limiting the discharge level and to avoid overcharging. There are mainly two basic charging regulation methods: constant voltage regulating or interrupting (on/off) regulating (Wenham, et al., 2007).

The charge controllers used in rural areas today often have a pedagogical approach showing green, yellow or red light indicating the SOC of the battery. Another version is a happy, intermediate or a sad face on the charge controller to show the SOC of the battery. The green light indicates when the battery is well charged and there are no restrictions in using energy to the loads, yellow light indicates a warning for a low energy content of the battery, and the red light appears when the power supply is cut off by the charge controller due to low energy available in the system. The charge controller gives important information when the energy supply is cut off, since it shows if the cut off depends on a too low availability of energy or a failure of some equipment. The users are enabled to undertake energy saving actions when the yellow lamp on the charge controller is indicating a low energy available and a risk that the energy supply is cut off soon (Ciudad Universitaria, 1998).

For optimal management of the battery it is important that there is a good match between the charge controller and the battery bank (Yang, et al., 2006). Different types of charge controllers create different operation temperatures for the batteries, even if the ambient temperature is the same. The rechargeable batteries have a limited number of life cycles, but it is almost always the temperature-dependent corrosion process that primarily limits the battery lifetime of photovoltaic systems (Spiers and Rasinkoski, 1995). The battery's working temperature depends both on the ambient temperature and the overcharging process, which increases the working temperature of the battery significantly (Yang, et al., 2006).

Off-grid PV systems can also be designed as self-regulating systems, where no charge controller is needed. Instead, the battery is directly connected to the PV panel and the natural self-regulating characteristics of the PV panel when shifting from maximum power point towards the open circuit condition regulates the power to the battery. Above the maximum power point the generated current is automatically reduced with increasing voltage, which is well suited for providing charge regulation to the battery – if the temperature remains constant. However, the slope of the current-voltage curve between the maximum power point and the open circuit point can vary considerably between different cell technologies, which complicates the design. The self-regulating system is sensitive to temperature variations and only small seasonal- and day-to-day temperature variations can be allowed for to be able to make the operation optimal. Furthermore, the battery needs to be relatively large compared to the size of the PV panel. A general approach is to remove approximately 10 % of the solar cells from the standard modules to reduce the probability of over-charging the batteries. Without a charge controller, less wiring and solar cells are required, and due to the simpler installation a self-regulating system becomes cheaper.

However, in general the self-regulating systems are quite inefficient, unreliable and bring many compromises in design due to risks of over-charging the batteries during cooler days and under-charging when there is hot weather. Another issue is the increased requirements of a good match between the loads and the PV capacity. During time periods with no load the batteries must be disconnected to prevent rapid destruction of the batteries due to severe over-charging, over-heating and rapid loss of electrolyte. Because of these aspects there are special requirements on the care and monitoring of self-regulating systems (Wenham, et al., 2007).

4.2.4 Inverter

An inverter is needed as an integrated part in a PV system if the power to the loads is required as AC rather than DC, since DC is produced by the PV panel and provided from the battery bank. Inverters are converting the low voltage, typically around 12-48 V DC, to typically 110 V or 240 V AC. In off-grid PV systems the inverter supplies constant voltage and frequency to the loads. Some of the aspects that have to be considered when selecting an inverter are; the efficiency; the standby power draw; the requirements on the wave shape of the AC going to the loads; and the resistance against short circuits.

Most of the OEM (original equipment manufacturer) inverters have an efficiency of around 80-85 % when loads in the range of 25-100 % of the inverter rating are withdrawing power from the PV system. However, for small loads the efficiencies can be considerably lower. Light duty inverters around 100 W up to 10 000 W can be relatively inefficient and can create undesirable noise. Some inverters can have a significant standby power draw, which can drain the energy in the batteries rather rapidly. The optimum of the AC curve is a sine wave. Many small inverters are producing square waves or approximations of sine waves, which can lead to damage of some equipment (Wenham, et al., 2007).

4.2.5 Balance of system components (BOS)

Balance of system components (BOS) is a collective name of the components associated with the delivery process of electricity, such as batteries, charge controller, inverter, electrical protection devices, wiring and monitoring equipment. In addition the BOS includes structural components, such as sun-tracking systems and mounting frames (Wenham, et al., 2007; International Energy Agency, 2011).

4.3 Software

The software aspect in a small-scale, off-grid solar PV system is for a standard PV system restricted to the software integrated in components like the charge controller and inverter. Hence, there are no extra software aspects included in the definition of a “standard PV system design” in this Master’s thesis.

However, for larger renewable energy systems, like larger stand alone PV systems, there is a high incentive to integrate a remote monitoring and controlling system (RMCS) into the system, since the control of output power is of major importance due to power system stability and safety requirements (Kalaitzakis, et al., 2003). There are also some examples where remote monitoring and controlling (RMC) have been implemented for smaller PV systems like SHS, and where consumer financing- and pay-as-you-go solutions for energy in rural areas, using the mobile network, have been created (GSMA Mobile Enabled Community Services, 2013) (Mobisol GmbH, 2013; Soto, et al., 2012; Simpa Networks, 2013). Both RMCS and pay-as-you-go solutions include software, which contributes to the software aspect in this context.

4.3.1 Remote monitoring and -controlling of PV systems

Remote off-grid electrification, monitoring and controlling or just monitoring can be useful for a number of reasons. A long term monitoring and evaluation of a PV system makes it possible to collect useful data regarding operation of the system and to provide information about what could be done to improve the system performance. It also creates a detailed understanding of the system's operating performance from a technical point of view (Ma, et al., 2012; International Energy Agency, 2003a). With a remote monitoring system (RMS) for rural, off-grid, small-scale PV systems, improper handling and system problems can be detected at an early stage, and after-sales maintenance can be performed more efficiently. In this way maintenance costs can be reduced and customer satisfaction can be increased (Schelling, et al., 2010).

One example of a monitoring solution for small-scale, off-grid PV systems using DC current, that has been pilot tested in rural Ethiopia, is the RMS SIMbaLink. The RMS consists of a voltage divider circuit, a microcontroller and a GSM module. The voltage divider circuit takes readings from the battery, the solar panel and the loads. The microcontroller then reads the voltages and translates them into a text message that is sent with a short time interval by the GSM module. Based on an algorithmic analysis of the logged data of PV panel voltage, battery voltage, battery amperage, load voltage and load amperage, the overall health of the system can be analysed by the help of a software programme (Schelling, et al. 2010). The difference between a RMS and a RMCS is that a RMS uses one-way communication, while a RMCS can communicate in both ways. In the case of a RMS, a monitoring system transfers information to a software program, while for a RMCS the behaviour of the PV system can be both observed and changed through a management software. An example of how a GSM-based RMCS for a PV system can function is described below.

The RMCS consists of three sub-systems:

- The PV sensor cell (PVSC), which provides an estimation of the radiation incident on the PV generator, and the theoretically available power.
- The data acquisition system (DAS), which measures certain quantities of the PV system, characterizes its performance and indicates possible problems. A management software is also integrated in the DAS.
- The transmission system, which manages the communication back and forward from the RMCS.

The GSM system as transmission system is considered as a good choice for the general case, due to the coverage rate and the GSM function SMS, which is regarded as cheap and simple. Other communication media that could have been considered are point-to-point phone connection (PPP), local area network (LAN) and the Internet. By RMC, PV systems can be monitored and controlled not only from a distance in a nearby city, but from any part of the world where there is a functioning GSM network or Internet. Hence, the deeper knowledge of the technology does not have to exist on-site, but can be outsourced, even to another country. To monitor the PV system the following quantities are measured; voltage, current and supplied power from the PV generator; current and power actually received by DC and AC loads; and voltage over the batteries. Then the produced power is compared to the measured short-circuit current of the PVSC, which corresponds to the theoretical value. The power absorbed by AC and DC loads and the batteries is compared to limits, which are adjusted through the management software (Gagliarducci, et al., 2007).

The management software manages three parallel processes; Firstly, it supervises the correct operation of the PV plant components by comparing the temperature, and the values from the short-circuit current, of the PVSC to the electrical quantities. An alarm SMS is sent to the operator if the PV generator does not produce the theoretical power, if the electrical powers drawn by the loads are different from the expected values, or if the voltage of the batteries is outside the predetermined range. Secondly, it records data regarding the regular operation of the PV system. The following indices, which define the PV energetic balance, are evaluated by the RMCS and sent to the operator by SMS: average efficiency, PV panel yield, reference yield and losses of PV panel capture. After a recording time fixed by the operator, the average and the maximum values of the following four are sent by SMS; solar radiation, produced power and energy, power on DC and AC loads and voltage of the battery bank. Thirdly, the management software responds to control commands sent by the operator through SMS. The commands can change the set-ups for the PV system and for the measurement system. The management software can be programmed to only respond to commands received from certain mobile phone numbers (Gagliarducci, et al., 2007).

4.3.2 Remote controlling and pre-payment

One application of RMC of PV systems is to combine it with the model of pre-paid mobile phone airtime. With a business model building on this strategy the problem with the high up-front cost for a SHS can be overcome, and a larger segment of the market can be reached. An example from India is Simpa Networks that installs SHS together with a charge controller, which regulates the SHS based on proof of payments. The customers pay for their systems over time through pre-payments for their electricity using an SMS service. If the prepaid consumption becomes exhausted the SHS is locked until another pre-payment is made. When the full cost of the SHS have been paid for in this way it unlocks permanently (Simpa Networks, 2013).

Another example is the SharedSolar project that has been pilot tested in some of the Millennium Villages in Mali and Uganda. The idea is to provide a grid-like service in remote areas with a generation- and metering system based on a PV system. AC power is distributed from a central facility to a number of households, which each of them has their individual connection and metering. A custom metering software allows for the electricity tariff to change depending on the time of the day, and is used to keep track of the electricity usage for each customer. The payments are made on a pre-payment basis using the GSM network. Through RMC the electricity is cut off when the pre-paid electricity is exhausted, or if the customer has reached the limit of the amount of electricity, which can be used per day and has been agreed on beforehand.

A major challenge with the SharedSolar design is the cost of additional hardware to provide metering and the extra power consumed by the metering-, communication- and switching components. In relation to the power consumed by the customers it is not a commercially viable solution with the technology available today. This type of design also requires skilled engineers to manage the server and communication maintenance, which further increases the costs, even though the monitoring system and the centralized design helps to facilitate the general maintenance of the system. There are also some problems with latency in the GSM networks, which causes customer frustration when the pre-payment function is not responding. The current design of the system is well suited for dense settlements, where the wires can be kept short. In areas where the households are more spread-out the cost of the wiring would become disproportionally high. The best solution is if the wires can be installed underground, since this lowers the risk of tampering. In areas with inappropriate geotechnical conditions where over-head wires is a better solution, tampering could become a problem (Soto, et al., 2012; SharedSolar, 2013)

5 ISSUES TO CONSIDER WHEN DESIGNING PV SYSTEMS IN DEVELOPING COUNTRIES – STAKEHOLDER SYSTEM LEVEL

This chapter describes some issues important to consider when designing small-scale, off-grid PV systems in rural areas in developing countries. According to literature the design of a PV system can affect how easy it is to handle installation, operation and maintenance of the system (Ciudad Universitaria, 1998; International Energy Agency 2012a; Wilkins, 2002; World Bank, 2012; International Energy Agency, 1999; Spiers, 2003). During the last decades many donor programs and projects have provided small-scale photovoltaic (PV) systems to people living in rural areas in developing countries. Some of the important issues to consider in PV programs and projects have been extensively covered in the "Recommended Practice Guides" from the International Energy Agency Task 9 (International Energy Agency, 2013). In these documents different issues are covered, such as; the different phases of designing, planning and implementation; capacity building requirements; quality management; payment organisation; hardware certification and accredited training in PV programs.

However, a PV system is part of a larger stakeholder system and it is not only technical issues that affect the long-term operation of a PV system. Also the challenges of the institutional/organizational, economic and social situation of people in the local area, in which the PV system is operating, play an important part. Some of these challenges, together with some lessons learnt, are described in literature. (Wilkins, 2002; Murphy, et al., 2009; Murphy, 2001) Some challenges, which occur when a new technology is introduced in a developing country in East Africa are described, and the concepts of technology transfer and appropriate technology are here presented.

The literature review serves as a base when investigating if the concept of technological complexity could have any relevance in the context of technology transfer, as well as when analysing the main considerations of the stakeholders of interest.

5.1 Main considerations and challenges when designing off-grid PV systems in rural areas

The designer of a PV system needs to consider the fundamental question of ensuring a balance between the supply and the demand of electricity. The design of a PV system can be carried out by an engineer/technician on site, an engineer/technician in a different location, or the system can be purchased as a standardised package, where all the components are already chosen. When it comes to electrification programs the World Bank (WB) has pointed out that there are three often conflicting viewpoints in the design phase of PV systems: The (i) international financial institutions, which are often oriented towards electricity for basic needs and cost-benefit analysis, (ii) end-users who often prioritise watching TV highest, and (iii) engineers, who typically determine standardized need levels and system sizes. There needs to be a balance between these three viewpoints for a successful sizing of off-grid PV systems (World Bank, 2012).

Generally, the users/owners of PV systems are interested in the service that the electricity of the system can deliver, rather than the PV system or the electricity in itself. Some services that the users want are; to charge their phones, light during the night, and to watch TV (International Energy Agency 2012a). In Kenya, access to TV has been a very strong driver for the purchasing of PV systems in rural areas (Jacobson, 2007). Most people prefer to have a connection to an electricity grid, because it allows them to use electricity whenever they need it and there are not the same limits for using high peak power (International Energy Agency 2012a).

5.1.1 Simplicity, user-friendliness and flexibility

Simplicity and flexibility of the system is of great importance when solar home systems (SHS) are designed for rural areas in developing countries (Ciudad Universitaria, 1998). One important aspect of simplicity is user friendliness. Seen from the user perspective, the SHS should be easy to understand, use and maintain. From the perspective of the technician/designer, the SHS should be easy to install and maintain, and it should be easy to replace components. Rogers refers to simplicity as an important factor for members of a social system to adapt to a new technology (Rogers, 2003).

A SHS can be considered as rather simple for users, when the intrinsic limitation of the available electricity delivered from the system is understood. One hardware component, the charge controller, is particularly important for the understanding of the amount of electricity available in the system. The charge controller’s main task is to control battery charging and protect the batteries from deep discharging. As regards to user-friendliness, the charge controller can also contribute with an important pedagogical function. The symbolic green yellow and red light can help the user to become aware of the state of energy in the battery, which makes it possible to plan the energy usage and prioritize the loads (Ciudad Universitaria, 1998). This can make the PV system more user-friendly. However, to be able to plan the energy usage, the users need to have the required knowledge and awareness to make use of the charge controller in this way. If specific knowledge is needed to benefit fully from the charge controller, it can be seen as less user-friendly. However, the presence of a charge controller is always beneficial, even if the user does not understand what it is or why it is there.

Flexibility in this context means that PV system components and spare parts are available locally, that the SHS is flexible in terms of changing sizes of components, and that replacement of components from another supplier is possible. It should be possible to enlarge the PV system, if the demand of energy increases, by increasing the power capacity with PV modules and batteries (Ciudad Universitaria, 1998).

5.1.2 The connection between quality in products and installation, maintenance and reliability in the operation phase

The two characteristics; quality and reliability of PV systems, have been discussed in literature. The characteristic of technical reliability is in this Master’s thesis understood as the system’s ability to deliver the sufficient quantity and quality of electricity during its estimated lifetime. The quality of products is essential to increase the reliability level of a PV system during its operation phase. Good quality of the technical components is also highlighted as an important factor in literature (International Energy Agency 2012a). The quality of a SHS can be evaluated in terms of its reliability, energy performance, safety, user-friendliness and simplicity of installation and maintenance (Ciudad Universitaria, 1998). Quality is hence seen as a superordinate concept where the subordinated characteristics serve as a confirmation that the whole PV system has quality. However, quality as a concept is most commonly used in daily speech, to describe the quality of products or installation works.

The characteristics of quality and reliability are closely related. The quality and reliability of a SHS, in the aspects of lack of failures and lifetime of the PV system, depend on several things; the reliability and quality of the components; the quality of the installation; how the components are sized; and the voltage threshold of the charge controller. The components must also be suitable for local conditions. Each component of the system must fulfil the required quality and reliability – one single bad component could limit the quality of an otherwise perfect system. When it comes to technical failures of SHS, the most common failures are caused by some of the balance of system (BOS) components and not by the PV module (Ciudad Universitaria 1998; Wilkins 2002). The WB (2012) addresses the need for reliability in SHS programs. It is recommended to give importance to appropriate technical specifications, national lab testing procedures and reception tests, to guarantee reliability. The Solar Energy Institute of the Madrid University has created a dataset based on data from the field performance of 50 000 solar home systems in Sub-Sahara, Latin America and the Caribbean. The key challenges for PV-based rural electrification, according to their field study, are reliability and appropriate sizing to meet the actual demand (World Bank, 2012).

Studies have shown that today there is a lack of quality standards and labelling of PV technology. It has been found that there exists hardware on the market, which is below internationally accepted standards or is not appropriate for local conditions. Local design, installation and maintenance practices have not been standardised. The lack of quality standards and labelling of PV system components is perceived as a challenge of the PV market today. It can result in reduced performance and reliability and thereby shorten the lifetime of the systems. Also the lack of warranty is a challenge. Even if warranty sometimes can be given for products, the warranty is still rarely utilised in practice (Wilkins, 2002).

When installing a SHS it is important that the technician installs the system in a proper way and that proper additional installation material, such as screws, battery connections, wirings of right size etc. is used. The system should be installed in a protected place and the batteries should be kept in a well-ventilated place. An appropriate charge controller will increase battery life and improve the system performance. In hot climates the battery should be shaded and put in an as cold place as possible. In cold climates the battery should be protected from extremely low temperatures to prevent freezing. It should be easy to control and maintain the components in the SHS. This can be seen as a good quality installation (Ciudad Universitaria, 1998; International Energy Agency, 1999; Spiers, 2003). Studies have shown that many installations of PV system are not performed in a standardized way, which makes it more difficult to make an installation of good quality (Wilkins, 2002).

There is a need for maintenance of PV systems. Some of the maintenance tasks which can be carried out directly on site are; cleaning of PV modules; mounting of wires; refilling distilled battery water; cleaning battery terminals from corrosion; and changing fuses, lamps and charge controllers (Ciudad Universitaria, 1998). To perform the maintenance tasks is necessary to make the PV system reliable. Maintenance and reliability are crucial issues in remote areas since there can be difficulties, delay and high expenses connected to technical support. It is also emphasized in literature to not underestimate the level of competence required to operate and maintain a PV system, so that users and technicians on site are able to understand, repair and handle the maintenance of the system (World Bank, 2012).

Studies have shown that a lack of lasting maintenance structures is a significant weakness of the PV systems' delivery service in many SHS programs (World Bank, 2012). The PV systems might not be efficiently used, or maintained in a proper way. The owners might fail to purchase all of the system components, or not manage to replace the broken or malfunctioning components in time. This can lead to poor performance or hazard situations. For example it has been found in studies that charge controllers many times are left out in PV installations in Kenya, which reduces the control over the important charging/discharging process of the batteries (Murphy, 2001). The WB (2012) argues that this to some extent can be resolved by implementing large-scale programs with high densities of PV systems. Higher densities can contribute to a growing business for local companies to specialize in professional operation- and maintenance service and training of local technicians (World Bank, 2012).

Quality of products, as well as proper installation and maintenance is a question strongly connected to finance and affordability. The main challenge when it comes to absorption of technology in a region is the high capital costs compared to the low income levels for most of the rural households in East Africa (Murphy, 2001). Lack of finance makes it hard to purchase quality products and hire educated technicians to install a PV system. The need for credit systems available for rural households is highlighted in literature. In discussions regarding why Kenya has not yet reached a full potential PV market, it is argued that the main reason is a lack of sufficient capital to purchase the equipment (Wilkins, 2002).

During the lifecycle of a SHS there are many costs to take into consideration and it is important to consider the customers' ability to pay. First of all, the initial system cost, makes it economically impossible for most Tanzanians to purchase a system. Furthermore, the costs for maintenance, replacements of parts and repairs of SHS are often underestimated (International Energy Agency, 2012b). Hence, to make PV systems affordable for people living in rural Tanzania it becomes important to look into financing methods and payment organisations concerning both implementation costs and savings for future needs. At a policy level it is understood that a self-sustaining PV market is very much depending on the institutional framework. The International Energy Agency has addressed this, and describe what mechanism could be put in place to ensure a healthier development of the PV market in rural areas. In the case of a direct sales approach, credit and loan schemes play an important role (International Energy Agency, 2003b).

5.2 Technology transfer, appropriate technology and connected challenges

The concept of technology transfer can, according to Wilkins (2002), be defined as the diffusion and adoption of new technical equipment, practices and know-how between different actors (e.g. government sector, private sector, financial institutions, research bodies, non-governmental organisations (NGOs), etc.) within a region, or from one region to another. The need for knowledge and training of both users and local technicians in usage and maintenance of PV systems are commonly highlighted in literature (Wenham, et al., 2007; International Energy Agency 2012a; Kivaisi, 2000; Murphy, 2001; Ulsrud, et al., 2010). It is also emphasized that the PV user's feeling of ownership and responsibility for the PV system is an important factor connected to the maintenance tasks. If a PV system is received from a donor, it can result in that the users do not feel responsible for the system or the maintenance and operation of it. However, if people pay for a PV system themselves, both the feeling of responsibility and willingness to take care of the PV system increase (Wilkins, 2002; (Murphy, McBean, & Farahbakhsh, Appropriate technology – A comprehensive approach for water and sanitation in the developing world, 2009).

Furthermore, some of the key lessons learnt, especially in PV projects, are that there is a need for long-term commitments between the stakeholders, and that the institutional settings play an important role (International Energy Agency 2012a; Ulsrud, et al., 2010). Wilkins' studies regarding technology transfer have showed that there is lack of systematic training of manpower in the field. There has been little education in PV technology in rural- and off-grid markets and other markets where the technology is viable (Wilkins, 2002).

