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Case study of a Solar Powered Drip Irrigation system for women farmers in Northern Benin, West Africa

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List of Acronyms

ADESKA	Association pour le Développement Economique Social et Culturel a Kalale'
AMG	African Market Garden
FAO	Food and Agriculture Organization
FSE	Center on Food Security and the Environment, Stanford University
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IREEP	L'Institut de Recherche Empirique en Economie Politique
IWMI	International Water Management Institute
NGO	Non-governmental organization
PILSA	Projet d'interventions locales pour la sécurité alimentaire
PV	Photovoltaic
SDI	Solar drip irrigation
SELF	Solar Electric Light Fund
SMG	Solar Market Garden
SONEB	La Société Nationale des Eaux du Bénin
UN	United Nations
USADF	United States African Development Foundation
WDR	World Development Report

Abstract

During the dry season in the Kalalé District of Northern Benin, water scarcity-related issues (for example the inability to irrigate fields and have access to potable drinking water) become a systematic dilemma for smallholder farmers – especially women farmers. In response to this situation, since 2007, a triumvirate of NGOs assisted group-based women farmers to adopt solar powered drip irrigation systems for the production of horticultural products on small communal gardens with the intention to reduce the vulnerabilities associated with rainfed agriculture. This paper will focus on the introduction of this new technology in the semi-arid region of West Africa.

Relevance to Development Studies

In rural communities, women farmers are of central importance because of their role as food producers and income earners for their families. Their access to water for irrigation can have crucial long-term impacts in terms of demographics, diets and the diversification of their income bases. Since agriculture is the main source of revenue for women farmers, this paper seeks to understand the link between access to irrigation services (in particular small-scale solar powered drip irrigation) and improved food security and income levels, focusing on the role of women farmers.

Not much has been written on the relationship between women (in semi-arid and arid zones where prolonged periods of drought affect crop production patterns) and access to irrigation (Upadhyay, 2005). Thus, this paper contributes to a better understanding of the intricate relationship between water development, food security and rural poverty alleviation.

Keywords

Horticulture, community based, women farmers, solar energy, drip irrigation, rainfed agriculture

Chapter one: Introduction

1.1 Introduction

Nearly one fifth of the world (about 1.2 billion people) live in areas of physical water scarcity, where not enough water is available to meet their daily needs (World Development Report, 2010). The International Water Management Institute (IWMI) however, states that 1.6 billion people live in "economically water-scarce basins, where human capacity or financial constraints, poor infrastructure and lack of management affect the quality and the quantity of water available for productive uses" (Molden et al, 2007:62). Within this scenario, this research paper reflects upon the difficulties that the majority of smallholder farmers face due to dependence on rainfed agriculture.

Much has been written on the difficulties farmers have in stabilizing crop production patterns because dependent on rainfed agriculture (Howes 1982, Davis 1986, Van Koppen 1998, Mollinga 1998, Mortimore 2001, Postel et al 2001). Realizing that the implications of this situation are complex and multifaceted, this paper looks at a specific case in the Borgou region of Benin. The relationship is straightforward. Due to low annual rainfall, judicious use of water is necessary (Sengupta, 1993:51). While water control is often not the only limiting factor in crop production, it is often the starting point for any improvement in agricultural productivity (Faurès and Santini, 2008). Therefore, a lack of water resources can negatively affect crop production which in turn can directly affect the health and nutrition of farmers and their respective households, even possibly leading to a transitory but chronic state of malnutrition, characterized by micro-nutrient deficiency and lack of calorific intake.

In Sub Saharan and Western Africa, failures in the adoption of irrigation systems for boosting food production are quite acute (Wani et al, 2009). About seven percent of total land is equipped with irrigation systems, while in Benin only 4 percent of the total potential area for irrigation is adopted with irrigation systems (FAO Aquastat, 2003). Hillel (1997) states that these historical failures relate to "unfavourable topography and soils, distant markets, lack of credit, labour and information and the depletion and pollution of freshwater resources" (Hillel, 1997:41) to name just a few.

Starting with the notion that irrigation and agricultural development are inseparable (Fishelson, 1986:2), it is clear that new technologies with the potential to improve irrigation are important. However, the advantages new technologies (such as solar drip irrigation) are limited at the localized level. The reasons are many but most importantly, 'food security' and 'rural poverty' are context-specific and hence cannot be understood at the global level but only extensively elaborated at the local level. In the area under investigation, the reasons for water shortage are less to do with physical scarcity of water than water access, depending on seasonality as well as on financial and technical problems (Gruber et al, 2009). Furthermore, issues related to the inaccessibility of foodstuffs are not considered a static issue but a transitory chronic state of being, where only during certain periods of time (for example due to prolonged drought periods) farmers are not able to afford nor produce enough food (Burney and Naylor, 2011). The situation results in absurdity when farmers producing food crops end up spending an excessive percentage of their income on additional food.

1.2 Background of study

In the Kalalé District of Northern Benin (comprising about 44 villages with a total of 100,000 inhabitants), an international NGO – Solar Electric Light Fund (SELF), has been assisting group-based women farmers to adopt solar powered drip irrigation systems on small communal gardens since 2007. Between April and November 2007, SELF installed three 0.5 hectare Solar Market Gardens (SMGs) in the villages of Bessassi and Dunkassa. The SMG project consists of a series of funds made available to the international NGO from the World Bank, the Nordic Fund and recently, the USADF.

It is important to note that the study under investigation is an agricultural project. In other words, an "investment activity where the expansion of capital resources create a producing asset from which expected (social and/or financial) benefits may be realized over an extended period of time" (Gittinger, 1972:1), but also reflecting on the overall national development strategy. The project is intended to accomplish a specific objective for a certain target group, that is, to boost crop production from communal gardens in an effort to improve food security levels, particularly during the long six month dry season (Burney et al, 2009).

Women farmers were chosen as target beneficiaries – based on pre-established criteria. In 1994, the World Bank financed a community-based development project – Projet d'interventions locales pour la sécurité alimentaire (PILSA), which assisted women farmers in the Borgou region in the formation of group associations for collective farming. The women already owned a small parcel of land on which they cultivated staple crops such as maize, corn, sorghum and yams. However they were experiencing evident difficulties in hauling water, especially during the dry seasons when women have to walk further distances because nearby wells dry out (Carr, 1982:3). In 2007, these same women farmers, with the collaboration of SELF and the local NGO, ADESKA were equipped with small-scale drip irrigation systems for horticulture production on small communal gardens. The importance of the drip method and its association to horticulture will be explained in chapter two.

The Solar Market Garden (SMG) is a concept based on the African Market Garden (AMG). Over the last ten years, four AMG models have been tested in the Sudano Sahel of West Africa under the leadership of the International Crops Research Institute for the Semi-arid Tropics (ICRISAT). The four main pillars that constitute the AMG and therefore also act as basic fundamentals for the SMG concept are: (i) the collective use of water; (ii) energy resources (iii) land; and (iv) complementary inputs and marketing (Woltering et al, 2011a). These four elements will be further elaborated in Chapter 2.2, but essentially the main novelty in the SMG concept relates to the use of solar energy to pump groundwater for continuous access of water. The use of solar pumps opens up an array of discussions on the technical, environmental and financial aspects of the energy source which will be briefly examined in Chapter 4.