The diffusion and adoption of a new technology in developing countries has showed to be complicated. According to Wilkins a successful technology transfer includes an awareness of the following aspects: affordability, accessibility, sustainability, relevance and acceptability (Wilkins, 2002). Some of these aspects are, as confirmed by the literature review, important when designing off-grid PV systems in rural areas. Affordability, which might be one of the major obstacles can be overcome by credit schemes. Accessability to the benefits of the technology can be enhanced by market development, more well educated local technicians and access to spare parts in the local areas. Relevance is in this context depending on the demand for electricity, which is there. Acceptability of the technology can be enhanced by user education and awareness raising. Furthermore there is a need for commercial management and market development. Economic competitiveness, technical adaption to local conditions, as well as to meet the energy requirements of the people is necessary (Wilkins, 2002).

According to Wilkins "*'Technology' should be regarded not only as the equipment, but also* *the information, skills and know-how which are needed to fund, manufacture, install, operate and maintain the equipment. 'Transfer' should be regarded as putting the technical concepts into practice locally in a sustainable framework so that local people can understand the technology, use it in a sustainable manner and replicate projects to speed up successful implementation."* (Wilkins, 2002)

Murphy (2001) addresses the obstacles connected to attempts to technology dissemination based on the definition of technology absorption, which according to Wilkins are part of the concept of technology transfer. According to Murphy (2001), technological absorption requires the development of technological capabilities, which are defined as the following skills; technical, organizational, and institutional. Access to information is also crucial. These capabilities enable businesses to evolve so that information and equipment can be utilized efficiently (Murphy, 2001). There are many challenges regarding the institutional and organisational structures and it is necessary in a long-term perspective that a market can grow around the PV system (Muntasser, et al., 2000; Mulugetta, et al., 2000).

Technological diffusion occurs in parallel with economic development and social change. Murphy et al. (2009) emphasizes that the main objective of an energy project should be to improve rural people's quality of life, not to disseminate a chosen technology or mitigate an environmental problem. Some energy planners tend to forget this when they plan and design energy projects. Murphy et al. (2009) also highlights that many dissemination projects determine the success by the number of new technology adopters. But numbers cannot properly disclose the utility efficacy or the sustainability of the technology. For example, these numbers do not tell how efficiently and safely people living in rural areas are using the technology, or how many PV systems that still operates after a longer period of time. Neither does the number tell if there has been a market created around the new technology, if any local entrepreneurs or businesses have been started, or if components are manufactured locally. Additional information is needed to be able to determine if the technology has been absorbed into the local area or not. According to Murphy et al. (2009), technology transfer and dissemination of energy technologies has been largely dependent on funding sources and technical assistance coming from outside of the (beneficiary) countries. Both Wilkins (2002) and Murphy et al. (2009) highlight the importance of knowledge and skills of the actors of the local PV market when it comes to technology transfer, dissemination and absorption (Wilkins, 2002; Murphy, et al., 2009). Murphy et al. (2009) addresses that independent and successful entrepreneurs in the PV system business are needed, who produce, market and service PV systems and the connected components. Without that kind of entrepreneurs it is unlikely that the PV systems would be absorbed and disseminated into the area (Murphy, et al., 2009).

Also the concept of appropriate technology is discussed. The definition and meaning of appropriate technology can vary depending on the field of application. Murphy et al. (2009) describes appropriate technology as something more than tools and techniques, Appropriate technology concerns more diffuse aspects that affect what is regarded as an appropriate technology, such as; knowledge transfer mechanisms; and social-, cultural- and gender issues.

For a technology to be appropriate, it always has to be adopted within the local circumstances where it is applied. (Murphy, et al., 2009)

The concepts of technological transfer and appropriate technology shows that that there is a body of literature that addresses how new technologies could be transferred and absorbed into developing countries. However, a top-down perspective is found to be used in many of the donor funded PV projects and programmes implemented in rural areas in developing countries. This is somehow expected, since a donor organisation or a company sets the goals connected to the implementation of the new technology. Also the studies and guidelines that have come out of PV system implementations are in this literature review found to use a top-down perspective. Even if these studies aim to to take the local context into consideration, the recommendations might not always be based on the full insight of the actual needs. Brent and Kruger (2009) highlight that renewable energy systems for remote areas in Africa often are designed with financial and technological considerations in focus, since the main stakeholders have this perspective. This results in an approach that does not necessarily lead to a holistic sustainable rural development. (Brent & Kruger, Systems analyses and the sustainable transfer of renewable energy technologies: A focus on remote areas of Africa, 2009)

5.3 Summary of the literature review

The literature studied shows that there are many aspects to take into consideration when it comes to designing PV systems in rural areas, as well as when transferring a technology to a developing country. Even if there are well-described theoretical guidelines concerning how to design, install, operate and maintain a PV system in a proper way, there are many challenges to be overcome to make PV systems operate well in a long-term perspective in practice. The local context and the stakeholders surrounding the PV system are the main factors affecting the success of the operation of the PV systems, both during the installation- and operation phases. This is not something that can be changed by designing the PV system in a certain way, since the local context is not something that can be designed away. It is also important to remember that the literature studied is mainly presenting a top-down perspective, where academics, engineers from the western world and large organisations present their findings in academic articles, reports and written guidelines.

This literature review has also contributed to an understanding of how a technical PV system can be studied at two different system levels. This was first presented as a conceptual model in figure 2 in section 2.2 and is here showed again, see figure 6. The figure shows the technical PV system, including its hardware and software (technical system level), in relation to the surrounding stakeholders and the local context (stakeholder system level). These relations have been addressed from different angles in this chapter.

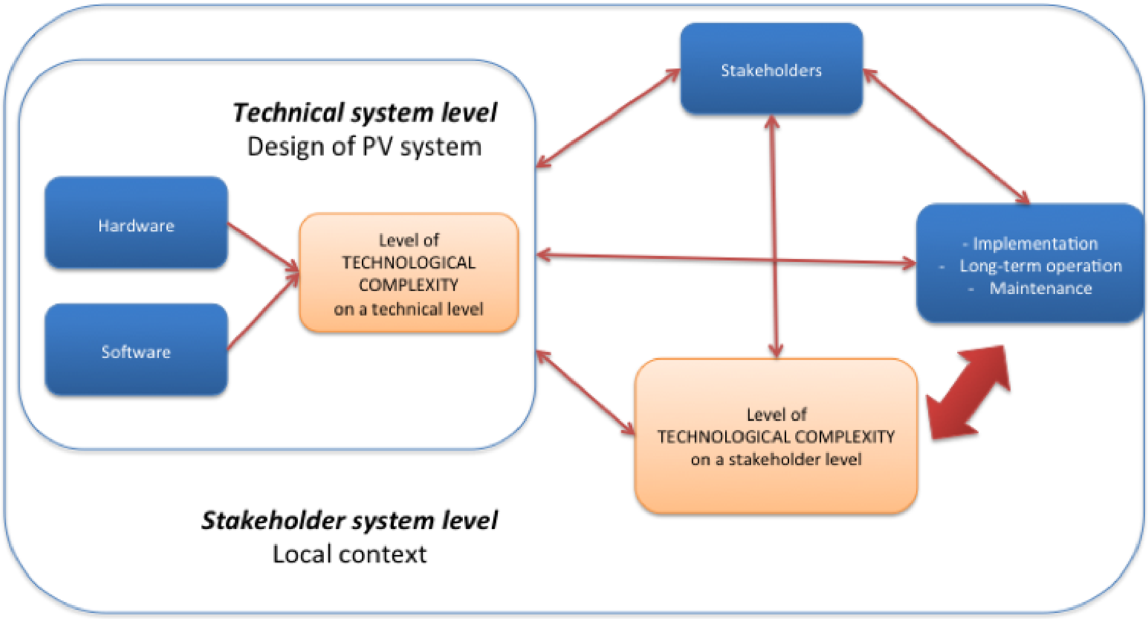


Figure 6: Conceptual model of the assumed relation between the level of technological complexity and implementation and long-term operation. The level of technological complexity is a result of the PV system design. The model shows how the PV system is related to surrounding stakeholders and the local context.

6 PV MARKET AND STAKEHOLDERS IN TANZANIA

This chapter briefly describes the Tanzanian photovoltaic (PV) market, and the stakeholders linked to it. The stakeholders most relevant for this Master's thesis are presented in section 6.2, and some background facts on the Tanzanian PV market is presented in section 6.1.

6.1 The PV market in Tanzania

The PV market of Tanzania started to develop in the 70's, after the first oil crisis in 1973/74. The initial demand for PV systems was mainly driven by electrification of institutions in rural areas, like health centres, churches and schools. Later, in the 90's a market for solar home systems (SHS) started to develop, partly as a spill-off effect from Kenya, where the SHS market began to evolve about ten years earlier. This is when companies selling SHS to households started to emerge in Tanzania. The SHS market was initially driven by the availability of TV sets and radios and the spread of broadcasting signals in rural areas not connected to the electricity grid. Later on, mobile phone charging and lighting in homes have become important drivers, and today those are the main reasons for buying a SHS in Tanzania. International donors and development organizations have played an important role in the development of Tanzania's solar market. Large parts of the market still depend on funding and active support from the government and these donors (Ondraczek, 2013).

The past years the amount of annual PV sales in Tanzania has grown rapidly from 100 kW_p in 2005 to 1.16 MW_p in 2009, and at this point it was estimated that 0.6-1 % of the rural households used solar energy as their main electricity source (Ondraczek, 2013). The market growth trend partly depends on the in general declining global PV prices. However it was noticed that during the period 2005-2011 there was a trend of increasing prices due to increased international demand of PV system components. At the beginning of 2008 the Tanzanian Government exempted all solar equipment from taxation (value-added tax (VAT) 18 %, import duties etc.) as an incentive for market growth. During that period the increased prices and exemptions of taxes were each cancelling out the other, and as a result the average price for a PV system did not change (Camco Advisory Service Tanzania, 2011).

Generally, it is very rare in all parts of the world that financial intermediaries, even the micro-finance sector, offer credits for SHS (International Energy Agency, 2012b). Tanzania is not an exception – 99 % of SHS are sold on a cash basis. The principal reason for the lack of credit finance stated by PV dealers in a survey made by the Sida/MEM Solar PV project is the country's poor history with rural lending and that many people do not honour their financial commitments (Camco Advisory Service Tanzania, 2011).

6.2 Stakeholders

All the various stakeholders linked to the PV market have an impact on the way that PV systems are designed. It is important to have a background of these different stakeholders to be able to understand what their main considerations are regarding the design of a PV system.

Different stakeholders have different motives for promoting a technology, and this has an impact on the development of the system. Wilkins (2002) says that the nature of renewable energy systems (RES) is often that they are small-scale, de-centralized systems with a large number of stakeholders. This is also the case for off-grid PV systems. Wilkins (2002) describes the key stakeholders connected to technology transfer of renewable energy technology as including policy-makers, legal and regulatory bodies, development agencies, financiers, utilities, manufacturers, suppliers, developers, installers, consultants, academic institutions, NGOs, community groups, recipients and users of the technology (Wilkins, 2002). In this Master's thesis the stakeholders in focus are the ones who design, supply, install, use and maintain the PV systems. Also knowledge institutions are of interest.

In the following sections a selection of stakeholders closely linked to the PV market are described; the Tanzanian government, donors and non-governmental organisations, consultancy firms, knowledge institutions, customers and beneficiaries, local technicians and dealers, and PV companies.

6.2.1 The Tanzanian government

The Rural Energy Agency (REA) is an autonomous body under the Ministry of Energy and Minerals of the United Republic of Tanzania (MEM) that became operational in October 2007. Its role is to increase the access to modern energy services in rural areas of the mainland of Tanzania, by using the Rural Energy Fund (REF). The purpose of REF is to provide grants to qualified project developers, to be used for capital costs of projects implemented, capacity building and financial assistance. Both REA and REF are governed by the Rural Energy Board (REB). REB and REF were both established by The Rural Energy Act in 2005 (REA, 2013). According to the body of literature concerning rural electrification in developing countries, governments should take a facilitating role in the area of off-grid PV systems. However governments should not interfere with the market, nor provide equipment subsidies, but instead gradually eliminate kerosene subsidies. The focus should be on quality assurance schemes, dissemination of reliable information and education of customers. Donors can play an important role by supporting micro-credit schemes, funding programmes to educate target groups, and helping to guarantee a minimum level of system quality (International Energy Agency, 2012b).

6.2.2 Donors and non-governmental organisations

In Tanzania donors have historically played an active role in the promotion of PV systems. One example is the Sida/MEM Solar PV Project that was implemented 2005-2010, which was funded by the Swedish International Development Agency (Sida) through the MEM. The overall goal of the national project was to contribute to the growth of the Tanzanian PV market, with special focus on the rural market, by creating market supply and -demand. This was done by, among other things, training of local PV technicians and -dealers, awareness raising among customers and support of the Tanzania Renewable Energy Association (TAREA) (Camco Advisory Service Tanzania, 2011). Another example is the Lighting Rural Tanzania Competition (LRTC), which is a collaboration between the World Bank (WB) and

REA. In LRTC various kinds of organisations submit project proposals to compete for money to implement projects with the aim to bring off-grid electricity solutions to rural Tanzania. The character of the competition can be compared to a challenge fund. Most of the donors and NGOs are focusing on implementation of systems for institutions like schools or hospitals. However, during the past years there have been other types of initiatives, like the Sida/MEM Solar PV Project, where the focus is to stimulate the PV market. Another type of project character that has developed more recently is projects where individuals being part of groups, working associations for example, get assistance to micro-finance their own PV systems – an example of this is an on-going project in the Lake Region, financed by the WB.

According to al Fayadh[1] there is a market distortion when it comes to the off-grid electrification market, since the investment at stake is relatively low for smaller energy systems. This is due to uncoordinated support, in terms of subsidies of material and education, coming from electrification programs on national, regional and global level, as well as a myriad of smaller non-governmental organisations (NGOs). The work of developing partners such as Sida is to support the private sector with the help of different financial instruments – either directly or through support to REA. To do that without distorting the market is a challenge, and according to al Fayadh[1] coordination is needed to create the very much-needed PV market development.

TAREA is a membership based association and a central player in the promotion of renewable energy in Tanzania, founded in year 2000 and based in Dar es Salaam. The main function of TAREA is to connect the renewable energy stakeholders in Tanzania and other countries, with the aim to raise the renewable energy sector in Tanzania. They work with education and research, dissemination of information, networking, representation and project support (TAREA, 2013).

6.2.3 Consultancy firms

Consultancy firms are many times working for a donor or the government, with the task to manage different types of PV projects, related to implementation of PV systems or education for example. The consultants hired for the tasks can be for example different experts from universities, or engineers, employed by a consultancy firm.

6.2.4 Knowledge institutions

Universities and other educational institutions have an important role in spreading the knowledge about renewable energy, and carrying out research within the field. The Vocational Education and Training Authority (VETA) has training centres in different parts of Tanzania, and they are, among other types of courses, providing education in electronics. In Mwanza they are specifically giving a course on PV systems. During the Sida/MEM PV Project, all VETA training centres were provided with training in order to be able to give

[1] Samer al Fayadh (First Secretary at the Swedish Embassy, Dar es Salaam, Tanzania) interviewed by the authors 28th of March 2013.

courses in PV installations on a fee-basis. However there was insufficient demand at the time to carry out such courses. One of the reasons for this was that similar training had been provided for free by donors earlier on (Camco Advisory Service Tanzania, 2011).

6.2.5 Customers and beneficiaries

Historically, missionaries and other donors of different kinds have implemented PV systems in Tanzania in churches, schools, hospitals and institutions. It is common that hospitals and schools are beneficiaries, rather than buyers of PV systems. The cost of a SHS is a significant challenge, and most families in Tanzania cannot afford to buy a system upfront. The average cost of a 50 W_p SHS is more than the double per capita income in Tanzania and there are few opportunities to pay a system in installations. 99 % of the SHS are sold on a cash basis (Camco Advisory Service Tanzania, 2011). The typical customer of a SHS in Tanzania is a middle-income family. In rural areas it was mostly teachers or governmental workers who could afford to by a SHS a few years ago, but nowadays it seems that also farmers can afford a SHS as the system prices are decreasing. There are also many types of pico-PV systems that can be an alternative for customers who cannot afford to buy a whole SHS. There are many PV products that are substandard. This is an issue that most customers are not aware of. They might not understand the importance of product quality, but rather prioritize a cheaper price. Also when customers are aware of the quality issue, a system with lower quality can be a more attractive option, because it becomes affordable. Beneficiaries, on the other hand, are provided with systems designed by a donor. Donors are aware of the quality issue to a higher extent than the individual customers, and do not have the same economic restrictions, which commonly results in PV systems of high quality for a higher price.

6.2.6 Local technicians and dealers

Local technicians can sometimes be hired by a larger PV company to install PV systems for the company in the village or region where the technician is living. Some local technicians are self-employed, and many times local technicians collaborate with local dealers or have their own PV shop. The knowledge level, regarding PV systems, of technicians who install and maintain PV systems varies a lot depending on what kind of education they have undergone. The local dealers can get their supply of PV products from various sources. Some local dealers only sell PV products with a high quality level delivered by larger PV companies. Others get their supply from local markets in larger cities where the product quality can vary a lot.

6.2.7 PV companies

In Tanzania there is a mix of companies working with PV systems. There are companies that only sell separate PV components, and there are companies selling PV systems as a whole solution, with the installation and sometimes even the maintenance included. There are a few established companies that started off with other types of electronic components, and are just adding PV components to their supply. Then there are companies that started in Tanzania with the aim to target the Tanzanian PV market specifically. Many of the larger PV companies are based in the economic capital Dar es Salaam. The need for off-grid PV systems is larger in areas where the grid has not yet been extended, but due to frequent power outages there is also a demand for PV systems in areas where the electricity grid is already built-out. Hence, many of the systems sold in Dar es Salaam are backup systems. It is also common that people who live in the cities buy PV systems for their relatives in rural areas.

7 PRESENTATION AND ANALYSIS OF THE RESULTS

In this chapter the five research questions are addressed based on the analysis of the results. Findings from site visits at PV systems in rural Tanzania, as well as interviews with the three stakeholder groups; technicians, PV company employees (PCEs), and energy sector stakeholders on national level (ESNs) are presented and analysed.

In section 7.1 the site visits at small-scale PV systems are presented. Section 7.2 describes the stakeholders' main considerations, related to PV system design, and their motivations for these. In section 7.3 the question of variations in design is addressed. The level of complexity at technical- and stakeholder system level for two different types of design is analysed. In section 7.4 the perception of the concept of technological complexity among the different stakeholders is addressed. In section 7.5 the usefulness of the concept of technological complexity in the context of PV system design is analysed. The relation between the stakeholders' main consideration and the concept of technological complexity is also analysed in section 7.5. Finally, the question of whether the concept of technological complexity could have any relevance in the context of technology transfer is addressed in section 7.6.

A stakeholder focus is applied, based on a systems approach. It is acknowledged that different stakeholders affect and get affected by the design of the PV system in different ways. The interviews with technicians are closely linked to the site visits at PV system installations and observations made by the authors, while the interviews with PV Company employees (PCEs) and energy sector stakeholders (ESNs) give slightly different, more theoretical perspectives.

7.1 Findings at visited PV systems

This section is based both on observations made at PV system installations and interviews with technicians. The results from the site visits serve as a frame of reference of what a small-scale PV system in rural Tanzania can look like. This is valuable when discussing variations in design and technological complexity.

First, an introduction of the visited PV systems is given in section 7.1.1. The general design, financing of the PV system and future system costs, and lifetime expectations for the different systems are described. In section 7.1.2 a description of how maintenance and operation was carried out is given. The topics of awareness, responsibility division and common maintenance issues are addressed. Finally, in section 7.1.3, some similarities and differences observed in the PV system design are described.

7.1.1 Introduction of the visited PV systems

Site visits were paid to PV system installations at ten different places in the Ruvuma region, Tanzania. Four institutions – three schools and one dispensary –, and six private homes were visited. All but three of the PV systems included in the study were designed and installed by the technicians interviewed. Technician 1 had made the major part of the PV system design and installations at two of the schools. Technician 3 had designed and installed the systems at the third school. The dispensary system was designed and installed by a PV company as a part of a larger project, where in total 40 dispensaries in the region had been provided with PV systems. Three of the private systems were designed and installed by Technician 2, and one by Technician 3. One private system was installed by a PV company as a part of a "cluster project", and one system was installed by the owner himself, who did not have any education in PV technology. The technicians interviewed, who also assisted as guides and translators during the site visits have been presented in method, section 3.7.1.

Each school had between two and five separate PV systems. The dispensary and all the private persons/families had one PV system each. In total 17 PV systems installed between the years of 2007 and 2012 were observed, where the majority of the systems had been operating for 3 years. All the PV systems were in the size of solar home systems (SHS)/stand alone PV systems of less than 0.5 kW_p.

At a technical system level the systems were fairly similar in design and size, and the majority of the PV systems were designed with the components: PV panel, battery, charge controller, BOS components, and sometimes an inverter. None of the visited PV systems had additional software in terms of a remote monitoring- and controlling system (RMCS), and the technicians were not familiar with using any additional software. The PV arrays had a power range of 60-480 W_p, the charge controllers, when existing, had the capacity of 6-45 A and the battery banks consisted of 1-4 batteries with 75-210 Ah at 12 V. About half of the systems also had an inverter, to supply loads with alternating (AC) current, and the inverter capacities were between 180-1000 W. Two of the systems were designed to deliver only AC, seven systems were delivering only direct current (DC), and eight systems were delivering both AC/DC. Four of the visited sites had access to electricity from other sources as well; two of the schools had a fuel generator, and two of the private systems were connected to the regional electricity grid.

The initial idea of investing in a PV system came from the users themselves for the private systems, and from teachers or the headmaster for the schools. For the dispensary the idea had been introduced from outside and the District Council owned the system. What differed most between the different PV systems at a stakeholder system level was the means of financing – there was a mix of donor funded systems and privately funded systems and variations in possibilities to split the payment. The schools and the dispensary had received grants from different donor organisations to cover the whole, or parts of, the cost for the PV systems. This was the case for one of the private systems, which was part of a "cluster project", where several hundred PV systems had been installed at the same time. The PV systems in the project had been subsidised with a small percentage by the Rural Energy Agency (REA) and the World Bank (WB). The family had been given a micro-loan to be enabled to pay in instalments during a period of three years.

For two of the six private customers and two of the schools it had been possible to pay for the PV system in two or three instalments, due to their good relationship to the technician whom they purchased the system from. According to one of the technicians a trustful relationship between technician and customer is a prerequisite for payment in instalments. Long geographical distances is a factor that also can make it difficult for technicians to give the customer this possibility.

The majority of the private persons had not reflected upon for how long the PV system would operate, while some had the expectation that it would operate for a couple of years. For the institutional systems, the expectations among the users were that the systems would operate for three years, or a couple of years. The technicians were in general expecting that the systems would operate for at least as long as the warranty for the different components were valid, which in general was 4 years.

All of the three schools were saving money for future maintenance needs by adding an extra fee to the school fees collected. The dispensary had a maintenance plan where they would collect money from payments for mobile phone charging. However the income generated was low, since people living in the area had been inspired by the idea and had started up similar activities. Only one out of six of the private families were saving money for future maintenance needs.

7.1.2 Maintenance and operation

There were no standardised procedures among the visited PV systems regarding maintenance tasks. The awareness of the need for simple maintenance, like; cleaning the PV panels, topping up battery water, and cleaning the battery terminals from corrosion varied among the users, both for the private and institutional systems. Some users were of the opinion that there was no maintenance needed at all for PV systems.

The technicians would come to supervise a private PV system only if the customer called for assistance. All the technicians stated that they give information to the customers regarding maintenance needs, but it became obvious that it was not clear to all users if it was the user or the technician who was responsible to carry out the necessary tasks. The relationship between the technician and the customer seemed to play a role here, and in some cases there appeared to be an issue of communication between the technician and the customer. In those cases where it was clear to the users what responsibilities they had, simple maintenance was carried out more frequently.

To some extent it seemed like private persons were in general more aware of the need for maintenance, than some of the employees at the institutions. This can be interpreted as a result of the connection between personal interest, ownership and the feeling of responsibility. The three schools and the dispensary had received grants for the PV systems, but the private persons had had to pay from their own pocket, which could be one of the reasons for the increased feeling of responsibility.

Two private systems diverged from the others. The first one had been installed by the owner himself. He was not aware of the need for maintenance, and did not have contact with a PV technician. The second one was installed as a part of a “cluster project”. The customer had been provided with a three years warranty for the whole system from the responsible PV company. The instructions from the company to the customer was to not interfere with the system or carry out any kind of maintenance. The PV company took responsibility for all maintenance; a technician was sent to supervise the system regularly, and the customer could call in case of any problems. This explains the choice of dry, maintenance free batteries, and the “box-design” – see picture 1, to the right. The box-design and the maintenance contract could be seen as an attempt to a more user-friendly design, where the customers do not have to take any responsibility for the maintenance of the PV system. However, since the box design made it more difficult for the users to access the system the users might not get the same understanding for the PV system. Worth noting is that it was unclear to the users what the maintenance plan was after those first three years of maintenance warranty.

Picture 1: AC/DC PV system part of a “cluster project” with “box-design” and dry batteries inside the box.

For two out of four institutional systems, a technician would come to supervise the PV systems a few times per year, and if the customers called for assistance in case of any problems. For the rest of the institutional systems, a technician would come only if the users called for assistance, which could be in a situation when the system did not deliver any electricity at all. The frequency of supervision partly seemed to depend on the personal relation between technician and the personnel at the institution. The users at the institutional systems were relying totally on a technician for all maintenance, except for two of the schools, where staff or students were cleaning the PV panels.

At two of the schools renovations of the systems had been carried out. Two DC systems had been in need of change of batteries two years after installation, since the wet batteries had not been topped up with battery water in a correct way. For one AC/DC system the batteries had been changed from wet to dry batteries after three years, due to that the electrolyte in the batteries had showed to be of low quality and had destroyed the batteries. The same AC/DC system had been in need of a new inverter four years after installation, and a new charge controller five years after that. The technician did not know what had caused the breakdown of the inverter or the charge controller.

A common reason for breakdowns of inverters mentioned by the technicians was overloading – that users draw a too large power output from the inverter by connecting too big loads, which can affect both the inverter and the whole PV system negatively. For example, the District Council and the staff at the dispensary had been given the information from the PV company that installed the system that it was not allowed to connect anything extra, like a computer or TV, to the PV system. The system had been sized to deliver a certain amount of electricity for lights and a microscope, and if that would be exceeded, the system would break. The charge controller can be used as a tool for the users to supervise the charging level of the batteries, and adapt their power consumption to that. However, the knowledge of PV system technology varied among the users at the sites visited, and only about half of the users knew how to use the charge controller for this purpose. The personal interest in PV systems seems to be the major factor affecting if the users supervise the charge controller or not.

7.1.3 Differences and similarities in design

All technicians interviewed had their own personal way of designing and installing a system. Three factors found having a large impact on the outcome of the design and installation were the purchasing capacity of the customer, the educational background of the technician, and what components and material that is available to the technicians. Several examples of this will here be presented.

One AC/DC system and two DC systems at two of the schools, installed by Technician 1, can be seen in pictures 2 and 3. The components were rigged in a structured way on a panel of wood on the wall and the batteries were placed below the panel. The system was protected from rain and the area was well ventilated. This could be considered a proper installation. The technician’s business card was attached in a visible place on the panel of wood, for the costumers to always have the contact to a technician at hand, which is also important for the operation of the PV system. Technician 1 always installed the batteries for DC systems at schools so that they were hard to see and reach, to prevent theft, since he had experienced that batteries had been stolen from a school. Similar solutions were observed at most of the sites visited. The batteries were locked into a cage, or put in a room where only certain people had access, to prevent theft.

Picture 2: AC/DC PV system with circuit breakers (left) in the administration office at one of the schools.

Picture 3: DC PV system for classrooms at two different schools. Batteries installed high up for security (right).

At the visited sites some observations on component level were made. All PV panels, inverters, batteries and BOS components were OEM (original equipment manufacturer) components and of high quality. This was also the case for all charge controllers, except one, which was locally assembled and not operating. According to the technicians it is very difficult to assemble a well-functioning charge controller. The non-operating charge controller installed at one of the schools seemed to have caused a breakdown of the batteries of the system. The system can be seen in picture 4.

Picture 4: AC system at the administration office at one of the schools. The charge controller is locally assembled, not operating, and has caused a breakdown of the batteries.

One privately owned system – the system where the owner had designed and installed the PV system himself – did not have a charge controller at all. Technician 2 usually installed two smaller charge controllers, instead of one larger charge controller – for example two charge controllers of the size of 6 A instead of having one single larger charge controller of 15 A. This was, according him, due to how he had been taught, as well as the fact that there are not always larger charge controllers available to purchase from the PV dealers. One of the systems installed by Technician 2 can be seen in picture 5. Technician 3 was also planning to implement the same kind of design as Technician 2 in a PV system that was to be expanded, due to cost issues; instead of buying a new, larger, charge controller he would add a second one to the system.

Picture 5: Private AC/DC PV system with two smaller charge controllers.

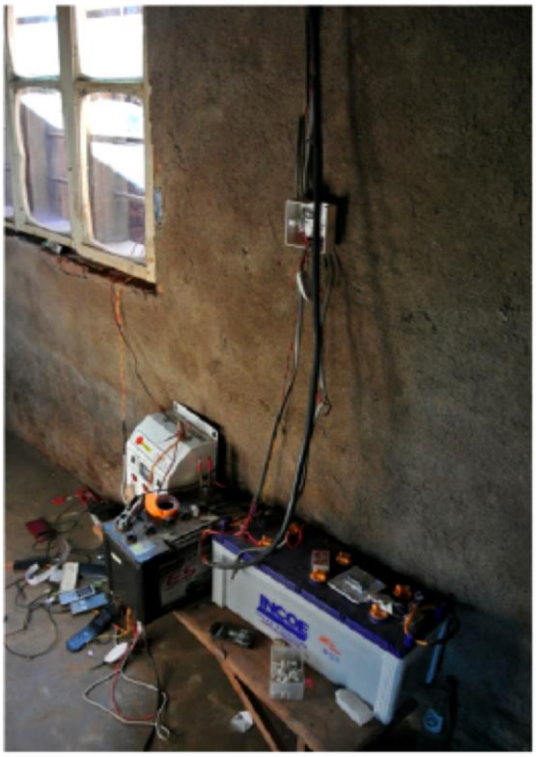
The PV system at the dispensary was the only system observed with a lightning arrestor. One of the technicians said that it was well needed, due to the weather conditions in the region. The system can be seen in picture 6. Some of the systems had circuit breakers installed between the PV panel and charge controller, as well as between the inverter/loads and charge controller (see pictures 2, 3 and 6), in order to protect the system components. However, the majority of the systems lacked this type of security.

Picture 6: AC/DC PV system at the dispensary. A lightning arrestor is attached to the PV panel (left).

At one of the systems observed, the PV panels were attached directly to the roof without an air gap between the roof and the panel – an example of an improper installation. No air gap results in higher temperatures in the PV panel, which lowers the efficiency.

The batteries were wet- or dry deep-cycle solar batteries in all cases except one. Many of the technicians recommended their customers to install dry batteries due to simpler maintenance, since there is no need for topping up battery water. However, one of the technicians expressed that a benefit with wet batteries is that they charge quicker. Many customers choose wet batteries due to their lower price, compared to dry batteries.

A private PV system designed and installed by the owner himself, who did not have any education in PV technology, was standing out from the rest of the visited systems, and can be seen in picture 7. The batteries were not deep-cycle solar battery type, but SLI (starting, lighting and ignition) batteries. The use of SLI batteries instead of deep-cycle batteries in PV systems results in a shorter battery lifetime (International Energy Agency 1999), but can still be a good option for PV systems in rural areas, due to lower cost and easier accessibility (Reinders, et al., 1999). The PV system did not have a charge controller, and the PV panel was directly connected to the batteries. The system had an inverter, which disconnected the batteries when the battery energy level got too low. However, without a charge controller there is no charging regulation when the batteries are charged, which results in an unsafe charging process. It is possible to design a well-functioning, self-regulating PV system without a charge controller, but that puts much higher requirements on the designer and user of the system (Wenham, et al., 2007). The lack of charge controller can lead to an early failure of the batteries due to continuous deep discharging. Another difference compared to the other visited PV systems was that the wiring was not fixed or as structured.



Picture 7: AC PV system designed by the owner. Batteries are of SLI type, and no charge controller is integrated.

The guiding technician did not approve of the design or installation works, since he saw that the system could cause a dangerous situation, and he explained this to the owner. During the discussion with the owner, it became clear that he did not know that his PV system could be dangerous. The main reason for the owner to make this type of design and installation was to reduce the system cost. He had saved money on installation works, by installing it himself, and by the choices made regarding batteries and charge controller. What type of design and quality level of a PV system that is most representative for rural Tanzania is not investigated in this study. However, it can be assumed that the type of design described above is quite common, since many people do not have the economic capacity to hire a technician.

7.2 Main considerations when designing PV systems

Section 7.2 describes and analyses the stakeholders' main considerations, and their motivations for these, when designing off-grid, small-scale PV systems in rural areas, in order to answer the first research question. The stakeholders are divided into three stakeholder groups – technicians PV company employees (PCEs) and enrgy sector stakeholders (ESNs). Many of the topics brought up in studied literature as challenges, or topics important to consider, when implementing PV system technology in developing countries were confirmed by the three stakeholder groups as being their main considerations when considering the whole lifetime of a PV system. The motives behind the main considerations are in general connected to the wish to make the lifetime of the PV system as long and smooth as possible, or the wish to make it economically possible for customers in rural areas to purchase PV systems.

The main considerations brought up by the respondents showed to cover both the PV system design itself, as well as surrounding factors that could affect how well the design matches the needs. This corresponds well to the model developed in chapter 2, with two system levels; the technical system level, and the stakeholder system level. The main considerations at the two different system levels are also many times linked.

The main considerations identified at a technical system level are presented and analysed in section 7.2.1 and the main considerations at a stakeholder system level are presented and analysed in section 7.2.2. All the main considerations identified can be seen in figure 7. In the following sections, the main considerations motivated by the stakeholders are analysed in the light of literature. Furthermore the opinions between stakeholder groups and respondents within stakeholder groups are sometimes compared to each other. In section 7.2.3 a summary and comparison of the stakeholders groups and their main considerations are given in order to answer the first research question.

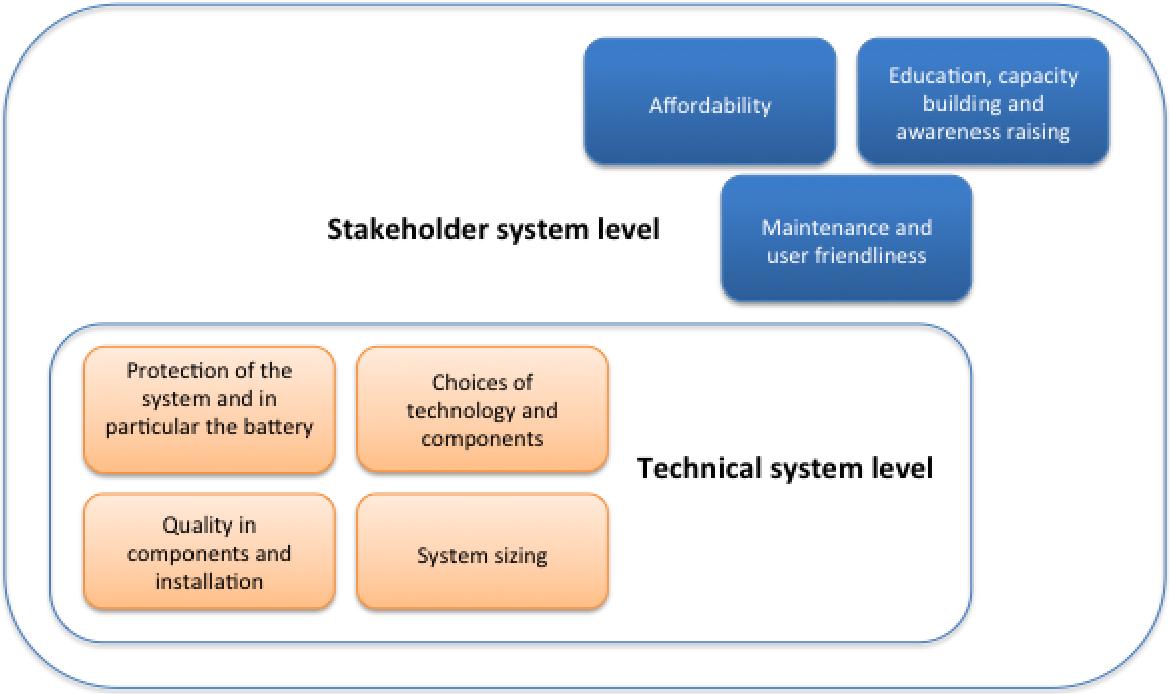


Figure 7: Identified main considerations when designing off-grid PV systems in rural Tanzania.

7.2.1 Main considerations at a technical system level

The main considerations identified at a technical system level are; choices of technology and components; system sizing; protection of the system and in particular the battery; and quality in components and installations.

7.2.1.1 Choices of technology and components

The choice of technology and components was identified to be a main consideration among all the stakeholder groups – technicians, PCEs and ESNs. It is a central part during the design process that will have an impact on the PV system during its whole lifetime, as well as the length of the lifetime of the system. Choice of components does also have an impact on the system cost. Most of the respondents in all the stakeholder groups described small-scale, off-grid PV systems as rather standardised, consisting of a number of standard components; PV panel, charge controller, batteries and BOS components. If the customer wants alternating current (AC), an inverter is needed and sometimes circuit breakers are also installed. This type of standard PV system design is described in chapter 4. The PV systems studied during site visits were most of the time designed in this way. For these standard PV systems OEM components are often used, which most commonly are produced outside of Tanzania and imported. However, some differences in design and PV components were discussed by the respondents, like; different types of OEM charge controllers, inverters and batteries; differences in components' size and quality; plug-n-play PV systems; locally assembled components; and the use of remote monitoring and -controlling (RMC). The latter two will be described and analysed in depth in sections 7.3.1 and 7.3.2.

According to the studied literature, simplicity, user-friendliness and flexibility are important factors in the design of PV systems. Several of the PCEs and ESNs emphasize that it is important to design with components that are easily available on the Tanzanian market, to allow for easier access to spare parts when there is a need for reparation. According to studied literature, access to spare parts is a part of the answer to the need for flexibility in PV system design (Ciudad Universitaria 1998). Access to spare parts also influences maintenance, at a stakeholder system level, which will be further analysed below.

A plug-n-play system provides simplicity and user-friendliness, but not very flexible. As a result of Company 5's ambitions to have a simple and user-friendly PV system they have a plug-n-play design, in order to minimise the risks of possible mistakes, which can occur during installation, operation and maintenance of the PV system. A plug-n-play PV system is sized and designed beforehand by a company, and many times the components are already connected. The approach of plug-n-play was discussed with several of the PCEs. The benefits connected to plug-n-play design are that the system could become more affordable and secure, compared to a PV system where the components are purchased separately and then installed and connected. If the plug-n-play PV system contains less replaceable parts it can result in simpler installation and operation, which is more user-friendly and reduces the cost of hiring a technician to install the PV system. The risk of mismatching different components in the PV system design is reduced considerably. Furthermore the transportation costs could be reduced, since delivering each PV component separately can be avoided. One drawback is that the plug-n-play PV system could become less flexible during the installation phase; there are limitations to how to mount the components, since the wires are sized beforehand. There is also a risk that it would be difficult for local technicians to find spare parts for, and repair a plug-n-play system properly, which also makes this type of PV system less flexible. All the respondents highlighted that there is a lack of knowledge and awareness among users and technicians in rural Tanzania regarding quality of components, installation, operation and maintenance of PV systems. Considering this, it seems like the approach of plug-n-play could be a suitable design approach to overcome some of these problems.

To choose components so that the system becomes robust is considered to be important, and the technicians and one of the PCEs gave examples of this. Many of the technicians are of the opinion that it is preferable to design a combined AC/DC system, rather than an only AC system, to give the customer a more reliable and robust PV system. AC is needed for AC loads – a TV for example and can also be used for lights, while DC can be used for LED-lamps. If a customer has an only AC system and the inverter breaks, the customer will not even have light at night, why the technicians argue that DC is better to use for lights than AC. One of the PCEs said that it is particularly important in rural areas to use technology that has been proven to operate well for a longer time in less rural areas. It is usually more difficult to provide proper maintenance in rural areas than in cities – hence the technology has to be rather robust.

The size of the PV system determines the choice of type of inverter and charge controller, according to the PCEs. The efficiencies of the components have to be sized in proportion to how much electricity the system is delivering. The size and quality of the components is affecting the efficiency, as well as the price. Charge controllers and inverters can also have different functions built-in, which affect the operation, efficiency and price of the system.

According to all the stakeholder groups locally assembled components most commonly have a considerably lower efficiency than OEM components, and are also cheaper. The arguments for and against using locally assembled components will be analysed further in section 7.3.1. All of the stakeholder groups preferred dry batteries to wet batteries, due to its simpler maintenance, which can lead to protection of the system indirectly. RMC was used by three of the interviewed companies, and the arguments for and against using this technology will be further analysed in section 7.3.2.

7.2.1.2 System sizing

The sizing of a PV system – to achieve balance between the supply and the demand of electricity – is one of the main considerations that all the interviewed stakeholder groups agreed on. This is mentioned in the studied literature as fundamental, and as a key challenge (World Bank 2012). The size of a PV system has a basic limitation based on the customer's economic capacity. The larger PV system, the higher cost, and system size is hence strictly linked to affordability according to the respondents. At the same time, most customers would prefer to not have any high peak power limitations at all (International Energy Agency 2012a).

All stakeholder groups mention that over sizing of a PV system, if economically possible for the customer, is preferable. Despite that flexibility is mentioned as important in the literature studied (Ciudad Universitaria, 1998), it is clear from the interviews that it is hard to scale up a PV system when it is already installed. No clear examples of "flexible" PV systems have been observed during the study. PV panels and batteries can be added to a SHS to make it larger, but charge controller, inverter and cables would have to be changed, which is costly. As described earlier, one PV system was observed, where the technician was planning to add a charge controller to an already existing PV system, in order to enlarge the system. This is however a type of installation that is not put into practice by any of the PV companies, and one of the PCEs says that a PV system with two charge controllers does not work properly.

Since it is hard to scale up PV systems, and customers tend to use more electricity than they think or increase their electricity use over time, over sizing can be a way to achieve more satisfied customers. The practice among all the stakeholder groups of applying over sizing shows how critical and difficult it can be to size a PV system correctly. The most challenging issue regarding appropriate sizing of a PV system seem to be how to predict the actual, and not assumed, electricity usage. It is also hard to find a way to limit the electricity usage if a customer is trying to use more electricity than the system is sized for. According to the respondents it is not uncommon that the users, either consciously or not, use more electricity than the PV system is sized for. Some of the respondents within all of the stakeholder groups said that sometimes it happens that a user tries to bypass the charge controller to be able to withdraw more power from the batteries. It also happens that a user connects a too big load to the system, which causes overloading of the inverter. Hence, over sizing can also be away of preventing deep discharging of the batteries or overloading of the inverter, which could damage the whole system. The issues with deep discharging of the batteries and overloading of the system are connected to protection of the system, and could also to some extent be managed by using components limiting the electricity usage. This will be further developed below. These issues are also directly related to awareness and knowledge, at a stakeholder level.

7.2.1.3 Protection of the system and in particular the battery

To protect the PV system, and especially the batteries, was identified to be a main consideration by all stakeholder groups. It is an important factor, since it can have a large impact on the lifetime of the PV system. In most cases it is about protecting the system from consequences of the human factor, like users wanting to use more electricity than the system is designed for, or forgetting to perform the simple maintenance needed.

Many times protection of the system is enhanced by the use of certain components, why this main consideration is closely linked to the main consideration of “choice of components”. Especially the PCEs and ESNs were bringing up different ways of designing the PV system to protect the batteries and the PV system itself, like; use of charge controller; choice of discharge rate; choice of batteries; use of RMC; use of circuit breakers; use of lightning arrestor; and “box design”. Two of the technicians explained that they used the following components in order to get a more safe design; circuit breakers; sometimes lightning arrestors; and dry batteries instead of wet batteries.

Frequent deep discharging of the batteries shortens their lifetime drastically. According to the studied literature batteries are often considered as the weakest and most expensive component in a small-scale, off-grid PV system. A proper charge controller is important to protect the batteries from deep discharging (Ciudad Universitaria 1998), and this was also emphasised by respondents from all the stakeholder groups. None of the respondents would choose to install a PV system without a charge controller. The discharge rate, regulated by the charge controller, should according to the respondents never be more than 50 %, which corresponds to studied literature (International Energy Agency, 1999). If the inverter in an AC system does not have a low voltage disconnect point it is particularly important to connect the inverter to the batteries via the charge controller. Locally assembled inverters, or inverters of lower quality, seldom have a low voltage disconnect point, according to some of the ESNs.