Figure 1 – Map of Africa and Benin, showing location of Kalale' District

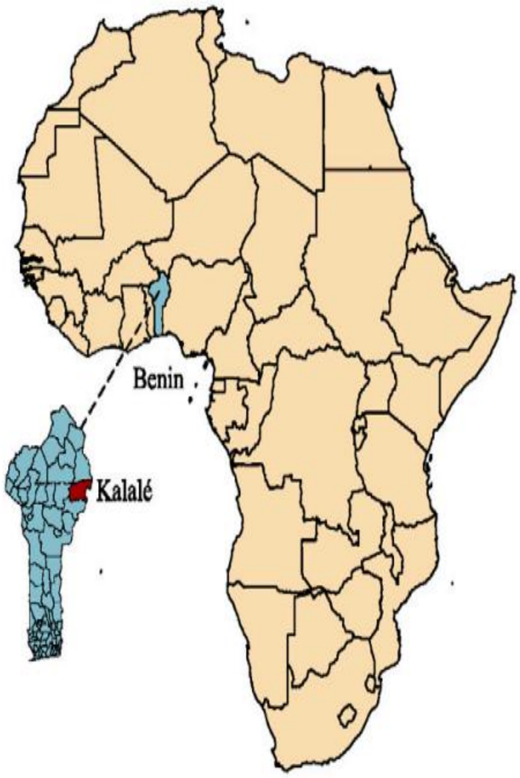

Fig. S1. Maps of Africa and Benin, showing location of Kalalé District.

The entire district of Kalale' includes forty-four villages comprising approximately 100,000 inhabitants. The figure above shows the geographical location of Kalale' District. To get a clearer idea of where the site is situated the following personal travel experience elucidates it relatively well. I departed early morning from Cotonou and arrived after a ten hour bus ride to Parakou (the largest city in eastern Benin). Usually, the braver men and women tackle another four-hour drive, but I decided to attend the next morning. The entire district is isolated from paved roads which exist jusqu'a Nikki, a city, an arrondissement and a commune in the Borgou department situated between

Parakou and Kalale'. However, due to the poor status of the dirt clay road, the 100km stretch from Kalale' to Nikki can take about two to three hours.

1.3 Problem Statement and research question

Given that horticultural production is a major source of income for millions of smallholder producers in Sub Saharan Africa (Weinberger and Lumpkin, 2005:1), water scarcity-related issues during the dry season becomes a systematic dilemma for women farmers. The inability to irrigate fields and have access to potable drinking water becomes a serious threat to their source of revenue. There are three main issues surrounding this situation. Firstly, assuming that one of the most critical components for optimal plant growth is a continuous supply of water, highly variable and unpredictable rainfall during critical periods of cropping season seriously harm production patterns (Wani et al, 2009:47). Secondly, given the context of arid and semi-arid regions, rainfall in Northern Benin is irregular with only one rainy season as compared to the South and Centre with two rainy seasons (Dansi et al, 2008). Thirdly, due to traditional farming methods (i.e. hand-watering), only 15-30 percent of the rain that falls on fields actually gets used productively for crops (Postel et al, 2001).

In light of the precarious rural water supply situation in the Kalale' District of Northern Benin (which will be further elaborated in section 2.2), this research paper attempts to investigate the potential of small-scale solar powered drip irrigation systems for group-based women farmers. To note, the role of women as beneficiaries in the context of developmental projects is of utmost importance. Generally, the gender aspect has been obscured in most literature available on drip irrigation which have so far focused on its hardware aspects and associated economic advantages (Mollinga, 2000:18). This poses certain limitations on the study which aims to evaluate the economics of the system but also focus on the following research and sub-research questions.

Research Question: Can high-input technologies like solar-powered drip irrigation systems enable smallholder women farmers to achieve higher incomes and improve their food security levels? And if yes, how?

Sub Research Questions:

1. How does access to water resources improve income and food security levels for women farmers?
2. What other ways (i.e. alternative energy sources or more cost-efficient methods such as treadle pumps) exist to obtain water and decrease the vulnerabilities associated to rainfed agriculture?
3. What are the financial costs of the solar photovoltaic (PV) drip system (construction, operation and maintenance)? Who bears the costs in terms of material and non-material resources invested?
4. What knock on tangible and intangible benefits can a technology like a solar drip irrigation system have on other productive off-farm income activities?