Many of the respondents were selling and installing dry batteries due to simpler maintenance, despite the higher price compared to wet batteries. If no one takes responsibility for refilling distilled water into the wet batteries when needed, the batteries can get a considerably shorter lifetime than expected. Since many of the respondents have experiences of this in practice, they recommend dry batteries. That dry batteries need less maintenance, compared to wet batteries, was also mentioned in the studied literature.

Overloading – when too big a load is drawn from the inverter – can affect the whole system negatively, but mainly the inverter, which can become overheated and stop working. This does not become a problem with an inverter with built in over-load protection, where the inverter will just stop delivering AC until the too big load has been disconnected. However, generally an inverter is more expensive the better quality and protection it has.

The PCEs working with RMC had the experience that the charge controller and batteries can be protected from bypassing by RMC. The battery can be protected from deep discharging, and the inverter and the system can be protected from overloading, since the system is continually monitored. This was also mentioned in the studied literature (Schelling, et al., 2010).

To install circuit breakers between the different components is another additional way to protect the system and battery that was mentioned by the respondents. However, there were a number of systems observed during site visits without circuit breakers. Circuit breakers imply an extra cost, but make the system more robust and safe in case of a short circuit. Further, lightning arrestors can be important in some geographical areas, but are many times not implemented, due to cost.

Two of the PV companies interviewed were implementing a type of "box design" to protect the system from being tampered with. This was combined with RMC and a monition to the customer to not touch the system. One system with a similar design, but without RMC, was also observed during a site visit. To be able to apply this type of design and strategy, there needs to be for example a company that takes care of all kind of maintenance for the customer.

There was a security thinking among some of the respondents, originating from the growing awareness among people of that PV components are of economic value. There were different expressions for this in the design. At some of the visited PV systems, the batteries were hidden or locked into a cage for example, to prevent theft. One PCE was talking about different technical solutions, like using GPS technology to locate PV components in case of theft, and some of the PCEs were arguing that the inverter and charge controller should be installed so that only the owner could access them. Two of the ESNs were actively promoting that community owned systems always should have a budget for a watchman, to prevent theft.

7.2.1.4 Quality of components and installations

To use quality products when designing PV systems, and to make sure that the installation work is of good quality, was considered very important by all the stakeholder groups, since low quality could lead to premature breakdowns of both PV components and loads, like lights and TVs. Quality was also confirmed by studied literature to be important, to provide a reliable electricity supply during the expected lifetime of the system (International Energy Agency, 2012a). However, quality in products and installation is also a challenge, and low quality products are prominent on the Tanzanian PV market.

The expectations on a system's lifetime differed between different stakeholder groups. According to one of the ESNs, the batteries should be able to operate well for 2-6 years, the charge controller and inverter for about 10 years, and the PV panel for 20 years, depending on how well the system is maintained. According to the technicians, on the other hand, they design a system in order for it to operate for as long as the warranty for the products is valid. According to the technicians that is in general 20 years for PV panels and 3-4 years for other PV components.

There is, both according to the studied literature and all the stakeholder groups, an extensive market for low quality products and installation works of low quality. This is connected to the question of affordability. The capital costs for a PV system are high compared to the low income levels of rural households in East Africa, and there is low access to finance in rural areas (Murphy 2001; Wilkins 2002). The PV system observed, designed by the owner himself, without charge controller and with SLI batteries described earlier is an example of this.

Some of the technicians interviewed refuse to use sub-standard product when making installations. However, some of the technicians explained that they sometimes could make PV system installations with products of lower quality, if that is what the customer can afford and wants. However they would then explain to the customer that the system would probably stop operating sooner than later. Hence, quality in products is a main consideration that is seldom put into practice for PV system installations, despite its importance.

According to all the stakeholder groups the lack of quality is, except for affordability, also strongly connected to awareness among the customers. Few customers are aware of how important it is to look for quality in products and installations. One of the PCEs said that most customers trust the local dealer or the local PV technician. In some cases, a dealer or technician might take advantage of this, and knowingly sell low quality products for a higher price, to earn some extra money. According Wilkins there is a problem with lack of quality standards and labelling of PV technology products (Wilkins, 2002). Respondents from all stakeholder groups describe products that are labelled with a higher power performance than they have in reality, which causes an unreliable PV system if used. There is low quality electrolyte on the market, according to PCE 7, which if used can destroy a wet battery in a short period of time. The local dealer or PV technician might not even be aware of that what is sold to the customers is of low quality or incorrectly labelled. It is important that the person selling the products has the knowledge and tools to check the quality of the products to overcome this problem. Hence it is also an issue of knowledge and education among stakeholders working with PV systems.

One of the ESNs argues that education, awareness raising, as well as increased customer rights is a must to put low quality installations to an end. If potential customers and users were trained in quality it would enable them to make educated decisions regarding what components to choose. According to one of the ESNs most people change their behavior as soon as they are informed about the importance of quality. This speaks for that it should be put extra emphasis on the importance of quality in awareness- and education programmes. Tanzanian Renewable Energy Association (TAREA) is one of the organisations already working with education of PV dealers, technicians and users in how to detect sub-standard products. TAREA is also working together with “Fair Competition Commission” in Tanzania and give information to authorities that have the power to intervene and reduce the amount of substandard products on the market, and a few of the ESNs are taking part in this work.

Warranties can be a tool to help the PV market in Tanzania to turn more towards quality in PV products and installation works. According to one of the PCEs warranties is a challenge, since many customers do not understand the importance of it or how it works in practice. Warranties can vary widely, and the different stakeholder groups provide different information regarding how a warranty can be framed. According to one of the ESNs, most PV companies in Tanzania are selling PV systems without any maintenance- or system warranty contract included. According to him, PV components generally have a warranty of 1-2 years, regarding manufacturing defects, however most products sold would not have any warranties at all. Inverters, batteries and charge controllers have a warranty period that varies a lot between the interviewed companies; between 2-10 years, while PV panels have a warranty of up to 20 years. Some of the companies can also provide the customer with a warranty for the whole system, apart from the product warranties. This is most of the time combined with a maintenance contract. Most of the technicians say that they provide the same product warranty to their customers as the company from which the products are bought. This is according to the technicians 3-4 years for most components. One of the PCEs explain that a warranty does not cover when overloading or by-passing has taken place, if the charge controller settings have been changed, if there has been a lightning strike, or if something thrown on the roof has broken the PV panel.

To give a product warranty for the batteries seems to be a challenge for both the PV companies and technicians. It might be hard to detect was has caused a battery failure and this can undermine the warranty. For example, Company 4 can give a warranty for the batteries only if they have a way of monitoring how the batteries are used. Similarly, some of the technicians say that it is hard to give a warranty for batteries if they do not know how the customer is using them, which they hardly ever do.

Quality of installation is most of all connected to knowledge and education of the person performing the installation. According to the interviewed technicians, there are people without education in PV technology who call themselves PV technicians and carry out installations. The technicians gave several examples of mistakes made in installation works that they had seen; PV panels installed without an air gap between the panel and the roof; not enough ventilation for the inverters and/or the battery; loose wirings; too thin cables; and too long cables between the different components in DC systems. One of the ESNs mentions that he has seen many systems installed where the orientation of the PV panels has not been made correctly. He has also met technicians who after an education in PV installation have said that they have performed installations before, without knowing what they were doing. Unfortunately, he says, sometimes there arise conflicts of interest between technicians and their employers. The employer, that might be a PV dealer, wants the technician to make a cheaper installation and “cut corners”, which leads to an installation of lower quality.

This situation calls for more strictly controlled quality standards and standardisations for installation practices, and this was also put forward in the studied literature (Wilkins, 2002). It is clear that considerations regarding quality in components and installation, at a technical system level, are strongly connected to considerations at a stakeholder system level, such as affordability, education and awareness. These topics will be further analysed below.

7.2.2 Main considerations at a stakeholder system level

The main considerations identified on a stakeholder system level are; affordability; education, capacity building and awareness raising; user friendliness, maintenance and responsibility.

7.2.2.1 Affordability

Affordability is one of the main considerations when designing a PV system, brought up by all the stakeholder groups. The cost of a PV system decides if a customer can afford to buy it – affordability is an issue at the stakeholder system level, which sets the limitations at the technical system level. There is consensus within all of the stakeholder groups that the design of a PV system, in terms of size and quality, depends on what the customer can afford, and that upfront payment of a PV system is a challenge for most households in rural Tanzania. According to literature studied 99 % of the SHS in Tanzania are sold on cash basis (Camco Advisory Service Tanzania, 2011). The link between affordability and quality in products and installation, as well as proper maintenance, is also brought up in literature studied.

Affordability is one of the aspects that has to be taken into account for a successful technology transfer, according to the studied literature (Wilkins, 2002). If customers are enabled to pay for a PV system in instalments over a longer period of time, that could be a way of making PV systems more affordable. However the PV retailers rarely provide this kind of opportunity, according to the PCEs. As described earlier, technicians can sometimes accept payment in instalments, if there already exists a trustful relationship between the customer and the technician. The more remotely a customer is living, the harder it is for a technician to enable payment in instalments, due to transport costs. This poses a contradiction, since the customers living very remotely could be expected to be in bigger need for off-grid electricity.

Increased access to micro-finance could be a way to overcome the barrier of high upfront costs, according to some of the ESNs. According to literature studied, it is rare in all parts of the world to give micro-credits for SHS (International Energy Agency, 2012b). Many PV dealers are of the opinion that one of the reasons for this in Tanzania, is that many people do not honour their financial commitments (Camco Advisory Service Tanzania, 2011). However there are ideas and innovative attempts to overcome the challenge of making PV systems affordable to a broader rural population, and three of the PCEs talk about different solutions where PV companies have found a way of reducing the initial investment cost of a PV system for the end-user.

One example of this, where the payment organisation is relying on the use of RMC will be presented and analysed in section 7.3.2. Another solution described is to support members of credits- and saving societies to go together and buy systems in bulk, and apply for a loan from a bank to be able to pay for the systems during a longer period of time. These projects are called “cluster projects”. Training for users, local technicians, quality controllers and cluster managers is also included in the concept. By limiting the alternatives to a few standard SHS of different sizes up to 100 the SHS price is brought down, and mismatching of components is avoided. It is a way of making the whole process less complex for the project management and the customers. A third solution described by one of the PCEs is that a PV company installs a larger PV system or several SHS with pre-paid meters connected to the systems. Instead of selling PV systems to the customers, the customers only pay for the electricity. RMC and a model of pre-paid mobile phone airtime can then facilitate organisation of the payment. An idea of system design is described by one of the ESNs as a “charging system”. A business could be started in charging batteries with solar energy that are then rented to households in the vicinity. This could be a way to overcome the problem of the upfront cost of a PV system, at the same time as the maintenance responsibility is removed from the customer. However, the ESN has not seen this in practice yet.

Two of the PCEs mention that community systems could be a way of reducing the cost for a PV system and electricity for each individual household. Today there are examples of systems in the size of around 100 W in rural market areas, which are owned by someone who sells electricity to other people at the market place for a small fee. However, one of the PCEs says that it is not common that private PV systems are community owned. Company 5 has developed an idea where customers can receive a discount by organising themselves and sign up as a group. The customers are then liable not only for the payment of their own SHS, but for the other group members’ systems as well. However, there have not been any customers signing up for this kind of contract yet. A PCE working at Company 5 thinks that a major reason is that people only wants to be liable for their own SHS, despite the possibility of a discount. One of the ESNs confirms that the feeling of responsibility for payment often decreases if more than one family is involved.

It can be noted that there is a connection between affordability and awareness and knowledge. According to some of the ESNs, awareness raising and education can be important tools to make people understand that a PV system can be more affordable in the long run, compared to the expenses for kerosene and firewood. An awareness also needs to be created regarding the need for income generating activities and saving money for future expenses connected to operation and maintenance of the PV system. According to the respondents, most users do not have an economic plan for future expenses, like replacement of system components. During the site visits it was observed that most private customers did not have an economic plan, while all the institutions were saving money for future expenses. With awareness and education people can also understand the importance of carrying out simple maintenance tasks to decrease the risk that a PV system would not break prematurely, and avoid unnecessary costs.

7.2.2.2 Education, capacity building and awareness raising

The knowledge level in PV technology among users and local technicians was identified to be one of all the respondents’ main considerations when designing a PV system, thinking of the future operation and maintenance of it. There is a concern among especially the PCEs and ESNs that many users and local technicians do not have the knowledge necessary to install, operate and maintain a PV system in an accurate way, and many of the respondents are of the opinion that more capacity building is needed. The knowledge level and awareness among the users and technicians is also something they have in mind, and have to adapt to, when designing a PV system. Just like the PCEs and ESNs, the interviewed technicians were of the opinion that many customers do not understand the importance of simple maintenance, and sometimes could use the PV system in a careless way.

There were especially three frequent problems mentioned by all stakeholder groups that they thought could be prevented by user training; deep discharging of the batteries and/or by passing of the charge controller; overloading of the inverter; and omitting to clean the PV panels. As explained earlier, all the three stakeholder groups also see education and awareness raising as tools to increase quality in products and installation, and to make people understand that PV technology can be an economically viable option.

One of the PCEs gave an example of how the level of awareness, knowledge and feeling of responsibility among the users can have an effect on the system design. The PCE had been working with the design of the 40 dispensary systems described earlier. The highest priority for the system installation outcome was that the labour room of the dispensaries would have light at all times. For some of the dispensaries, the company had seen indications that the dispensary staff would not feel responsible for the functioning of the system, or would not be able to restrict the use of electricity to what it was meant for. The company had then decided to install two separate systems at the site, instead of one, to reassure light in the labour room. This is an example of where conditions at the stakeholder level have an effect on the design at the technical system level.

All the PV companies interviewed carry out end-user training to different extents. Three of them are also training local technicians and three of them are, or have been, training local dealers or PV shop owners. Local PV dealers and PV shop owners are trained in product knowledge, quality control of products and marketing. Company 1 is training shop owners who are resellers of their products in simple maintenance and trouble-shooting. The aim is that rural customers should be able to get help if there is a problem with their system without calling for a technician from town. Also some of the ESNs have experience of user training, and the technicians always make sure to instruct their customers in how to use their systems. User training can include explaining how much electricity the system can deliver and what devices can be connected to the system. It is emphasized that the customer should not add any extra loads, but only use the loads agreed on during the certain amount of hours that the system is sized for, and not change the wiring or disconnect the charge controller. The customers are instructed in how to handle the different components, as well as performing simple maintenance; making sure that the PV panels and the battery terminals are clean; to fill up battery water in wet batteries; putting the batteries in a battery box in a well ventilated place and not put things on top of the box; and making sure that the PV panels are not shaded. One of the ESNs explain that when he is educating PV technicians he teaches them, among other things; how to identify quality in products; how to install a system properly with the right settings for inverter and charge controller; how to maintain the system; and how to educate the users.

The expectations from PCEs and ESNs is in general that education of users and local technicians would result in properly installed PV systems of higher quality, which are better maintained. This would in the end contribute to a longer lifetime of the PV systems and a better reputation of PV technology. However, according to the respondents this is not always the case. Through their own experience they know that users do not always follow the instructions they have received, and well-educated technicians does not always make perfect installations.

Neither among the respondents, nor in literature there seems to be an understanding of exactly how much education or awareness raising that is needed for the users and technicians to, for example, handle maintenance in a correct way. Furthermore, it seems like education and awareness raising is not always enough to result in action among users and technicians – there are other factors that also affect the possibility and willingness to act. The need for knowledge and education of users and local technicians in operation and maintenance is brought up in literature studied (Wenham, et al., 2007; International Energy Agency, 2012a; Kivaisi, 2000; Murphy, 2001; Ulsrud, et al., 2010). It is also emphasized in literature studied not to underestimate the level of knowledge required from users and local technicians to handle operation and maintenance of a PV system (World Bank 2012). One of the PCEs explained that the geographical size of Tanzania poses a challenge, since the cost of sending staff and equipment to carry out awareness raising and capacity building hinders the speed of the PV market development and the awareness needed, connected to it. This could be one of the explanations to what is stated in studied literature; that there is a lack of systematic training of manpower in PV technology in rural areas (Wilkins, 2002).

Awareness raising, capacity building and education in PV technology at a stakeholder level are seen as important tools to create a more suitable environment for PV technology, to help the technology become sustainable, and to help people access the technology. According to literature studied this is also one of the major parts of technology transfer (Wilkins, 2002). It is clear that it is important to keep in mind the knowledge level among technicians and users when designing a the technical aspects of a PV system.

7.2.2.3 Maintenance and user friendliness

To keep the system well maintained was seen as crucial, among all the stakeholder groups, to extend the life-time of the PV system. Therefore maintenance was identified to be a main consideration that the respondents would have in mind while designing a PV system. Maintenance was also seen as a challenge, since the lack of maintenance is often what makes PV systems fail, especially in rural areas, according to the respondents. As described earlier it was observed during the site visits that there was a lack of standardisation regarding simple maintenance. Sometimes there was also a lack of communication between the local technician and the customer, which could lead to system failures in the long run. The importance of correctly performed maintenance is also highlighted in literature (Ciudad Universitaria, 1998; World Bank, 2012). Furthermore, user friendliness was identified as a main consideration that was seen to have an effect on the operation phase, as well as the maintenance. Respondents from all the stakeholder groups were of the opinion that a PV system should be simple to install, use and maintain, for both users and technicians, which was also confirmed by studied literature. Concrete ways of enabling simpler maintenance, through the design, mentioned by the respondents are; to use dry batteries instead of wet batteries; to mount the PV panels in such a way that they would be easy to access when being cleaned; and to design in such a way that spare parts can easily be found in the local area. RMC can also simplify the maintenance for both the PV company and the user, as will be analysed further in section 7.3.2.

To offer a maintenance contract, which means that a PV company is handling the maintenance during a limited period of time, is another way of making the maintenance simple for the customers. According to some of the PCEs the customers do not care about the system itself, but wants a service of electricity. Despite this, maintenance contracts are in general rare, since most customers cannot afford it. Three of the interviewed PV companies can offer some kind of maintenance- or service contract to their customers. Two of the companies have a compulsory maintenance contract for all systems they install. If someone who is not contracted by the company is carrying out maintenance of the system, the product warranty lapses. All responsibility for maintenance is put on the company and the customer is told to not touch the system, but only use the electricity. One of the PCEs working with maintenance contracts says that ideally, the customer should not have to do any kind of maintenance of the PV system, but just use the electricity provided, as an energy service, like the electricity grid. However, such maintenance models are not very common, due to the extra cost, as well as lack of awareness for the importance of maintenance among customers, according to one of the ESNs.

According to many of the respondents, the customers are in general not aware of that there will be a need for maintenance and are not planning for it economically. This corresponds well with observations made during the site visits. Neither are all local technicians or PV companies giving importance to that the PV system should have a long lifetime, and are hence not always giving the customers information regarding maintenance, according to one of the PCEs.

According to some of the ESNs a way of increasing the user friendliness, as well as the feeling of responsibility among users, when designing PV projects for communities is to involve the users during the planning- and design phases. The local context also has to be considered to make the design of a PV system user friendly, according to some of the ESNs. The latter is valid for both community owned systems and private systems. Regarding the feeling of responsibility, which according to the PCEs and ESNs can have an effect on the maintenance phase, it can differ a lot between private and community owned PV systems. It was confirmed in literature studied that it could be the case that the owners feel more responsible for the system if it has been paid for with private money, rather than given by a donor (Wilkins, 2002; (Murphy, McBean, & Farahbakhsh, Appropriate technology – A comprehensive approach for water and sanitation in the developing world, 2009). During the site visits it was also observed that owners of private systems were in general more aware of maintenance needs than employees at institutions with a PV system.

For community owned systems it is important to have a well-defined management group, according to one of the ESNs, to keep the system well maintained, since the feeling of responsibility is in general decreasing when more than one family is involved. Another of the ESNs is proposing that each District Council should hire a technician who would be responsible for the maintenance of all community owned systems in the District, as a solution to poorly maintained institutional PV systems.

Awareness raising and education seems to play a role when it comes to maintenance, as confirmed by studied literature (World Bank 2012) and mentioned earlier. According to all the stakeholder groups, many customers are not aware of the need for maintenance, or would not remember to carry out simple maintenance tasks. This was also observed during the site visits. According to one of the ESNs this is why most PV companies today prefer to install as maintenance free PV systems as possible. According to some of the PCEs and ESNs the responsibility to give information regarding maintenance, and explain when certain components might need to be replaced, lies with the technician or company installing the system. Unfortunately not all local PV technicians or companies are doing this, according to the respondents from all the stakeholder groups.

During the site visits it was observed that there were no standardised procedures for how maintenance should be carried out in a long-term perspective. It was not very clear, neither among the users nor the local technicians who was responsible for doing what kind of maintenance and when, even if the users were ultimately economically responsible. This strengthens the view of the respondents emphasizing that a PV system, on a technical system level, should be designed to be simple to maintain. Furthermore it also strengthens the opinion that, on a stakeholder system level, there is a need for more education among users and technicians in how to develop a well-functioning maintenance plan for a PV system.

The confusion regarding responsibility for maintenance is also reflected in the diverging opinions among the PCEs on who should be responsible for the maintenance. Engineers or experts from PV companies; well-educated local technicians; the customers themselves; or customer by the help of PV companies, were all proposals put forward by the PCEs. This is reflecting who is handling the maintenance of PV systems in rural areas today, even if the vast majority is probably maintained by local technicians with varying level of education, or by the customers themselves. The ESNs touching upon this topic were of the opinion that well educated local PV technicians and PV dealers established in the vicinity of installed PV systems, rather than experts or the customers themselves, should handle the maintenance.

Access to spare parts is important according to all of the stakeholder groups, to be able to perform proper maintenance. One of the PCEs explains that this is a challenge, since the access to spare parts is not always there. One of the companies interviewed is actively focusing on expanding its business in rural areas by supporting local PV shops and dealers. Besides reaching more customers, it is an answer to the challenge of finding spare parts in rural areas. The transport of equipment to rural areas is a challenge since the fragile PV system parts can easily break during longer transports. Hence, how easy it is to provide accurate maintenance of PV systems is also linked to the state of the PV market in general. According to studied literature the lack of maintenance could be resolved by supporting growing local business to specialise in maintenance. This could be done by supporting PV projects with high densities of PV systems, to expand the PV market. The cluster projects described earlier is an example of where standardisation and a high density of PV systems can simplify maintenance.