1.4 Justification

The main objective is to improve food security levels which represent a state "where all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (Mollinga, 2000:14). Thus, in a general sense, it can be assumed that a lack of access to water for women farmers poses as a major obstacle to their food security levels because it directly affects crop production patterns.

Solar-powered drip irrigation systems might sound a bit too sophisticated for rural women farmers who usually have low capital investments. Given the historical failures of irrigation systems and the use of pumps to extract water, the future for this technology in West Africa does not seem too rosy. At the same time, there is growing literature that raises the issue of national food security and higher food prices (Smith, 2004:243). It is therefore argued that the social, institutional and technical perplexities must be looked at against the comparative advantages the technology might have for a specific geographical location.

From a purely technical side, there are two main reasons as to why access to water for productive uses is considered key to increasing food production. Firstly, because the availability of water can stabilize crop production patterns on a yearly basis (Frausto, 2000). Secondly, which is directly related to the first point, water availability can improve production yields (by allowing multiple cropping seasons) thereby increasing income levels. In many cases, the potential of drip irrigation is often associated with horticulture production for both home use and sale (Upadhyay, 2005:2). Thus, information on market accessibility and market information on prices is a crucial component to consider. The interest lies in examining the potential of drip for the production of high value crops such as okras, tomatoes, carrots, amaranth, aubergine and papaya which contribute to an improved calorific intake of nutritional crops. Furthermore, since high value crop are female intensive industries, with women dominating most aspects of production and processing (Weinberger and Lumpkin, 2007:1469), it is assumed that with access to water resources for agricultural production, women can leap "from subsistence to marketing farming" contributing to rural development (Van Koppen, 1998:13).

Hence, the focus of this research paper is not only confined to an exploration of how a new technology can impact the livelihoods of women farmers, but also to understand how the technology becomes a mechanism for promoting social, economic and nutritional benefits for local rural communities.

1.5 Methodology

This thesis is based on prior work I conducted with the International Fund for Agricultural Development (IFAD) and supports my general interest in rural energy and water technologies. In August 2010, I drafted a grant proposal for

SELF, an international NGO based in Washington D.C. In August 2011, I visited the work SELF has been conducting since 2007 in Northern Benin. This recent consultancy entailed preparing an update report on the grant proposal I had prepared the previous year. Details in terms of my duties and responsibilities are not crucial for this paper although it is important to note, I travelled to Kalale' District for a six-day visit where I conducted three semi-structured interviews. The fact that I was representing a specialized UN agency poses certain limitations to the research paper and is discussed in Chapter 1.6.

The study conducts a cost benefit analysis based on estimates on the income benefits for women farmers from the production of horticulture production through the use of solar powered drip systems. Costs and benefits were obtained by deducting the construction, operation and management of the system from the revenues obtained from the sale of crops and replication of seeds. The analysis is based on a previous cash flow analysis prepared by the international NGO under the supervision of Mr. Jeff Lahl, project manager of SELF. The elements that constitute the cost benefit analysis are based on Gittinger's (1972) model for assessing agricultural projects. Empirical data is also obtained by a series of surveys performed by L'institute pour le Recherche Empirique d'Economie Politique (IREEP) in strict collaboration with the Center on Food Security and the Environment (FSE) at Stanford University.

The qualitative part of the research methods include two semi-structured interviews and three brief meetings with a total of five group-based women farmers (ranging from 15 to 35 women per group). The interviews consisted in understanding the social and environmental costs and benefits of the system. The samples had been purposefully chosen as the women farmers interviewed were the core beneficiaries of the project. Prior to the interviews, women farmers were requested to prepare themselves for answering any question in relation to the garden. Questions asked to women farmers can be divided into three sub-categories: (i) information on the project (why it exists, what are the expected objectives); (ii) information on the SMG (expenses, agricultural work) and; (iii) information on factors affecting income and nutritional levels. (Please see Annex I for a detailed review of the questions posed to women farmers). Lastly, some key information was obtained on market prices for vegetables, market accessibility and related transportation costs from two briefing sessions that took place with the executive director and both solar engineers of ADESKA and SELF, respectively.

1.6 Limitations to the research

During the interviews with women the first most important barrier to acquiring information came from the fact that I could not speak the local language, *Fon*. Therefore, all interviews were conducted with the support of translators. The executive director of the local NGO was my translator for two semi-structured interviews, while for the third interview (in the village of Bessassi), since women preferred speaking another local language (*Bariba*) the solar engineer of ADESKA was my translator. This posed many limitations on the answers I got. Firstly, I simply had to trust what I was told by my translators. Secondly, at times some insecurity in answers was perceived as women would tend to collectively 'decide' on how to respond to my questions when there were uncertainties. For example, from their pauses to their nodding it seemed that they needed to agree on answers prior to 'officially' replying to the translator (and hence keeping a hold on the truth). Hence, due to the language barrier, I was unable to decipher these hesitancies and could only rely on the 'official' answers.

Representing a specialized UN agency has given me access to key secondary data otherwise unavailable to the public domain, as well as the possibility to conduct three group based interviews. Nevertheless, the disadvantages inherent in representing a donor funding agency and not an independent researcher might have affected the honesty of the women farmers regarding their expenses towards the SMG. As a result, this has had some repercussions on the preciseness of the cash flow analysis. Based on the interviews, the figures in the cash flow analysis cannot be exact. Data related to the revenues from sale of horticultural products is difficult to capture as sales are done on an individual and informal basis (Mr. Robert Freling, personal communication, October 15, 2011). Based on the local knowledge ADESKA has absorbed throughout the past four years, it is strongly believed that the revenues are under-reported. This is because presumably, farmers are hesitant to be seen as doing "too well", in fear of creating envy among neighbours and of having family members asking for money (Mr. Bio Wade Seydou, personal communication, September 2, 2011). In other occasions, it was noted that women tended to exaggerate the difficulties inherent in managing the SMG as they tried to make evident the need for more funding because prices of complementary inputs (such as fertilisers, pesticides and improved seeds) had increased. This behaviour can be supported by the fact that they lost interest in my questions as soon as they were told that I had simply come to study and understand the benefits (if existent), and seek field knowledge for the possibility of replicating the project in other villages.

Time was limited as well as resources. The evaluation focused therefore on interviewing the direct target beneficiaries. Although women without the system were briefly interviewed (in the villages of Kidaroukperou, Peonga and Kalale' Centre), a comparison of women farmers without the system (i.e. a control group) has not been explored thoroughly. The lack of data on women's incomes is also a major limitation. To an extent, this is a relevant issue also for women in villages with solar powered drip systems. However, the local NGO has helped them keep track of yields, costs and revenues. Essentially, knowledge of all these limitations are fundamental for understanding the importance of this study however, they do not limit the inherent potential of the technology if examined within the given organizational structure stemming from the inherent "social relations of power" (Mollinga, 1998:12) present in the specific area that shape the roles and responsibilities of women farmers, the local NGO and the international NGO.

1.7 Organisation of the paper

The following chapter looks at the historical evolution of drip irrigation as a technological innovation. It describes where drip technology was first introduced and for what purposes. It also seeks to contextualize the technology. It is argued that supportive institutions are a crucial element for the provision of irrigation services. This notion is supported in the descriptive model of the solar powered drip system. Chapter three provides a conceptual framework on irrigation technology based on Mollinga's work on the social construction of technology (Mollinga, 1998). Essentially, this chapter seeks to highlight the relationship between water resources development, food security and rural development (Mollinga, 2000). The chapter defines food security and elaborates on the potential role of women for rural poverty alleviation. Chapter four provides a tangible cash flow analysis based on Gittinger's (1972) model for assessing agricultural projects. In this chapter, the mechanism of possibly cost recovery and contributions to maintenance of solar pumps as well as the function of the communal pot are explained. Chapter five provides conclusive remarks on whether the technology shows overall viability in terms of delivering the expected returns. The findings show that the major difficulty in assessing the system is quantifying the social and environmental benefits accrued from the collective use of water for productive uses.