Communication between the user and the technician, or PV company, was something considered as important by all the stakeholder groups, to enable good maintenance. . According to both some of the PCEs and technicians, it becomes more difficult to maintain a well-functioning communication with customers living very remotely. This would in the prolongation mean that PV systems installed in more remote areas would not be maintained as well as systems installed closer to town, due to less communication and longer distances for the technician to travel. However, if there is a maintenance warranty agreement signed, the responsibility for communication is put on the PV company. RMC can then be a tool to monitor when the customer needs to be contacted. During the site visits it was observed at some places that the technician had put a business card next to the installation, so that the customer would be able to contact the technician if needed. It is then important that the customers do not wait too long before calling the technician if there is a system problem

7.2.3 Summary of main considerations

In section 2.3 the following research question is introduced:

"How do the stakeholders motivate their main considerations when designing off-grid, small-scale PV systems (stand alone PV systems and SHS) in rural Tanzania, considering the whole lifetime of a PV system, when looking at planning-, installation- and operation phase – including maintenance?"

The motivations behind the main considerations highlighted by the three different stakeholder groups; technicians, PCEs and ESNs, were directly or indirectly connected to the wish to make PV systems accessible for potential users and customers. The local technicians and PCEs had a fairly similar viewpoint for obvious reasons, while the ESNs many times had a slightly more holistic view. The wish for making the lifetime of the PV system as long as possible, as a motivation, was present. However, as for now it seems like each main consideration motivated by contributing to the PV system's lifetime is connected to a number of challenges that are yet not possible to overcome on a broader scale.

It is also important to note that the main considerations that have been addressed and analysed here are the main considerations that the respondents want to stress. It is their viewpoint of what the main considerations are.

The main considerations on a technical system level are; choices of technology and components; system sizing; protection of the system and in particular the battery; and quality in components and installations. The main considerations on at stakeholder system level are; affordability; education, capacity building and awareness raising; and maintenance and user friendliness. All the considerations stated above were not mentioned to the same extent among the different stakeholder groups. Furthermore, there were also differences among the stakeholders and their perspectives regarding the "whole lifetime" and what emphasis they put on the different phases; planning-, installation- and operation phase of the PV system. However, some of the main considerations mentioned above were strongly emphasised by all stakeholders groups as priorities; system sizing; protection of the system and especially the battery; and quality of components and instalments and affordability.

Even if all the stakeholders were asked to consider the whole lifetime of the PV system, especially the planning- and installation phases were emphasised in particular by most stakeholders. This includes the economic capacity of the customer, how to size correctly, the quality level of components, and how to make the PV system functional in the near future. The maintenance and operational phases were mostly emphasised by the PCEs who could provide maintenance service contracts to their customers, and to some extent by the ESNs. User friendliness and simplicity was highlighted especially among the PCEs and ESNs. The consideration of education, capacity building and awareness raising was mostly emphasised and discussed in general terms among the ESNs and to some extent by the PCEs. Different choices of technology and components was emphasised mostly by the PCEs and to some extent also discussed with the ESNs and the technicians.

7.3 Variations in PV system design and technological complexity

Two design approaches that are varying from a standard PV system design are here in section 7.3 presented. Their level of complexity is analysed in comparison to the standard PV system.

The majority of the small-scale, off-grid PV systems described by the respondents and observed during the site visits followed a type of standardised design. When the respondents were asked about their own design, their companies' design, or the design of a typical PV system, the answers most of the time described a standard PV system design, with the standard OEM components PV panel, charge controller, battery bank and BOS components, and sometimes an inverter. This was defined in chapter 4.

Further, referring to observations made during the site visits, it seems like the design, operation and maintenance of PV systems might not always be a planned or standardised process. The general approach when designing PV systems is to consider the majority of the main considerations at both technical system level and stakeholder system level. How important each consideration is tends to vary between the different stakeholder groups and sometimes also within the stakeholder groups.

However, some design approaches, which are varying from a standard PV system design, and arguments for these, have been identified. The stakeholders' design choices seem to be closely related to the their main considerations, also when it comes to design approaches differing from a standard PV system. Two approaches that showed to have some modifications compared to the standard PV system design will in this section be presented and analysed. The variation in design appears to have an effect on the long-term operation of the PV system, as well as the level of complexity.

The presence and usage of locally assembled components, instead of OEM components, could be seen as one specific choice of design – one approach – when designing a PV system. Locally assembled charge controllers, inverters, as well as PV panels were observed and discussed during the study, including site visits. Several respondents from all of the stakeholder groups put forward arguments both in favour of and against locally assembled components. Another choice of design distinguished is the approach of including a RMCS in the system design. This approach was mostly discussed with four of the PCEs who were working with RMCS integrated in PV system design.

These two ways of designing PV systems will be further analysed in sections 7.3.1 and 7.3.2 in relation to the literature studied and the main considerations described and analysed earlier. The two approaches described here cannot be compared directly to each other, since one is concerning component level, while the other one is concerning both component level and a holistic business model. The analysis addresses different benefits and drawbacks of the two approaches at a technical system level and a stakeholder system level. Due to their variations in design, the two approaches could consequentially have a varying level of complexity, compared to a standard PV system, which is analysed in detail in section 7.3.3. Finally, in section 7.3.4 a summary of the two identified approaches is given, in order to answer research question 2.

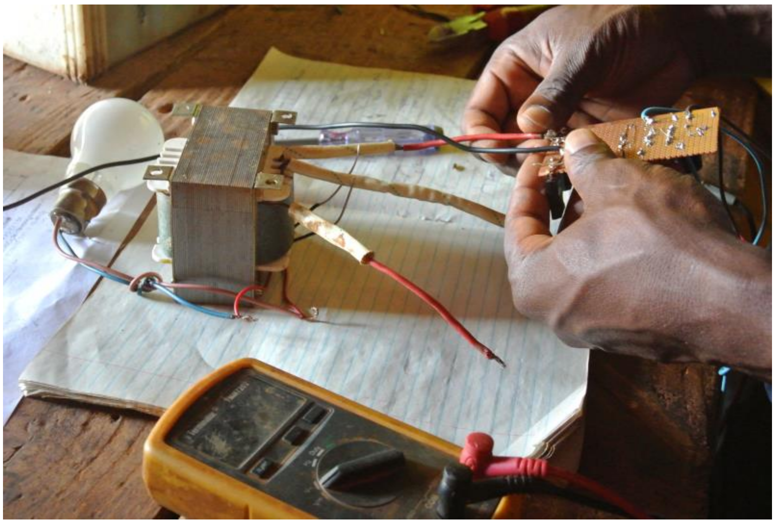
7.3.1. The approach of using locally assembled components in the PV system design – benefits and drawbacks

Arguments both in favour of and against locally assembled components were put forward by technicians, PCEs and ESNs. One of the technicians has strongly positive opinions regarding locally assembled inverters due to their lower price and their simplicity. The inverters he assembles himself, partly with second hand material, he is able to sell two to three times cheaper than an OEM inverter. According to him it is easier for local technicians to repair locally assembled inverters than OEM inverters. Also one of the ESNs argues that OEM, imported products are more expensive, and that the maintenance of the products becomes more complicated, compared to locally assembled components. This due to the design, and the lack of spare parts for imported products on the local market. The material and spare parts needed to assemble or repair locally assembled components is in general available on the local market. Hence, the use of locally assembled components could be considered to contribute to the flexibility of a PV system. The components can also be considered rather technically simple to assemble and repair without high requirements on equipment or manufacturing processes. It is interesting to notice that one of the technicians says that about half of the PV systems he knows about in the region have a locally assembled inverter.

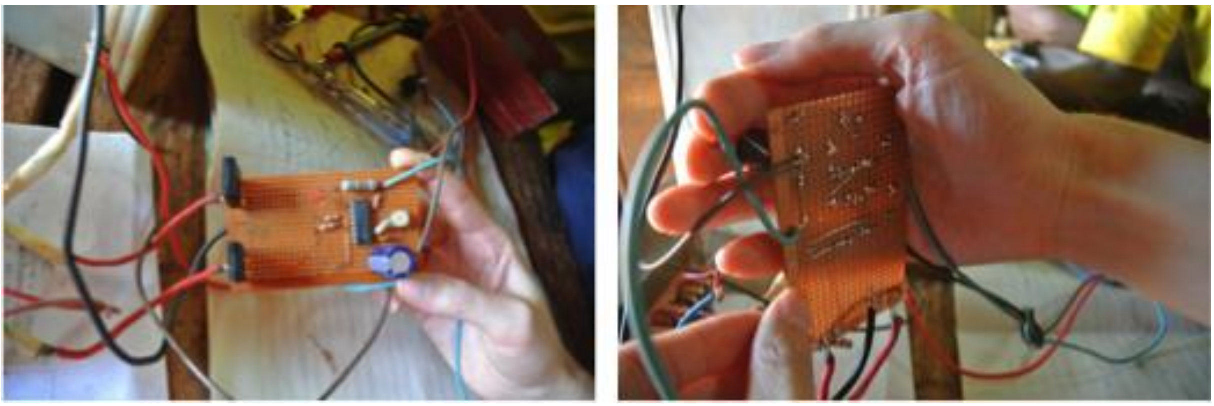
However, the technicians point out several disadvantages, such as; short or unpredictable lifetime; unreliable performance; unpredictable quality; high standby power consumption; difficulties to achieve an acceptable transformation of the voltage; no overload protection; and no low voltage disconnect point. According to one of the PCEs locally assembled inverters can consume around 50 % of the electricity the PV system produces. A common efficiency for an OEM inverter would be maximum 80-85 %. Another drawback is that the material or workshops with proper equipment needed to assemble or repair PV components locally might not always be available. This could lead to that the components might become unsafe and of lower quality.

The presence of locally assembled components can contribute to capacity building and awareness raising. One of the technicians interviewed is assembling inverters on a regular basis, and has a few students in his workshop that he, among other things, is teaching how to assemble inverters. Since the knowledge regarding the design and how to construct and repair locally assembled components often can be found in the local region, capacity is built up in the local region and the awareness of PV technology is increasing. These two aspects are seen as something important by the PCEs and ESNs. However, there might also be a risk that some technicians assembling their own PV components do not have the adequate knowledge to assemble and repair the different components of a PV system in a correct and safe way.

One of the technicians showed the process of assembling an inverter, which takes less than three hours (see picture 8). When he assembles an inverter he takes a transformer from another component, and then solders the electronic components such as resistors, capacitors and transistors on a circuit board (see picture 9). He uses a scheme called “4047 inverter simple circuit” that he has found on the Internet. The standardized voltage for AC systems is 230 V_{RMS}. However, the measured voltage from this inverter showed a value of 208 V_{RMS}. According to the technician the diverging voltage is not a sign of that the transformation of the inverter is not operating properly, but depends on that the battery connected to the inverter has a low energy level.



Picture 8: A local PV technician shows how to assemble an inverter.



Picture 9: Circuit board of a locally assembled inverter

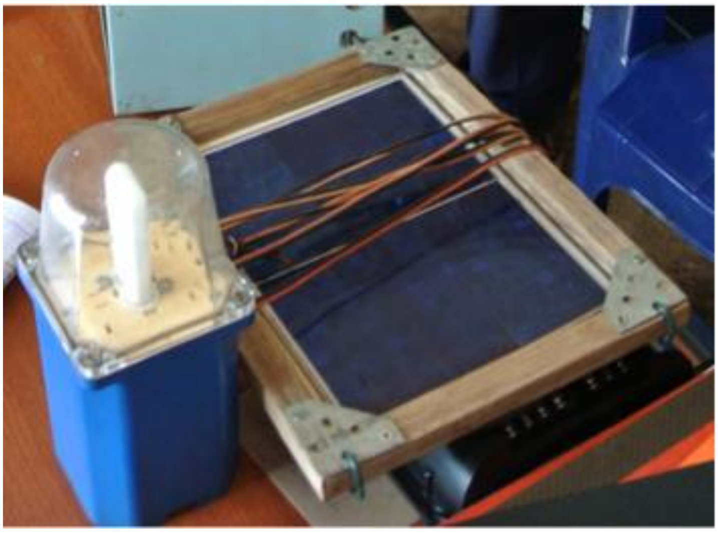
The lifetime and quality of locally assembled inverters is unpredictable, and it is rare with quality standards. One of the technicians says that the lifetime for some locally assembled inverters could be 2-6 years, but that it is hard to know beforehand. The electronic components used to assemble and repair locally assembled inverters are often available on the local market, which is a benefit. However, there can be large uncertainties regarding the quality of these components, which according to one of the technicians makes it impossible to predict the quality of the inverter before it is assembled and tested. Another technician explains that he usually tests his inverters at his customers' homes by checking if the TV is working. If the TV is not working he draws the conclusion that the inverter is not in a good condition. That locally manufactured components are usually not tested for quality and performance before being sold to the customer is a big problem according several of the PCEs and ESNs. However, one of the ESNs explains that there exist inverters manufactured locally in small scale, which are controlled by the Tanzanian Bureau of Standards and sold on the market.

Locally assembled inverters many times lack important functions, like an automatic low voltage disconnect point. If connected directly to the batteries, this can cause deep discharging of the batteries and an early failure of the battery bank. An inverter can either be connected to the batteries via a charge controller, or directly to the batteries. Some of the ESNs think that an inverter should always be connected via a well operating charge controller, and are emphasizing that it is especially important for locally assembled inverters. One of the PCEs, who is educating technicians is on the other hand arguing that it is more appropriate to connect the inverter directly to the battery, since a charge controller of larger size is needed if the inverter is connected via a charge controller, which increases the total system price. The interviewed technicians are also aware of these two different ways of design, and the common practice seems to be to connect the inverter directly to the batteries, as recommended by the PCE referred to earlier. To avoid deep discharging of the batteries if connecting the inverter directly to the batteries, it is crucial that the inverter has a low voltage disconnect point that switches off the power supply when the discharging level of the batteries is reaching the maximum discharge rate chosen (normally 50 %), to avoid deep discharging of the batteries. OEM inverters often have this function, while locally assembled inverters usually do not have that.

Seen from the customer/user perspective locally assembled inverters can result in a more complex, unreliable and unsafe operation of the PV system, which results in a less user-friendly PV system. To avoid deep discharging when the inverter is directly connected to the battery, the technicians’ solution is that the user should keep an eye on the charge controller, and when the charge controller shows that the discharge level is reaching its limit, s/he should manually turn the inverter and the electricity off. One of the technicians says that it is the customers’ responsibility to turn off the inverter when the charge controller starts to show that the energy level of the batteries is low, and that the customers in general understand this responsibility. However, he was not sure if the customers follow this advice. Most of the time, locally assembled inverters do not have an overload protection either, which can result in a breakdown of the inverter and other components or loads, if a user is connecting larger loads to the system than it is sized for. This also puts more responsibility on the user, and according to some of the technicians it is not uncommon that overloading, which can cause a safety risk, is taking place. One of the technicians thinks that this increased customer responsibility, as well as the increased safety risk, are strong arguments for why locally assembled inverters are not as preferable as OEM inverters.

To the topic of locally assembled components, PV panels and charge controllers can be added. A locally assembled charge controller, which was not operating was observed during the site visits. None of the interviewed technicians would recommend locally assembled charge controllers, since it is very hard to construct them correctly, and the technicians are of the opinion that locally assembled charge controllers seldom operate well. However, one of the technicians says that there are other technicians in the region, who assemble charge controllers, despite this. One of the main problems with locally assembled charge controllers according to one of the ESNs is that they can only be used together with wet batteries. This, since they cannot sense the difference between wet and dry batteries, like OEM charge controllers can. This function is important for the charge controller, to be able to fill its purpose, since it should operate in different ways with different types of batteries.

Regarding locally assembled PV panels, some examples of pico PV systems with locally assembled PV panels were observed. The performance of these panels is not as high as OEM PV panels, but can serve to charge smaller devices. One of the technicians showed a PV panel of 4 W that he had made during a training session led by a German non-governmental organisation (NGO) a few years earlier, see picture 10 (left). During a short period he was part of a group manufacturing and selling that type of PV panels in the local area. The panel can charge the battery of a small lamp. However, today he rather sells OEM solar lamps, because he finds it more convenient. Another example is an interviewed missionary from South Korea based in Dar es Salaam. He has come up with a model for producing locally assembled PV panels at a low cost that can charge smaller devices like mobile phones or lamps. The pico PV system, a PV panel and a small lamp that can be made locally, can be seen in picture 10 (right). The PV cells used to build the panels originate from broken PV panels, and can therefore be purchased at a lower price. The manufacturing model has not been scaled up yet. However, the purpose behind the idea is to teach people with little access to electricity about PV technology, how to make PV panels, and make the technology accessible and affordable to a larger group of people. The idea is also that people would be able to make a small business by assembling panels and lamps and sell in their local area.[2]



Picture 10: Locally assembled PV panel (left) and locally assembled pico PV system (right)

Almost all the respondents conclude that OEM, high quality products are better than locally assembled components in all aspects, except in the affordability aspect. Furthermore, components of low quality in combination with lack of technical knowledge can lead to a bad reputation of PV systems in general, which is something that all the respondents want to avoid. However, locally assembled inverters seem to be present on the market, and whether people buy these products or not probably depends on their expectations on the lifetime and performance of the PV system and the PV components. Since people pay less for locally assembled components, compared to OEM components, their expectations on quality might not be as high as if they buy OEM components.

[2] Hong Kyu-Choi (Ph. D. Solar Engineering and missionary based in Dar es Salaam, Tanzania) interviewed by the authors 6th of May 2013

Each benefit and drawback of locally assembled inverters identified and described in this section can be connected to one of the main considerations at technical- or stakeholder system level identified and described in section 7.2. This is visualised in figure 8 and 9.

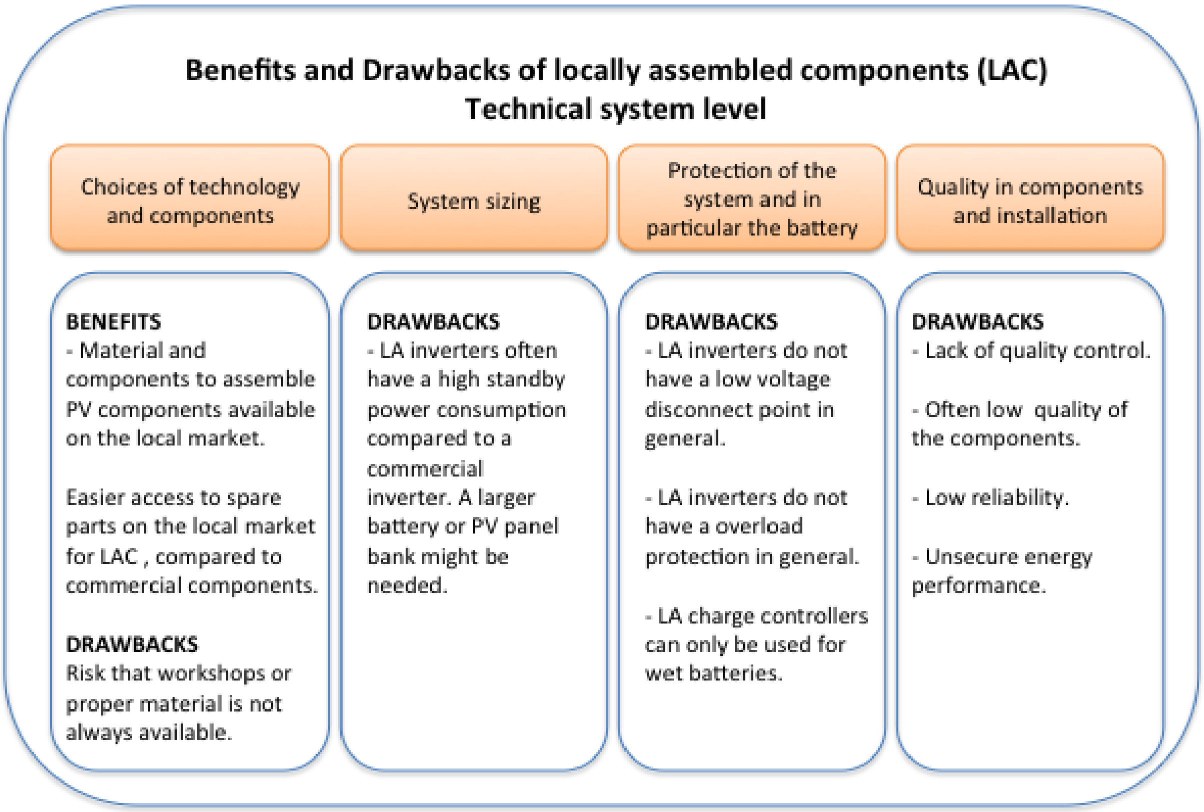


Figure 8: Benefits and drawbacks of locally assembled (LA) components (LAC) at technical system level.