Chapter two: Conceptualizing the technology

2.1 Brief history of drip irrigation technology

Four decades have passed since the introduction of drip irrigation technologies and over the last decade, the evolution of the technology in academic literature and at the policy level has become recognized as an efficient tool for managing and conserving water resources as well as increasing crop productivity (Narayanamoorthy 1997, Frausto 2000, Upadhyay 2005). The following section provides a brief overview of the origins of drip technology simply because it is not realistic to assume that drip method is the most efficient for watering crops. In addition, the historical evolution of the technology serves as a tool to better comprehend the reasons for its recent acclamation in Western Africa.

Drip irrigation has been taken up in many countries across the globe. In the early 1970s, a first step was taken in the Jordan Rift Valley for the adaptation of drip irrigation to traditional farm practices (Or, 2000). The system was adopted for fruit crops on small orchards. By the mid-1970s, farmers in Australia, Mexico, New Zealand and South Africa started using this new method of irrigation in crop cultivation (Postel et al, 2001). In the late 80s, the system had already become established as one that can improve agricultural water productivity, create more output (in physical and economic terms) with less water (Woltering et al, 2011b) – in other words, a system "that can economize and minimize the use of water" (Narayanamoorthy, 2004:120). By this period in time, "seeing water shortages as best handled by irrigation had made water harvesting and conservation almost lost arts" (Uphoff, 2002:33). The table below highlights the general advantages of drip irrigation, however, it is important to note, the technology had not yet been accustomed to developing countries since "an estimated 80 percent of all pumps installed in Third World villages were out of order" (Carr, 1982:8).

Starting from a small base of approximately 56,000 hectares worldwide, drip and other micro-irrigation systems spread rapidly to 1.6 million ha in 1991 and expanded by 75 percent at approximately 2.8 million ha by 1998 (Postel et al, 2001:5). In India, throughout the 1990s, micro-irrigation technology (in particular drip) flourished the markets and started dominating the irrigation scene for its evident efficiencies in terms of increase in yield quantities of 'thirsty' crops such as fruits and vegetables (Hislop, 1992). In tandem to the drip method, one important component to take into consideration was the use of an efficient renewable energy source to pump groundwater for a continuous access to water. In 1992, a programme for solar photovoltaic (PV) pumps was introduced in several phases. By 1995, about 463 pumps had been installed and by the end of 1997, a total of 1,816 solar pumping systems had been installed in India alone – about 30 percent dedicated to horticulture production (Van Campen et al, 2000:41).

Table 1 – General advantages of drip irrigation

Efficient	Better plant health	Water conservation	Improvement in quality of yield
Profitable	More animals can be raised	More land can be cropped (higher productivity)	New, more marketable products
Cost-reducing	Water saving per unit of land	Saving in other costs (fertilisers, pesticides)	Better utilization of the entire water system

Source: Narayanamoorthy, 2004

Today, much literature available on irrigation technology (Sengupta, 1993; Hillel, 1997; Frausto, 2000; Mollinga, 2000; Narayanamoorthy, 1997, 2003, Parlin and Lusk, 1991) highlight that the "successful introduction of irrigation is mostly dependent on improved farming techniques and market access and the pumping technology is but one component" (Van Campen et al, 2000:38). In other words, soil characteristics and other agro-ecological factors (topographies, climates, qualities of water and land need to be taken into consideration (Sengupta, 1993:66). This broader view of understanding the system within an enabling environment unfortunately did not really take off before the late 1990s and probably constitutes one of the main reasons behind the failures of irrigation projects in Africa.