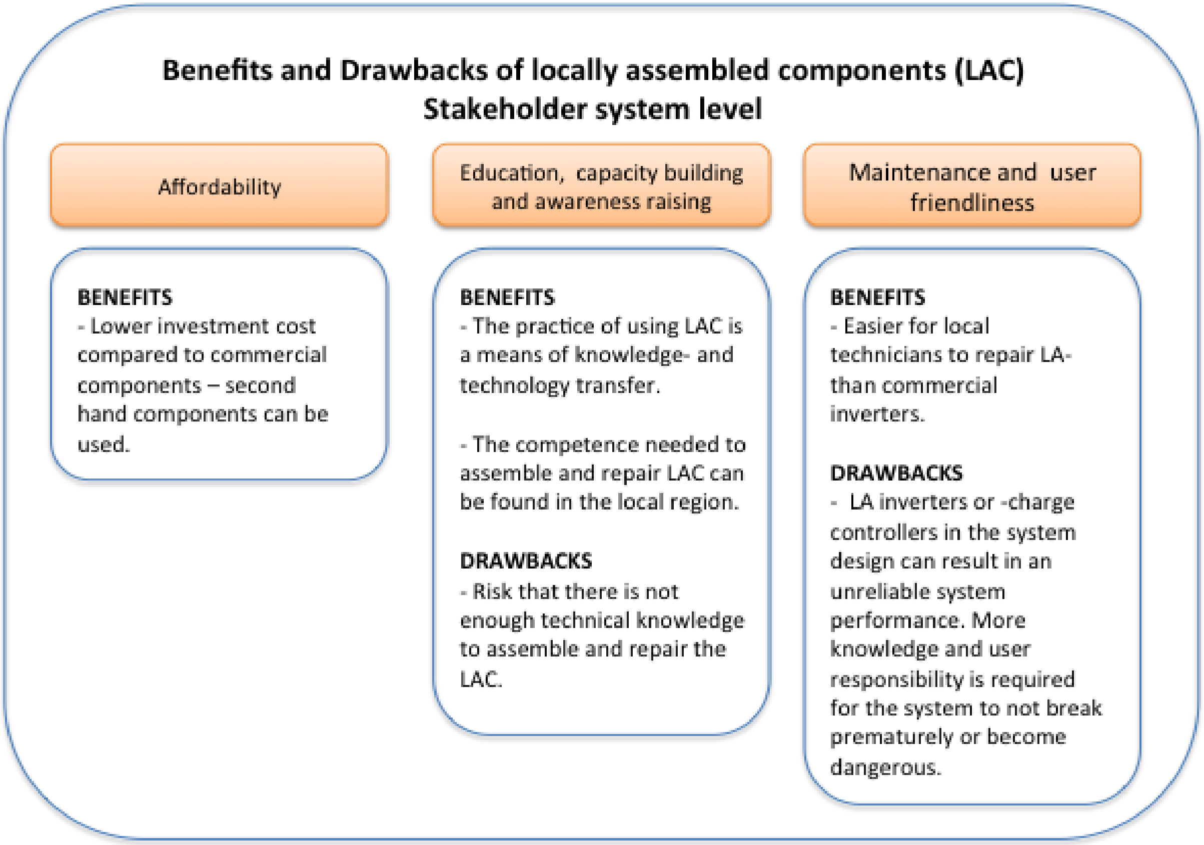


Figure 9: Benefits and drawbacks with locally assembled components (LAC) at stakeholder system level.

7.3.2 The approach of using RMC and a business model integrated in the PV system design – benefits and drawbacks

Three of the interviewed PV companies are installing PV systems with RMC. Company 4 and Company 3 use RMC mainly for larger on- and off-grid systems, while Company 5 uses it only for smaller off-grid systems of the sizes 30-200 W and is working with a customer segment in rural areas with lower income levels. None of the technicians interviewed in this study have used RMC in their design, and during the field study no examples of smaller PV shops or local technicians using RMC were found. There were no possibilities to visit any PV system using RMC as a part of this study. However, PCE 8 working for Company 4 showed the performance of a PV system installed by the company, on-line on his computer by using RMC, an online software and database. Discussions regarding RMC of PV systems were an especially important part of the interviews with the employees at Company 4 and Company 5, since both of these companies used RMC integrated with PV systems as an articulated business idea. The companies use software with a web-based interface connected to the PV systems via the GSM network. Through the software, information about the state of charge of the battery, voltage and current for the power coming in and wattage of the power going out is recorded in an web-based database, and can be monitored online.

A number of benefits with RMC are highlighted by the PCEs, for example the possibilities of; online monitoring of the PV system performance; changing system settings remotely; updating the software remotely; detection of improper handling or other system problems; and the possibility of switching the PV system on and off remotely. One of the major benefits the respondents see with the monitoring- and control system that it can be an extra help to prevent deep discharging of the battery bank. The three companies working with remote monitoring can also see a benefit in it for the learning- and development process of the company. They get access to information that can help them to design PV systems more appropriate, for example considering battery size, by understanding how the customers are using the electricity. Some of these benefits are also mentioned in literature studied (Ma, et al., 2012; International Energy Agency, 2003a; Schelling, et al., 2010).

Also some drawbacks are identified. Most PCEs and ESNs are of the opinion that it is an expensive technology that is not affordable to most customers in rural areas. Another drawback is that the technology is dependent on the reliability of the GSM network. The companies using RMC say that they do not install PV systems with RMC were there is no access to the GSM network. This can exclude a number of the rural customers in Tanzania to get access to this type of PV system. Even if there is GSM network coverage, there can be occurrences of gaps in the system information, due to GSM- or Internet network failures.

The cost of a PV system with RMC does not necessarily have to be more expensive than a standard PV system. The general perception among the PCEs and ESNs is that technology used for RMC is expensive, since it is a relatively new application of the technology, and mostly used in larger stand-alone PV systems. Depending on the technology used, as well as the size of the PV system, a RMCS can become disproportionally expensive in comparison to the total system price. A comparison in cost between SHS from Company 5 and 3, with and without a RMC systems integrated in the SHS design, can be seen in figure 10. Worth noting is that the cost between a SHS with and without an RMCS is not differing much. In the price for the SHS with RMC, maintenance during a three-year period is also included. There are several factors affecting the price of the system except the technology used, like business model used, quantity of similar systems installed at the same time, and investors involved. However, the comparison in cost can serve as an example to show that a SHS with RMC can be as affordable for a customer in rural Tanzania, as a standard SHS. Furthermore, according to some of the PCEs and ESNs, it can be expected that the cost of RMCS will drop in the future, as the technology develops, which would allow for RMC of smaller SHS to a larger extent.

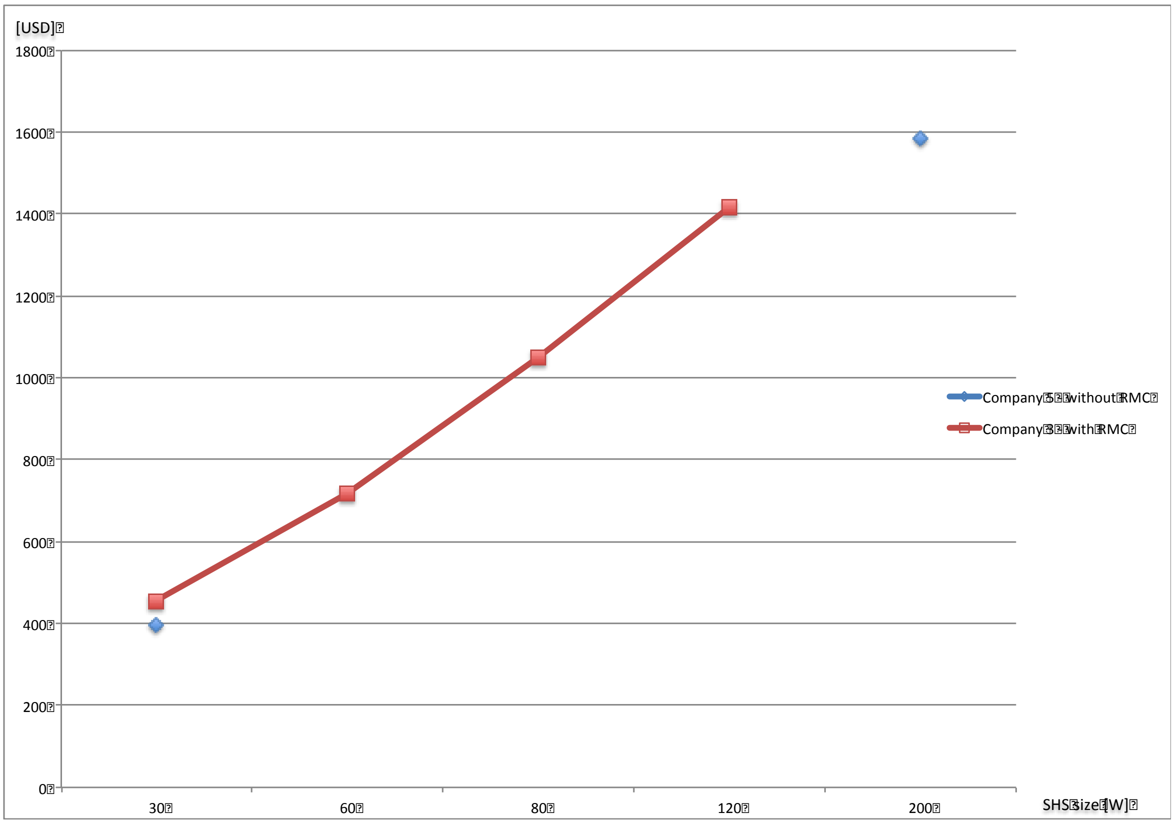


Figure 10: Price of off-grid PV systems of the sizes 30-200 W_p with and without an integrated RMCS.

RMC can be used to facilitate leasing models of PV systems, to make off-grid electricity affordable. Company 5 is using a business model, including a type of a payment organisation, which enables leasing to private customers during a period of three years. The price also includes a warranty and maintenance service of the PV systems during the leasing period. By collaborating with mainly investors and banks and applying for grants and financing, the company itself is micro financing the SHS for their customers during a period of three years through leasing. The standardized plug-n-play SHS have the sizes 30/80/120/200 W, and the customer pays between 11-44 USD/month, depending on the system size. The monthly price is adjusted to an average family's expenses for kerosene and wood in the area where the company is active. The company is implementing as many as 1000 systems at a time, which helps to push the price. The payments for the SHS are made through a mobile banking service, by e.g. sending an SMS. By remote controlling the SHS is then delivering electricity during the period the customer has paid for. If a customer has not paid the monthly fee, the system is switched off by remote controlling, which gives the company a guarantee that the customer will pay. This makes it substantially easier for the company to find investors to micro-finance the SHS for the customers. Company 5 also offers their customers a grace period of in total three months, where they can delay their monthly payments but still get electricity from the system.

Company 5 employs two types of technicians, and carries out training of both technicians and users. There are local technicians hired and educated by the company. They get education in system installation, how to perform simple maintenance and change broken components. The local technicians are also taught how to carry out customer education, which is an important part of the business model of the company. The company has a service hub with specifically trained technicians handling tuff maintenance cases. They can analyse why a RMCS is not working as it should and repair it, and are also working with the development of the technology. Most local technicians employed by the company do not participate in development of the technology or the maintenance in more complicated maintenance cases.

A drawback with this type of business model is the capacity building and technology transfer is limited. It could be expected that the awareness and knowledge in the local area regarding installation and simpler maintenance tasks should increase, as a result from the capacity building part of the business model. However, the in-depth knowledge of the design and manufacturing of the SHS is based within the company's head office. Furthermore, the hired local technicians have limited access to the data from the RMCS, and the users do not have access to it at all. Thus, there are limitations for the local technicians and users to actually learn about and understand the specific design. This is somehow not unexpected, since it is a company that, like all companies, aims for profit and would not share their business secrets. It could be expected that the in-depth knowledge of the technology is not spread in the area where the company is operating. There is also a large risk that RMCS, complementing software and spare components for the RMCS would not be available for a local technician who is not employed by a company using RMC. The availability RMC technology might be dependent on certain companies providing these products. However, in this Master's thesis it is not investigated further to what extent different RMC products are sold on the PV market in Tanzania.

Several of the PCEs, also some not working with RMC today, argue that RMC could solve some maintenance problems. Company 5 is taking full responsibility for the maintenance of the PV systems they install, and it is made possible by the use of RMC. The employees at Company 5 use the term "remote maintenance" and give some examples of how system maintenance can be simplified by analysing data collected by remote monitoring; it can be detected right away if a battery is worn out or if a component is broken; if a voltage drop is detected in a system each afternoon, it is possible that there is something shadowing the PV panel; if there is a continuous weakening of the power output from the PV panel, there is a possibility that the panel starts to get dirty or dusty. The three PCEs working with RMC describe how they work with automated alerts, which are informing the company about the status of the system, if there are any specific problems, or if the customer would need to be contacted. If preinstalled settings for the SHS are exceeded, this can be detected quickly, and more expensive maintenance costs can be avoided. The company can, depending on the nature of the problem, either suggest a solution to the customer over the phone, or prepare a technician by providing information about what might be the problem and the solution, so that the technician does not have to go to the site twice.

With RMC it can be detected if a customer is trying to by-pass the charge controller or if overloading – withdrawing a too big load from the system – is taking place. If this is happening, the company can see this, and take action. When buying the system, the customers are informed that the system warranty lapses if tampering is taking place. Company 5 also has an SMS service, where they send an SMS to the customers as reminders. During the dry season, when panels get dusty, an SMS reminds the customers to clean the panels. 3 days before the monthly payment is due, it is also sent a reminding SMS. If it is detected that the battery has not been fully charged in a month, the customers are told to not use the system for two days, to allow for the battery to be fully loaded. If the battery has been discharged more than 50 %, the charge controller turns the system off automatically, and the customer is informed why the system is turned off. Company 5 also has a toll-free service line where customers can call if they have a problem with, or questions regarding, their SHS. PCE 9 says that many times customers call to ask questions about what was said during the customer education, or to double-check if their payment has gone through if they are unsure.

The company's cost for maintenance is reduced in two ways; less travelling, as well as less working hours of technicians. At the same time, people with the right education, who are working with system monitoring and customer service have to be employed, to get the benefits from the RMC.

After the system maintenance and -warranty period of three years that is included in the business model of Company 5, the customers can choose to not be connected to the company anymore, but maintain the system themselves. Even if the SHS that Company 5 installs are plug-n-play systems, one of the PCEs says that a customer would be able to install other types of components in the system than the ones that are supplied by Company 5. However, if the customers chooses to leave the company s/he would not have any benefit of the RMC system built into the system, which only Company 5 can make use of. Preferably, the company would like to keep the relation with their costumers and extend the contract with a service contract after the first three years, where the company continues to take responsibility for the PV system, for a monthly fee.

It is hard to say anything general about quality and technical reliability in relation to PV systems with an integrated RMCS, since no PV systems with RMC were visited during this study. Furthermore, the respondents who had the most positive opinions about RMC also had RMC integrated in their own company's PV design, which can explain their positive viewpoints. However, RMC is a tool for a company to provide a customer with a service, and be able to provide the customer with a reliable PV system, where quality is probably a part of the concept. For Company 5, the RMC becomes a tool for the company to provide reliability and energy performance of the PV system during the warranty period of three years, until the customer has paid for the system. It can be assumed that the RMCS as well as the rest of the PV system components will have enough product quality to be able to perform its tasks.

According to the studied literature quality can also be seen as a superordinate concept, where the subordinated characteristics of reliability, energy performance, safety, user friendliness and simplicity of installation and maintenance can, if they are fulfilled, serve as a confirmation that the whole PV system, in terms of products and installation, actually has quality. The usage of RMC in a PV system design seems to be a well-aware choice of design in order to provide reliability, energy performance and safety. Furthermore, for Company 5, user-friendliness and simplicity of installation and maintenance seem to be the aim and goal integrated in their business model. In conclusion, when analysing the approach of RMC, it is not only the RMCS that is contributing to the high quality in terms of the superordinated concept of quality, but also the whole business model connected to the RMC.

Seen from the user perspective it seems like the RMC functions can result in a more user-friendly PV system, if the use of RMC is enabling a business model where a PV company is taking full responsibility for the system and the PV system becomes more of a service than a product. This requires that the company stays in the area, and can continue to supply this service to the customer. Another prerequisite is that the price for maintenance is affordable to the customer. The functions connected to RMC that can enable a company to take responsibility for the operation and maintenance of a PV system seem to be able to enhance the long-term performance of the PV system.

Each benefit and drawback of the use of RMCS in the PV system design identified and described in this section can be connected to one of the main considerations at a technical- or stakeholder system level identified and described in section 7.2. This is visualised in figure 11 and 12.

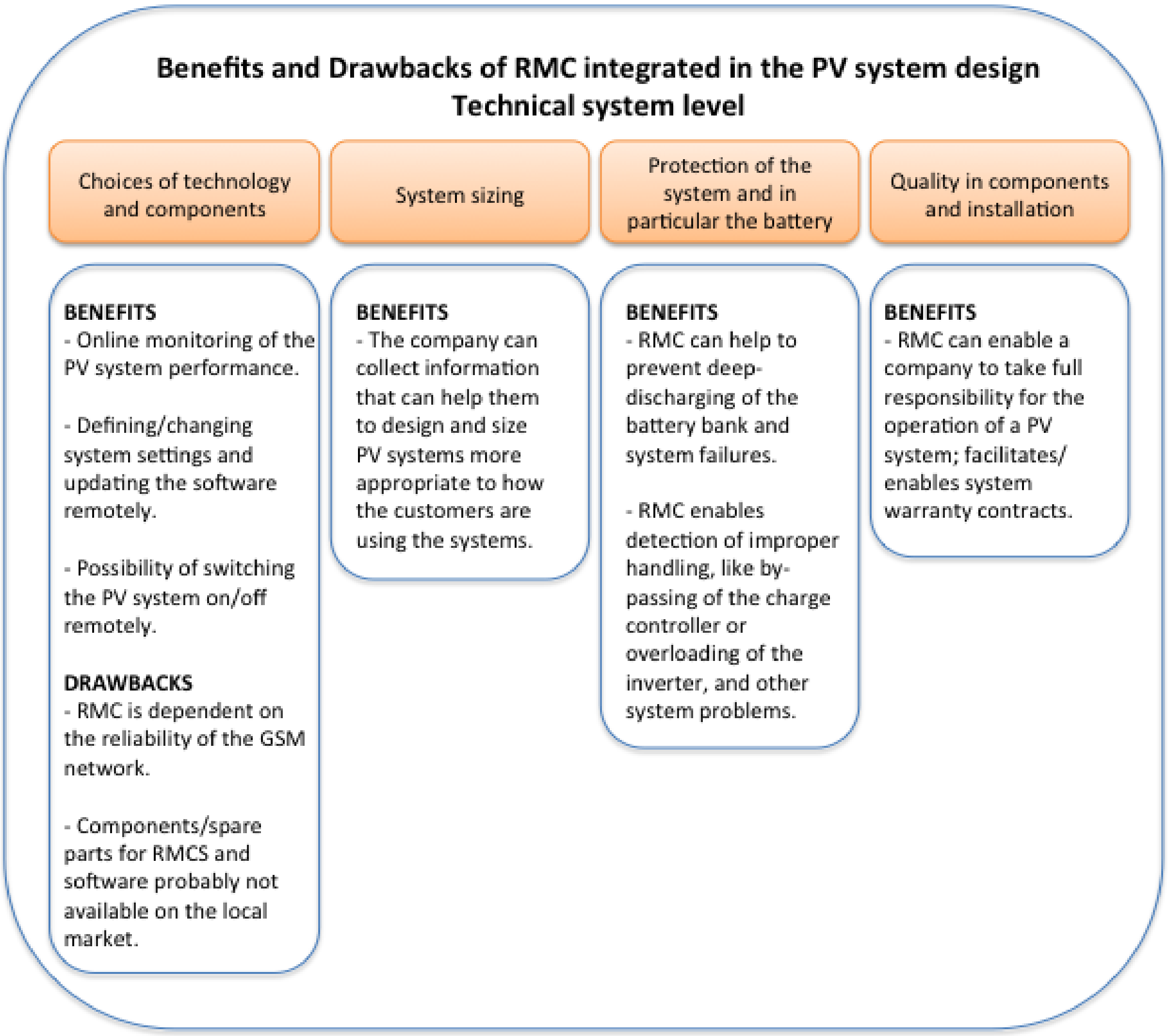


Figure 11: Benefits and drawbacks with remote monitoring and -controlling (RMC) at technical system level.

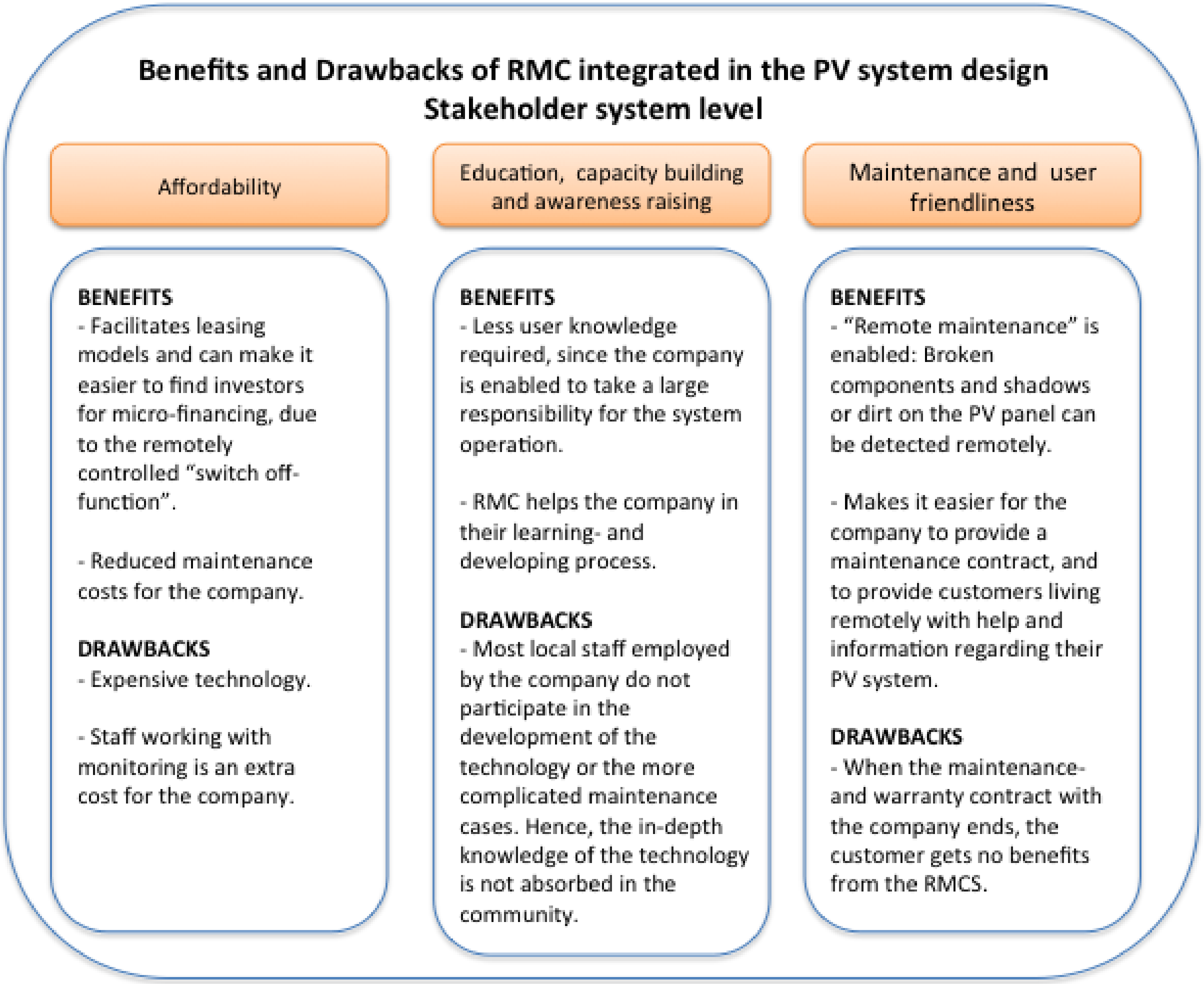


Figure 12: Benefits and drawbacks with remote monitoring and -controlling (RMC) at stakeholder system level.