Given, the lack of basic infrastructure and the absence of developed markets, the insistence to propose technological innovations such as solar-powered drip irrigation stem from the belief that irrigation should play a key role in raising food production, especially in Africa (Faurès and Santini, 2008). In addition, it is assumed that the biggest potential gains in water productivity (more crop per drop) are in low-yielding rainfed agricultural areas (Molden al, 2001). While benefits have spurred worldwide over the past decades, irrigation in general and drip technology in particular are still relatively unknown and not widely adopted in most of West Africa (Koohafkan and Stewart, 2005). For this reason, the solar drip irrigation system seeks to integrate the technical, financial and organizational lessons learnt and proposes a new "adaptive technology that can minimize seasonal variability" (Mortimore, 2001:233).

2.2 Descriptive model of a solar powered drip irrigation system

The solar drip irrigation (SDI) system propels itself as a water and labour saving technology (Burney and Naylor, 2011). The water is pumped to a ferro-cement reservoir, which then gravity-distributes the water to a low pressure drip system. These reservoirs are approximately 4m tall and 4m in diameter. Each reservoir uses about 1.5 tonnes of cement. The reservoir includes a drain at ground level to facilitate monthly cleaning. The solar panels are situated about 80m north of the reservoir and the tube that brings in the water from the forage to the reservoir is the only part that requires electric power produced by solar energy. The system is designed in such a way that it does not require the use of a battery. Energy is stored in the form of water which is pumped into the reservoir during the day (through the use of solar panels). Thus, the only moving part is the pump which is designed to be repaired in the field by local expertise (Mr. Adrien Namur, personal communication, September 1, 2011).

The figure on the next page depicts the SDI system in the village of Bessassi. Solar pumps are equipped with an electric alimentation cord (orange cords) which connects the pump to the solar panels. Each SMG represents a deployment of 1.2kW of photovoltaic (PV) power. A water level sensor automatically regulates the amount of water that needs to be pumped into the water reservoir. The big blue sealed cylinder is the head of the forage. The two light blue tins are the meter counters. The counters exactly show how much water has been pumped during the day. The pumping capacity of this system is limited by the recharge rate of the borehole which averages 40-50 litres/minute. The recharge rate is dependent on the amount of water that is found below ground. The drill is 30 metres deep therefore guaranteeing also a source of safe, clean potable drinking water for rural communities (Mr. Adrien Namur, personal communication, September 3, 2011). This benefit comes with certain ecological issues pertaining water tables and aquifers which are examined in section 4.3.

Figure 2 – The Solar Drip Irrigation (SDI) model

As mentioned previously, the basic organizational structure in which the system presents itself is based on four elements that constitute the SMG which are: (i) the collective use of water; (ii) energy resources (iii) land; and (iv) complementary inputs and marketing (Woltering et al, 2011b).

The collective use of water

In the Kalale' District, water supplies are provided by three main sources. By the National Water Company of Benin (SONEB), through wells or water towers and rivers. At the village level, since there is a lack of institutional structures that fail to assure the accessibility of water resources for rural communities, the local NGO assumes the responsibility for the provision of agricultural water requirements. The construction of deep wells that supply groundwater for small irrigation plots have a large development potential in Benin (Gruber et al, 2009:204). The drill (ranging from 30 to 40 metres) goes beyond the water table in order to avoid seasonal water shortages in the dry season (Mr. Adrien Namur, personal communication, September 5, 2011). However, modelling groundwater aquifers bears some uncertainties and constraints for the mere reason that the practice of accessing groundwater via pumps is less common in Africa (Hollermann et al, 2010). The technical advantages and favourable conditions of solar pumps (high insolation and low rainfall, especially in the dry season) are evaluated within this framework.

Energy resources

The adoption of drip technology for women farmers is accompanied with the use of solar pumps to extract water from below ground. Solar energy is used because the geographical location of Kalale' is blessed with high solar irradiation. (See Annex II for a world solar map). More importantly, since the main driver of both the pump speed (flow rate of water that is extrapolated from below ground) and crop evapotranspiration is solar radiation, irrigation through solar pumping is self-regulatory (Woltering et al, 2011a). Thus, the volume of water pumped in hot days increases as plants require more water and vice versa (Burney et al, 2009). In essence, solar pumps powered by renewable energy customize water use accordingly to the plants' necessities for optimum growth. It is important to note, calculating system size depends on volume of water required, total head, and the solar irradiation (Howes, 1982).