7.3.3 Level of technological complexity for the two approaches

The level of complexity of the two variations in design; the use of locally assembled components, and; the use of RMCS, will in this section be analysed. The analysis of the level of complexity at both technical- and stakeholder system level is presented in table 1. The analysis is based on the definitions of the level of complexity presented in section 2.2. The analysis is made by comparing the level of complexity of each of the two approaches to a standard PV system design. The approaches cannot be compared to each other. The complexity at a stakeholder system level is analysed for the different actors involved in the processes of design, manufacturing, installation, maintenance and system usage. In the table, "Company" is referring to a company working with RMC, and "Technician hired by company" is referring to a technician working for the company using RMC. The analysis presented in the table is based on what has been observed during this study. It is assumed that PV companies, or technicians hired by a PV company would not be producing locally assembled components of the type described in section 7.3.1. It is also assumed that independent local technicians, not hired by a company, would not have the possibility to work with RMC of PV systems. Based on these assumptions, information regarding the level of complexity is only given where it is relevant.

System level	Definitions of technological complexity	Actors	LAC; level of technological complexity (H/L/=)	RMC; level of technological complexity (H/L/=)
Technical system level	A. Number of PV system components		-	**H**
	B. Number of electronic components integrated in the PV system component(s)		**L**	**H**
	C. Non-human requirements on the workshop/ factory/ manufacturing process of the PV system component(s)		**L**	**H**
Stakeholder system level	D. The availability of electronic components for the PV system components	Independent, local technician	**L**	-
		Company	-	**=**
		Technician hired by company	-	**=**
	E. Requirements of knowledge to design the PV system and/or PV system component(s)	Independent, local technician	**L**	-
		Company	-	**H**
		Technician hired by company	-	-
	F. Requirements of knowledge to manufacture the PV system component(s)	Independent, local technician	**L**	-
		Company	-	**H**
		Technician hired by company	-	-
	G. Requirements of knowledge to install the PV system	Independent, local technician	**=/H**	-
		Company	-	-
		Technician hired by company	-	**L**
	H. Requirements of knowledge to maintain the PV system and/or PV system component(s)	Independent, local technician	**L**	-
		Company	-	**H**
		Technician hired by company	-	**L**
		Customer/User	**H**	**L**
	I. Requirements of knowledge to use the PV system	User	**H**	**L**

Table 1 Technological complexity of two variations in design, compared to a standard PV system design. "L" means lower level of technological complexity. "H" means higher level of technological complexity. "=" means same level of technological complexity.

In the following, the information in table 1 is presented with explanations.

At a technical system level, locally assembled components have a lower complexity level than OEM standard PV components. Earlier it has been described how locally assembled components have less electronic components integrated – for example no low voltage disconnect point or overload protection, for inverters (B, table 1). The requirements on the manufacturing process are not very high, and the components can be assembled in local workshops – that is in a way the definition of locally assembled components (C, table 1).

An RMCS integrated in a PV system on the other hand, results in a higher complexity level of the PV system, compared to a standard PV system. The number of PV system components increases (A, table 1). An RMCS contains more electronic components. The software and database needed to use the RMC also contributes to the increased complexity (B, table 1). The requirements on the manufacturing process of an RMCS could also be expected to be higher, than other OEM PV system components (C, table 1).

However, when focusing on the stakeholder system level, the picture changes. For locally assembled components the complexity level is in general lower, compared to standard PV components, for the technician, but higher for the user. As described earlier, electronic components and spare parts to assemble and repair locally assembled components are in general easier accessible than material needed to repair OEM components (D, table 1). The knowledge required to design and manufacture for example an inverter can often be found in rural areas (E, F, table 1), and the knowledge needed to install a PV system with locally assembled components does not differ much from the knowledge needed to install a standard PV system. Possibly, it could be a bit more complex (G, table 1). The maintenance of locally assembled components is seen to have a lower complexity for the technician (H, table 1), since it is easier to repair a locally assembled component than an OEM component for a local technician. However, the maintenance becomes more complex for the user. More user knowledge is needed to make sure that the components do not break, or cause a system failure (H, table 1). For the same reasons, it becomes more complex for the user to use a system with locally assembled components, than a system with OEM components. For example, locally assembled inverters and charge controllers lack some important functions that OEM components would have. This can cause deep discharging of the batteries, overloading of the system, or directly dangerous situations, if the user does not know how to handle the system (I, table 1).

Also for a PV system with an RMCS, the complexity level becomes different for different stakeholders, compared to a standard PV system. The business model of Company 5 has been used to analyse the outcome of the complexity level. In general, the complexity level becomes higher for the company, while it becomes lower for the user. The availability of electronic components and spare parts can be assumed to not differ from OEM standard PV components for either the company or hired technicians, since the company has the capacity to manage the supply chain of components used (D, table 1). The requirements of knowledge to design an RMCS are higher than for OEM standard PV components, not only because the hardware is more complex, but because the logistics regarding communication and service to customers also have to be worked out (E, table 1). The knowledge requirements to manufacture an RMCS are also higher than for OEM standard PV components (F, table 1). Since Company 5, here used as an example, has designed the SHS they install as plug-n-play systems, the installation process becomes simpler for the technicians hired by the company, than it would have been with a standard PV system (G, table 1). By RMC, the company is enabled to take on a large responsibility for the maintenance of the PV system. It becomes more complex for the company, compared to a standard PV system, since staff working with monitoring of the PV system is needed (H, table 1). At the same time, maintenance is simplified for the customer, compared to a standard PV system, since the company is sending reminders for certain maintenance tasks, and taking care of the heavy maintenance for the customer (H, table 1). When the company needs to send a technician to carry out maintenance work, the technician can be prepared beforehand, since the monitoring is a help to draw conclusions regarding what the system problem might be. Hence maintenance is also simplified for the technicians employed by the company, compared to a standard PV system, (H, table 1). Finally, the user phase can be seen to become simpler for the user, compared to a standard PV system, because of the contact with the company that is monitoring the system and making maintenance easier for the user. The company is using RMC to give the customer the service of electricity, rather than a PV system. If RMC is used to enable a leasing model, as in the case of Company 5, the possibility of leasing can also decrease the complexity for the user, and the complexity in the payment process is decreased for the company, through RMC (I, table 1).

It can be noticed that for the design with a RMCS, someone has made a conscious choice of technology at a technical system level, while thinking of the implications of the technology at a stakeholder system level. In this case the implication of the technology means benefits, and a lower complexity level compared to a standard PV system, for the company and customers. In the light of the concept of technological complexity, the conclusion can be drawn that; a conscious choice of high complexity at a technical system level has been made to achieve a low level of complexity for the user and hired technician, at a stakeholder system level.

As described earlier, the choice of locally assembled components is mostly based on their lower cost. The complexity level becomes somewhat lower for the local technicians, compared to a standard OEM PV component, but considerably higher for the users. This is also seen as a drawback by the technicians interviewed. In the light of the concept of technological complexity, the conclusion can be drawn that; a conscious choice has been made to achieve a cheaper product, with a low complexity level at a technical system level, that has a low complexity level at a stakeholder level for the local technician. However, for this case, it results in an unwanted high complexity level at a stakeholder system level for the user.

7.3.4 Summary of the two approaches

In section 2.3 the following research question is introduced:

"What variations in PV system design, compared to a standard PV system, are observed or described by the stakeholders, and how do these design variations differ in their level of technological complexity at a technical- and stakeholder system level?"

Two different design approaches that are varying in their design compared to a standard PV system, that were identified during interviews, have been presented; locally assembled components in section 7.3.1; and RMCS integrated in the PV system in section 7.3.2.

The respondents argued for a number of benefits and drawbacks for the two different approaches. All of these benefits and drawbacks could be connected to the main considerations identified among the stakeholders. The benefits and drawbacks can be seen in figures 8 and 9 in section 7.3.1, for locally assembled components, and figures 11 and 12 in section 7.3.2, for RMCS integrated in the PV system. The benefits and drawbacks are divided in main considerations at technical- and stakeholder system levels.

It has been found that the complexity levels at technical- and stakeholder level of the two approaches vary, compared to a standard PV system. This is described in detail in section 7.3.3. The analysis shows that there, for the same type of design, can be a variation in complexity for different stakeholders. It also shows that a seemingly complex technology, like RMC, can become simple for the user, and that a seemingly simple technology, like locally assembled components, can become complex for the user.

7.4 The stakeholders' perception of technological complexity

As a part of the investigation of the concept of technological complexity, it is important to understand how the different stakeholders perceive the concept. In section 2.3 the following research question is introduced:

"How is the concept of technological complexity in this context perceived by different stakeholders?"

The understanding of complexity of PV systems at a technical system level and at a stakeholder system level was varying among the three stakeholder groups, and to some extent also among the respondents within each group. Due to the explorative nature of this study, the distinction between technological complexity at a technical system level and a stakeholder system level was not yet defined during the interviews. The consequence of this was that many of the respondents were focusing mostly on complexity at a technical system level. However, some of the PCEs and ESNs could relate to the existence of the different system levels. They also acknowledged that there could be variations in the level of complexity within these system levels, which could have an effect on each other.

Some of the ESNs would consider the level of complexity at a technical system level as an aspect among others when designing PV systems, but they do not see it as a main consideration. Some of the ESNs did also discuss whether there could be a certain complexity level that is more appropriate for rural areas in Tanzania.

When the technicians saw an early version of the conceptual model showing the concept of technological complexity (see figure 3, section 3.6), they had some difficulties to understand the concept. The technicians interviewed did not have experience of varying PV system designs, and had not reflected upon the level of complexity in a PV system or its components. However, the technicians with experience of locally assembled inverters, had thought about that the design could result in a less user friendly system, as described earlier.

That a low level of complexity for the user is the same thing as user-friendliness, as defined by Rogers (2003), was something that all the respondents could relate to (Rogers, 2003). There was a consensus among the stakeholder groups that a PV system should be simple to use and maintain for the user and technician, for the PV system to be able to operate properly in a rural area in a long-term perspective. Hence, the aim when designing a PV system should always be to achieve a low level of complexity at a stakeholder system level when considering the user perspective.

Many of the PCEs and ESNs argue that the user interphase of the PV system can be enhanced by advanced technology, which can affect the lifetime of a PV system positively. Relating to the picture of the concept of technological complexity shown (figure 3, section 3.6), one of the PCEs suggests that complexity exists on three system levels; technical-, end user- and organisational- system levels, and discusses how the level of complexity on these different system levels can affect each other. He thinks that technological complexity on a PV system level can help to decrease the complexity of the user- and organisational complexity, and gives some examples; pico solar lamps, which has a low end-user complexity, usually have a high technological complexity on technical system level; RMCS, which increases the technological complexity on a PV system level, can be used in a SHS, to be able to give a system warranty, simplify the maintenance and to monitor and simplify payments. Also two of the ESNs discuss how more complex technology on the technical system level can result in lower complexity for the user and for the management of the PV system on the stakeholder system level.

Most PCEs and ESNs are of the opinion that the level of complexity has a connection to system size and price. There is a perception among the PCEs and ESNs that standard PV systems of smaller sizes are not very complex. SHS of the size up to around 100 W are perceived as simple, with standardized technology. Three of the PCEs say that as long as a smaller SHS is of good quality, there is not a big variation in technological design or the complexity of the components possible to choose between – the differences would be the brand, capacity and size of the components. The more complex a PV system is, the larger and more expensive it becomes, according to the PCEs and ESNs. This is partly because some technology is so expensive that it can only become proportionally economically feasible to use in PV systems of larger size. For example, RMC is most commonly used for larger systems, due to the cost of the RMC technology. The one example found during this study, that goes against this understanding was the system design and business model of Company 5, where the price for a small-scale solar home system (SHS) with RMC was in the same price-range as a standard SHS of the same size, without RMC. According to the PCEs also the maintenance becomes more expensive for larger, more complex PV systems. They say that local technicians can handle the maintenance of smaller SHS, while engineers are needed to carry out maintenance for larger, more complex systems. Several of the PCEs argue that the more technologically complex a PV system is, the more knowledge is needed to design and implement and maintain the system, and the more the involvement from the user has to decrease.

Most of the ESNs touching upon the topic of appropriate complexity level do not see a specific level of complexity at a technical system level as particularly appropriate for PV systems in rural areas. They argue that a specific level of complexity, higher or lower, could have both a negative and/or positive impact on a number of things, depending on the local context, like; user friendliness; maintenance- and operation; affordability; communication between user and PV company; higher electricity productivity; payment. However, two of the ESNs think that a lower level of complexity at a technical system level is more appropriate for rural areas, if no educated technicians are living nearby. Several of the ESNs are of the opinion that the level of complexity of PV systems in rural areas has to be well matched with the human resource capacity in the local area, to facilitate the maintenance and operation, and increase the lifetime of the systems. One of the ESNs says that it could be of interest to introduce more complex energy systems, if that means higher electricity productivity or lower price per unit of electricity. If a higher complexity would mean a need for additional support to build up human resources in the region, this cost also has to be taken into consideration.

7.5 The usefulness of the concept of technological complexity in the context of PV system design

In section 2.3 the following research question is introduced:

How do the stakeholders' main considerations and design of PV systems have an impact on the level of technological complexity? How could the concept of technological complexity be useful in the process of designing PV systems?

As described earlier, the stakeholders have a number of main considerations in mind when designing a PV system, to make the PV system accessible to potential customers. Based on these, they make certain design choices, which results in a final PV system design. The final design of the PV system will have a certain level of complexity at a technical system level, in terms of hardware and software. The level of complexity at a technical system level will in turn have an effect on the complexity at stakeholder system level. This has been described in detail for two design approaches varying from a standard PV system design. Hence, the stakeholders' main considerations link directly to the level of technological complexity at both technical- and stakeholder system level. This is illustrated in figure 13.

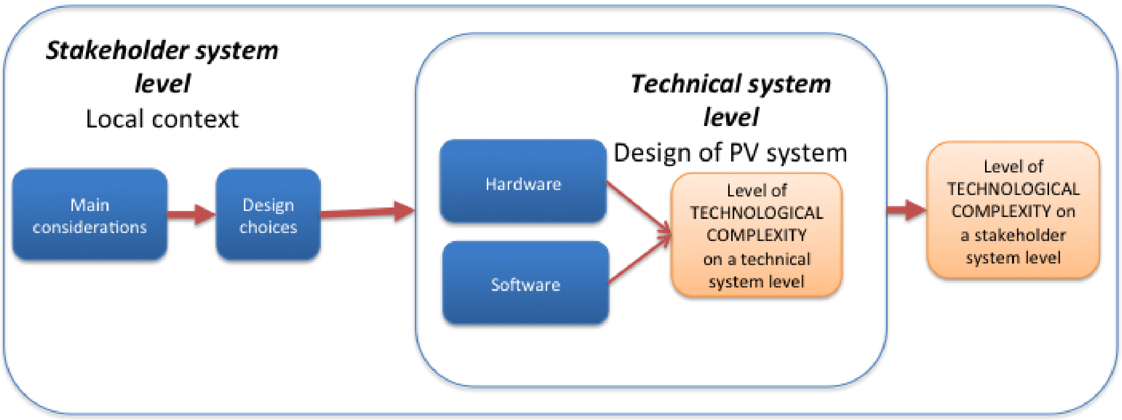


Figure 13: The relation between main considerations and the level of complexity at a technical- and stakeholder system level.

The level of complexity at a stakeholder level is of special interest, since it is defined by the level of knowledge required to manufacture, install, maintain and use the PV system. For example, more knowledge is needed from the company's side to maintain a PV system with RMCS, than a standard PV system. Another example is that it is usually easier for a local technician to repair a locally assembled inverter than an OEM inverter.

The analysis of the complexity level for different design approaches shows that the concept of technological complexity is a fruitful way to analyse how different types of PV system designs, in terms of complexity at a technical system level, can affect the complexity at a stakeholder system level. This is a main contribution from the analysis. It shows that the concept of technological complexity can be used as a tool when designing PV systems, to achieve a certain level of complexity for e.g. users, technicians, or a PV company. "Back looping" can hence preferably be used at a stage where design choices are made. The level of complexity should then be taken into consideration together with a number of main considerations. This is illustrated in figure 14.

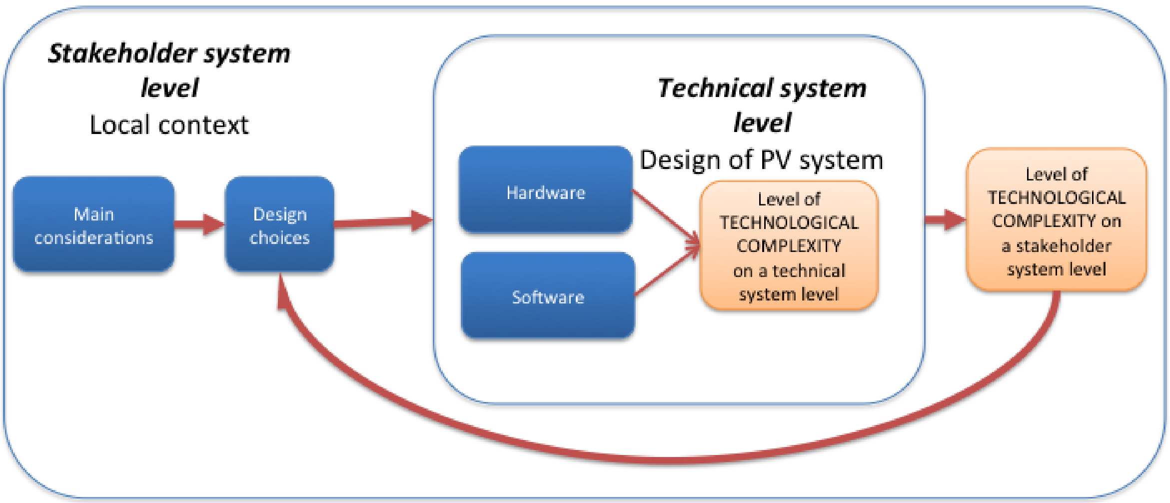


Figure 14: The usefulness of the concept of technological complexity when designing PV systems.

All the interviewed respondents were of the opinion that for a PV system to have a long life-time, it needs to be simple to use and maintain for the users and technicians. This could work as a starting-point when using the concept of technological complexity to design appropriate PV systems in a certain context. As described earlier, the design choice to use RMC, seems to be a well aware choice to meet the needs for user friendliness. Hence, the case of RMCS implemented in the PV system design can be seen as an example of where the concept of technological complexity has been used as a tool, whether the designer was aware or not. Using the concept of technological complexity to carry out an analysis as the one shown in table 1 could also contribute to a more diversified picture of a certain type of technology in a certain context. Such an analysis can be of use before implementing new technologies or before implementing a proven technology in a new context. One of the theoretical starting points, and hypothesis, in this study, is that the complexity at a technical system level could have an effect on the stakeholder system level, and vice versa. In this section it has been shown that this is the case also in reality (see figure 14).

7.6 Technological complexity in the context of technology transfer

In the literature studied, a number of aspects important to consider when designing PV systems and transferring technology to developing countries are mentioned. According to Wilkins (2002) not only the access to the equipment/technical system, but also the information, know-how and skills needed to fund, manufacture, install, operate and maintain the equipment/technical system are important when bringing a new technology into a society. Furthermore, the technical concept should be understood and brought into practice by the local people in order to achieve a successful technology transfer (Wilkins, 2002). According to Murphy (2001) there needs to be some technological capabilities developed in order to absorb a technology into a society. These capabilities can be defined as the following skills; technical, organizational, institutional and access to information that enables business to evolve (Murphy, 2001). It has been concluded that the approach of locally assembled components has a lower complexity level at a technical system level, compared to standard OEM PV components. It has also been concluded that the approach of an RMCS integrated in a PV system has a higher complexity level at a technical system level, compared to a standard PV system. In this section those two approaches will be analysed, in the light of discussions with the respondents regarding PV market growth and technology transfer, in order to answer the following research question, introduced in section 2.3:

Is the concept of technological complexity relevant in the context of technology transfer, and how does technological complexity affect the process of technology transfer?

Several of the PCEs and ESNs touch upon the topics of the state of the PV market in Tanzania and the need for coordination between institutions and other stakeholder, as well as knowledge transfer, to achieve a thriving PV market. Some of the PCEs and ESNs are of the opinion that in order to reach the electrification targets in rural areas, the off-grid PV market has to remain diverse in terms of technology and affordability. One of the PCEs argues that there will always be customers who are able to afford being connected to a mini-grid, and other customers who can only afford to buy small solar lanterns. There have to be different types of actors serving different types of customers with different types of PV systems. One of the PCEs gives an example; the solar energy provision for telecommunication masts that need a high reliability, where there are resources to pay companies to install and maintain advanced technology, versus; the small rural households with two light bulbs, where SHS and local technicians with lower prices are more appropriate. He emphasizes that the network between different actors on the PV market is important, for them to be able to support each other.

Some of the ESNs argue that the status of the PV market, seen as a network or a stakeholder system, has an impact on the design of PV systems, and say that the PV market needs to be enhanced. This can be done through local capacity building and awareness raising, according to the respondents. To make the PV market grow, collaborative and complementing efforts between NGOs, universities, vocational training institutions, micro-credit institutions, companies and ministries have to be carried out, according to one of the ESNs. He says that the connections between these stakeholders are rather weak today, and that there is a need for coordination.

According to one of the ESNs, sustainability of a technology can be understood as when there exists a network around the technology with after service as well as the technical know-how of how to manage the technology. When a new technology is brought into a country, this system has to be built around it, addressing needs for technical support throughout the whole lifecycle of the technology. As a representative for a developing partner, he argues that it is not sustainable to keep bringing in expertise from outside the country, since it becomes very costly. The local human resource capacity has to be built into the technological system. How this capacity is going to be built has to be addressed; should an international company give special support for a period of time or should the support be given through a supplier within the country?

As regards to the role of the concept of technological complexity in the context of technology transfer, the two different design approaches – locally assembled components, and RMCS integrated in the PV system –, with different levels of complexity are here used as examples. The purpose is to present a picture of what impact the level of complexity might have on the possibilities of technology transfer.

From what was gathered during this study, the technical skills to assemble and repair locally assembled components, as well as the access to information, is present in the rural areas in Tanzania. Both the electronic components used to assemble PV components and the know-how has been found available among the technicians in the visited local region. The skills in how to fund, manufacture, install operate and maintain the locally assembled components can be found among the local people and these skills have also been brought into practice. One of the technicians showed his own business, were he also teaches students how to assemble inverters. He also showed a circuit diagram that he is using when assembling inverters, which he had found on the Internet. This is an example of that there is both access to information, and a business that has evolved, related to locally assembled components. Hence, if analysing the approach of locally assembled components from the perspective of the technicians, with Wilkins’s definition of technology transfer, it seems like this technology has been successfully transferred into the visited parts of Tanzania. However, seen from the user perspective, it is not sure if the users would have the know-how and skills needed to maintain and use the locally assembled components in a correct and safe way, as described earlier.

According to the studied literature there are often many challenges regarding the institutional and organisational structures. When considering the long-term perspectives it is necessary that a market is growing, connected to the PV systems and its components. The approach of locally assembled components could lead to local markets growing with these components. There is no doubt about that there exists a market of locally assembled PV components in rural Tanzania, even if it is not investigated in this study to what extent. If the approach of locally assembled components and the local knowledge regarding how to handle these components will grow to a larger market in the future is hard to predict. Two of the ESNs mentioned that they do not think that the market with locally assembled products will grow much in the long run, due to the competition from imported OEM components with decreasing prices. On the other hand, one of the PCEs pointed out that the market of local technicians repairing mobile phones and cars has been growing in the past. It is possible that a market with locally assembled PV components could grow, if the customers see it as a major benefit that these components can also be repaired by local technicians, and if that would not be possible for OEM components. Increased local knowledge regarding assembling and repairing PV components could make people less dependent on specific companies or specific products to install and maintain PV systems. If a market with locally assembled PV system components would grow, it could be seen as a way of enhancing local capacity building, know-how, and hence technology transfer.

The approach of RMCS integrated in the PV system design means a more technically advanced hardware and software, compared to standard OEM PV components. The know-how that is needed to deeply understand and manufacture the technology is in general not found among local technicians in rural Tanzania. The approach of using RMC integrated in the PV system design was something that the technicians interviewed were not familiar with. On the other hand, the PCEs within the PV companies selling PV system with integrated RMC seemed to have a strong belief in the approach of using RMC in the PV design. This indicates that there might be a growing market with the concept of RMC in PV system in rural Tanzania. The existence of RMC in PV systems was also found in literature, which also is an indication of that there might be a growing approach of using RMC in PV system design.

The approach of RMC includes involvement of experts from outside of the local region, which have the responsibilities for development, manufacturing, distribution, and reparation of the RMCS, as well as management of the payment organisation. The use of RMC puts higher demands on the company managing the PV systems, in terms of economic resources, knowledge and organisation. In this way, the level of complexity on the stakeholder system level increases. For a company that have access to such resources that is however not a problem.

However, for a local technician it should be rather complex to assemble and repair, use or understand, a RMCS. It can be assumed that there are not many local technicians in rural areas who could handle a RMCS or get the benefits from it without special education. In a context where RMC is used, local technicians would merely become a part of the machinery of a larger company. There is a large risk that the required in-depth knowledge is staying with specific companies. This results in a situation where the in depth knowledge, skills and know-how will not be available in the local region, and this can be seen as a non successful technology transfer, according to Wilkins's definition. On the other hand, the customers who buy a PV system with an integrated RMCS and a system warranty will have a user-friendly and highly reliable PV system, which is guaranteed to work during the time warranty time.

Furthermore, the basic understanding, know-how and skills in how to operate and maintain a PV system seem to be spreading in the areas were Company 5 have implemented PV systems with RMCS. Company 5 performs training of both technicians and users as a part of their business model. This will probably increase the overall awareness and understanding of how to handle a PV system. If there exists a lot of well functioning PV systems, this can enhance the reputation and general awareness of PV electricity, which is positive for the PV market in general.

In conclusion, Company 5's approach with a business model and a plug-n-play design including RMC, seems to contribute to spreading of general awareness, skills and know-how connected to operation and performance of easier maintenance of PV systems. However, if considering the in depth understanding of how to manufacture the RMCS and PV system, and to manage the RMC functions, it does not seem like a successful technology transfer has occurred in rural Tanzania yet.

These two design approaches with different levels of complexity, compared to a standard PV system, can be seen as different ways of how the PV market in Tanzania could develop, if technology transfer is able to take place. Are PV systems with a higher complexity on the technical system level, which might demand more knowledge and expertise from outside of the local area, more appropriate in the long-term operation of the PV system? Or is PV system with lower complexity on the technical system level, which can be assembled, repaired and maintained by local technicians, more appropriate in the long-term operation? These questions are complex and many aspects need to be taken into consideration when analysing appropriate PV system design. During this study no clear answers regarding the most appropriate PV system design, to allow for a sound technology transfer to take place, have been found. As described earlier, there are a number of main considerations brought up by the technicans, PCEs and ESNs, that they have in mind when designing PV systems. The motive is to make PV systems accessible to potential customers, make them affordable and durable. How this can be achieved, as regards to the technical design, is still open for discussion.

The two design approaches analysed are examples of that the level of complexity of a PV system can have an effect on what type of actors would be able to access the knowledge and information required to manage a technology and create a business with it. Hence, the level of complexity could have an effect on the possibilities of technology transfer and absorption. The growth of the PV market is something the stakeholders see as important, and the concept of technological complexity could be a tool when assessing the technology transfer potential of a technology in a certain context.

8. Discussion

In this chapter suggestions for future studies are made.

In a future developed study, it would be useful to focus more on the users' opinions regarding what problems they might face regarding operation and maintenance. What they think is good in the design of their system, as well as what improvements they might be interested in. This could be carried out as case studies, where PV systems and the surrounding users are studied during a longer period of time.

For future studies, the concept of technological complexity could be further developed as a contribution to systems theory. The concept of technological complexity as a model could be applied to any type of socio-technical system, and used as a tool to investigate the interactions between stakeholders and a technology. This would be particularly interesting for newly developed technologies, to enhance the understanding of what type of technology could be appropriate in different kinds of environments.

An improvement of this study would have been to study PV systems with more varying design. An extension of the study could be to investigate different types of energy sources in terms of technological complexity, like the intention with this study was from the beginning. However it would probably be found difficult to compare different types of energy sources to each other, since the technologies differ considerably. An enhancement of this study would be to develop tools to grade a technology, in order to measure its technological complexity at a technical- and stakeholder system level. This would make comparison of different technologies and designs easier.

9 Conclusions

The aim of this study was to exploratively investigate the role of the concept of technological complexity when designing small-scale, off-grid photovoltaic (PV) systems in rural Tanzania, considering the whole lifetime of the PV system. Five research questions were developed in order to better understand the role of technological complexity in this context;

- How do the stakeholders motivate their main considerations when designing off-grid, small-scale PV systems (stand alone PV systems and SHS) in rural Tanzania, considering the whole lifetime of a PV system, when looking at planning-, installation- and operation phase – including maintenance?

- What variations in PV system design, compared to a standard PV system, are observed or described by the stakeholders, and how do these design variations differ in their level of technological complexity at a technical- and stakeholder system level?

- How is the concept of technological complexity in this context perceived by different stakeholders?

- How do the stakeholders' main considerations and design of the PV system have an impact on the level of technological complexity? How could the concept of technological complexity be useful in the process of designing PV systems?

- Is the concept of technological complexity relevant in the context of technology transfer, and how does technological complexity affect the process of technology transfer?

19 interviews were carried out with different stakeholders in Dar es Salaam and Ruvuma Region during a nine week long field study in Tanzania. The stakeholders interviewed were grouped into three stakeholder groups; local PV technicians; PV company employees (PCEs); and energy sector stakeholders at national level (ESNs). Definitions for the level of technological complexity at technical- and stakeholder system level were developed. A conceptual model illustrating how technological complexity at the two system levels could link to the long-term operation of a PV system was also developed as a part of the study. One of the main contributions of this study is the theoretical conceptual development of the concept of technological complexity, which has been used to analyse the results.

It has been found that all stakeholder groups have a number of main considerations in common, when designing small-scale, off-grid PV systems in rural Tanzania. The motivation behind these main considerations was mainly based on the wish to make PV systems accessible to potential customers. It was noticed that the ESNs had a longer time perspective, and were also driven by the wish to make the lifetime of the PV system as long as possible.

Seven main considerations were identified among the technicians, PCEs and ESNs. At a technical system level, the main considerations identified were; 1) choices of technology and components; 2) system sizing; 3) protection of the system and in particular the battery; and 4) quality in components and installation. At a stakeholder system level the main considerations identified were; 5) affordability; 6) education, capacity building and awareness raising; and 7) maintenance and user friendliness.

It was found that the major part of small-scale, off-grid PV systems in rural Tanzania were designed in a similar way, while the quality of components and installation could vary. It was also strongly emphasized by the large majority of the respondents that there is a need for more quality control of both PV components and PV system installations. However, two approaches of PV systems with certain choices of technology and components, which differ from a standard PV system design, were found; to use locally assembled components instead of OEM (original equipment manufacturer) components, and; integration of a remote monitoring- and controlling systems (RMCS) in the PV system design. Technicians, PCEs and ESNs interviewed articulated both benefits and drawbacks of these two approaches, based on the main considerations identified.

Integration of RMCS in PV systems can enable a company to provide a large number of PV systems with maintenance- warranty- and leasing contracts in an efficient way, which would make the PV systems more user-friendly. This can improve the long-term operation. The use of locally assembled components was mainly based on the argument of affordability and that the knowledge of how to assemble the components, and the construction material, was present locally. However, compared to OEM (original equipment manufacturer) components of high quality, locally assembled components could result in a non user-friendly, dangerous PV system with low efficiency and an unpredictable lifetime.

The level of complexity of the two approaches was analysed by comparing them to a standard PV system. It was interesting to notice that the level of complexity at a stakeholder level for each approach was varying for different stakeholders. It was concluded that locally assembled components have a low level of complexity at a technical system level. However, the level of complexity at a stakeholder system level is rather high when considering the user perspective. PV systems with RMCS have a higher level of complexity at a technical system level, compared to a standard PV system, while the complexity level at a stakeholder system level can become low for the users.

When considering independent, local technicians perspective and their possibilities to design, assemble, repair and maintain PV components, the locally assembled components seem to have a low complexity level, and RMCS a high complexity level, at a stakeholder level. This is important information when assessing the possibilities for a certain type of technology or design to be transferred or absorbed into a community. The two approaches were used as examples to show how the concept of technological complexity is relevant in the context of technology transfer. It seems that locally assembled components could contribute to a successful technology transfer in rural areas due to their simplicity at a technical system level.

RMCS is however something that is accessible to PV companies but not to local PV technicians, due to the cost of the technology, as well as the skills and know-how required to manage it.

These two approaches are merely examples of how the level of complexity at a technical- and stakeholder system level can interact, and have an impact on the long-term operation of a small-scale, off-grid PV system in rural Tanzania. No clear conclusions regarding the most appropriate complexity level at a technical system level in this context can be drawn based on this study.

The perception of the concept of technological complexity varied among, as well as within, the stakeholder groups. The technicians had difficulties to understand the concept, while the PCEs and ESNs could relate to the concept. However, it was found that all of the stakeholder groups found it important to make the PV system simple for the technician, and especially the user, to use and maintain. This study, including the analysis of the two design approaches, serves as examples of that various stakeholders do consider the complexity level of a PV system, directly or indirectly.

It was concluded that the concept of technological complexity can be useful in the context of PV system design as a tool to analyse the implications of a certain design at a stakeholder system level. By defining the desired level of complexity for certain stakeholders, "back looping" could be used to find technical solutions at a technical system level, to achieve the desired level of complexity at a stakeholder system level.

Concerning small-scale, off-grid PV systems in rural Tanzania, it seems that it is desirable to design affordable PV systems of high quality, that are simple for the users to use and maintain. The concept of technological complexity does play a role in relation to these factors, especially user friendliness. However, it is hard to say if a high or low level of complexity at a technical system level is more likely to result in the desired low level of complexity for the users at a stakeholder level.

Some of the respondents interviewed would like to see a diverse PV market, with different types of actors collaborating, providing different types of designs and solutions. Among these respondents there is hence no resistance towards that several paths of technology development could keep evolving to reach higher electrification rates. Both RMCS and locally assembled components are examples of different paths towards a more diverse and thriving PV market. It is clear that a platform is needed, to bring the different actors on the Tanzanian PV market together to share knowledge and to keep developing. In the future, it would be interesting to further investigate how the aspects of complexity at the technical- and stakeholder system levels can interact, and what type of PV system designs could be more appropriate for rural Tanzania.

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APPENDIX I – INTERVIEW GUIDE

1. Introduction questions

1. What is your experience of working with small scale, off-grid, rural electrical systems operating on renewable energy?
2. What are you working with today?
3. (Apparently) you have experiences from various system implementations. Could you mention some specifically successful small-scale, off-grid electrical systems? Or, if you have been working with a specifically successful approach when designing, implementing and operating well-functioning small-scale, off-grid electrical systems (which have been able to generate electricity of adequate quality and quantity over a longer time period), can you describe this approach?

…When we give you the following questions, can you have that successful system (or approach) in mind?

General information about the system

4. From where came the initial idea? Who thought there was a need for an off-grid system? Who has been financing the system?
5. Who owns the electrical system? Has it been the same owner all the time?
6. Who is using the electricity produced? Has that been changing during the operation time of the system?
7. What were your initial expectations on how long time the system would operate? Does the system have a warranty? How long is the warranty time?
8. What were your initial expectations on the quantity and quality of delivered electricity from the electrical system? Has it been delivering electricity continually as expected since it was installed?

2. Information about the system design

9. Could you tell us about the technical design of the system?
10. How was the design of the system decided?
11. Who was responsible for the different steps of the design process of the system?
12. What factors were considered when deciding on design?
13. Which components are included in the electrical system? (for example PV panels, charge controller/regulator, inverter, nr of batteries)
14. What kind of PV panels are/were used? (Why?)
15. What kind of batteries are/were used? (Why?) Did you consider any other type of energy storage except for batteries?
16. Is/was there a charge controller and inverter in function and used?
17. Is/was load and/or generation meters used in the communities?
18. Does the technical design have an impact on the functioning of the electrical system? How? What design is more suitable in a long time perspective in rural areas in Tanzania, according to you? Could you describe, please?

19. How was the payment relation to the users designed and organized? How did you reason about the user-interphase?
20. What is the capacity of the electrical system? (e.g. W of PV panels, Ah of battery capacity) Was the sizing of the electrical system adjusted for present or future demand? (Per consumer? Per household?) Was the capacity increased after the initial installation?

3. The steps of implementing the systems

21. Can you tell us about the different steps of implementing the systems?
22. Who was responsible for the different steps in implementing the system?
23. Was the system (all parts of the system?) bought and installed at the same time?
24. Who installed it? (Different companies or the same company?)
25. Does the type of system also have an impact on the implementation and long-term (life span/longevity) sustainability? Why? Can you describe, please?

4. Definition questions

26. As you know, we are studying if technological complexity affects the system survival in rural areas in Tanzania. Here is a picture/conceptual model of our idea of how we can understand the system and the areas of complexity (explain the picture). What are your comments on this? Do you think we should add or change anything? We know there are several perspectives and we would like to understand your perspective on technological complexity in this context.
27. In general, what is your definition of a complex (and simple) system? And in what ways can a system be more simple or complex, according to you?
28. In general, what is your definition of long-term sustainability in this context?
29. Do you think more hi-tech (more expensive?) or more low-tech systems are most suitable for rural areas in Tanzania? Why? What do you consider as a good solution/strategy for Tanzania?

Coming back to the successful system/successful approach you were describing earlier on:

30. Have the successful electrical system (or the successful approach) been of complex or simple design, according to your definition? Can you describe?
31. Would you call the system you have described long-term sustainable? Why?

5. Operational phase

32. The system you have told us about, is it still operating? Has that been changing during the operation time of the system?

<u>Maintenance (Operation and Management)</u>

33. Would you like to describe the maintenance of the system?
34. Who is responsible for assuring that the maintenance takes place?

35. Who is taking care of the maintenance? (Local technicians or technicians coming from other parts of Tanzania, technicians hired by companies, or independent technicians? Local users taking care of the “basic” maintenance?)
36. Can you describe what kind of maintenance that is carried out? (Go through all the components/software: batteries, inverter, charge controller, PV panels.. (go back to notes from “2. Information about the system design”))
37. How often should maintenance of the system be provided?
38. How does it work to provide that level of maintenance? What is happening if the maintenance is not provided? (Are there any problems?)
39. Have there been any problems with poor maintenance or operation? Has the equipment ever been used in an improper way? What is the solution to that?
40. Does the system stop working sometimes? Why? What causes the breakdown? How long time does it usually take until the system is functional again? After being fixed has there been any changes in capacity?
41. Is there a need for any kind of spare parts in the system you have described? Do you expect some parts of the electrical system to break down before other parts? Do you have any experience of that? Are all components working as they should today?
42. Have you changed the batteries? (How often?) Do you know why the batteries stopped working?
43.Has the charge controller ever been disconnected from the system?
44. Does a breakdown affect anything else except for the electricity supply? (e. g. customer relations..)
45. Has the maintenance situation at the site been taken into consideration, when designing the electrical system? Could you describe, please? (Was there a specific choice on a more advanced/complex system design or a more simple system design, or a specific structure of the organisation of the payment, to make it easier to maintain the system in a long-term perspective?)
46. Do you have any experience of systems having different needs of maintenance, due to varying level of technological complexity of the system design? Could you describe, please?

<u>Availability and quality of components</u>

47. In general, how would you describe the availability of electrical systems and spare parts in this area and in Tanzania over all? (new batteries and second hand batteries? Is there any recycling of the batteries?)
48. In general, what is the quality of the components? Is there a difference in quality of for example imported and locally manufactured components? Does the quality vary between different suppliers or dealers?
49. The system/approach you described before, would you describe it as reliable? Does the reliability of the systems change over the year, with the dry and rainy seasons?
50. Does availability and quality of components have an impact on the technical design? Could you describe, please?
51. Does availability and quality of components affect the operation and maintenance? In short- and long term perspective? What is your experience of that?

<u>Infrastructure</u>

52. Does the condition of the roads or availability of freight transports influence the functionality and operation of the electrical systems? Does the infrastructure situation have an impact on the system design or the choice of system/equipment? Could you describe, please?

6. Economic situation

Investments and costs

53. The system you have described, could you explain what costs have been associated with the implementation, operational phase and possible other expenses?
54. In general, do you experience that the costs (investment or cost of operation) for the systems vary depending on the level of technological complexity of the systems?
55. How is the payment from the electricity costumers organized?
56. How large was the system investment costs? How did the buyers get the money? Loans, grants?
57. Are there any operational (maintenance) costs?
58. In general, do you experience any difference in functionality between a more expensive PV system and a less expensive PV system?

7. Education, organisation and management

Education

59. In the system you described before, what education does the technicians who are maintaining it have? How did they achieve it?
61. Did the level of knowledge in the adjacent area affect the choice of system design? (Technological Complexity? Interest in building competence in the area?)

Organisation, management and ownership

62. Does the ownership structure affect the level of success when operating and maintaining an off-grid electrical system? Can you describe, please? What are the advantages/disadvantages with different types of ownership?
63. In this case, has there been any cooperation between different actors, e.g. private owners, companies, NGOs, government? How does it work? (show picture)

8. Conclusion:

65. Do you think the level of technological complexity of the hardware, software and organisation of payment is an important factor that is affecting the long-term sustainability (that the electrical system is in function and generating electricity in planned quality and quantity during the whole planned lifetime) or are there other factors that are more important than the level of technological complexity? Can you describe, please?
67. Do you see any connection between the level of complexity in the PV systems and the long-term operation of the system, with kept quantity and quality of electricity production? (Software, hardware, payment/organisation)

68. Are you going to work with more off-grid rural electrical systems in the future? What would you like to improve, based on previous experiences?
69. Is there anything that you would like to add?
70. Is there anything that you would like to ask us?

APPENDIX II – PV SYSTEM CHECK LIST

Design and installation - questions

- Size of loads
- Duration time (for the different loads)
- System components? Why have these been chosen (dry/wet batteries etc.)? How has it been working? Would you have liked to do anything differently if you would have installed the system today?)
- Size of system components (PV panel, charge controller, inverter, batteries, cables)
- Connection and sizes of cables
- Polarity reversal – is that ever a problem?
- Use of the system – irregular/regular? Is the system used as expected (type of batteries used, wiring etc.)? Why/why not? Has the design turned out well in this case? Have the users been changing the system somehow?
- Battery usage – how many percentages is the depth of discharged every day?
- How does the use of the system change over the year? (Dry/rainy season? Are the batteries treated differently during different periods?)

"Trouble shooting"

<u>Visual check</u>
- Dirty panels (dust and algal growth)?
- Cracks in the glass?
- Water intrusion?
- Shading (building, overgrowth)?
- Angle (10-15 degrees)
- Distance, PV panel and roof (at least 15 cm)
- Sizes of cables
- Connections of cables (loose connections?)
- Fuses?
- Multimeter, check voltages; PV panel and compare with specification, battery, loads.
- Power pliers, check current; PV panel and compare with specification, battery, loads.

<u>Charge controller</u>
- Visual check (green, orange, red light)
- Connections of cables

<u>Cable sizes (between PV panel and battery/charge controller)</u>
- 20 W = 4 mm
- 100 W = 6 mm
- 200-500 W = 10 mm
- Larger than 500 W = use template to calculate (what template is the technician using?)

Cable sizes to the loads
- DC loads = 2,5 mm
- DC loads = 1,5-2,5 mm (TV, light, radio)

Battery
- Check battery box (whole and protected, enough air circulating, temperature)
- Corrosion on the terminals (loose the cable, clean with brush)
- Level of electrolyte and corrosion inside the battery (check every 3 month)
- Hydrometer (measure when fully charged), can be red, orange, green or the density number
- High rate discharge test