Other major advantages are the low maintenance costs of solar panels (as the only labour required is to clean solar panels with a wet cloth which can be done easily by women farmers themselves), the long useful life the equipment has (solar panels are calculated to last a minimum of fifteen years) and the relative straightforwardness to install (Pande et al, 2003:387, Hislop, 1992).

Land

The project is addressed for women farmers who already own a parcel of land on which they cultivate staple crops. This portion however is not dealt with for two reasons. Firstly, because it would not make sense to deploy a solar drip system (with high initial investments) for the production of low-value staple crops such as corn, maize and millet. Secondly, because the fields under which women farm their staple crops are larger than the garden plot under consideration (about two hectares compared to 0,5 hectares). The key potential is therefore recognized in the adoption of the drip system on small traditional gardens for the production of high value crops. Since a secure access to water supply is of prime importance, the land site is chosen based on hydrogeological studies (performed by a local company) to determine the availability of water resources below ground level.

Complementary inputs and marketing

Most literature that praises the efficiencies of drip technology however never forgets to mention the complexity and therefore the skills required to manage the system. Complementary components include automated pumps, filters, pressure regulators and metering valves (Hillel, 1997). Considering that the area under study is a rural community, most parts cannot be supplied on a daily basis since certain materials are imported. Capital items such as solar panels come from China (Suntech) or the United States, while the solar pumps are manufactured by a Danish firm (Grundfos). The associated technical and economic costs are highlighted in Chapter 4.3.

The marketing support women receive is also an essential component to consider and is elaborated in the analytical framework in Chapter 3. Supporting institutions (mainly reflected in the role of ICRISAT) are present in the local area that help women farmers in all aspects of vegetable seeds production, nurseries activities and market information on vegetables prices.

<u>Table 2 – Summary of duties and responsibilities executed by each institution</u>

Service	Facilitation tasks	Provider
Training women farmers on vegetables seeds production Training ADESKA technicians on aspects of women group organization and monitoring Provision of fertilisers, pesticides and improved seeds (first two years) Training on nursery activities	The regional institution mainly provides technical assistance and training programs *(software)*	International Crops Research Institute for the Semi-Arid Tropics (**ICRISAT**)
System installation, repair and maintenance Procurement of project equipment and Technical design of photovoltaic systems Training ADESKA solar engineers on aspects of solar panels and pump installation, operation and maintenance	The international institution mainly provides the equipment and installation *(hardware)*	Solar Electric Light Fund (**SELF**)
Market access and information (help with markets identification) Project administrator Financial organization / Monitor producers for each growing season	The NGO serves as the local development on-the-ground project administrator Collect money / deposit in bank account of women farmers	L'Association pour le Developpement Economique, Social, Culturel de Kalelé (**ADESKA**)

The organizational structure is shaped by the local NGO, ADESKA, the international NGO, SELF and the regional NGO, ICRISAT whom all play a pivotal role in the study under investigation. The NGOs all have an empowerment approach, which gives financial, technical and organizational support to women (Van Koppen and Mahmud, 1995). The table on page 17 provides a summary of the duties and responsibilities executed by each institution because "irrigation technology not only mediate people's relationship with biophysical processes, but also shape the people-people relationships that are part of irrigation" (Mollinga, 1998:12).

2.3 Other technology options for village scale irrigation (for pumping groundwater and irrigating)

There are unlimited ways of tackling issues of water scarcity for small-scale farmers. However, none are actually comparable with drip irrigation simply because drip systems necessitate the availability of other inputs - energy to pump water, machinery, fertilisers, pest-control measures and high value seeds (Hillel, 1997) hence, making it obvious that "these schemes can function as long as there is a high level of well-trained technical inputs" (Lutz, 2002:45). The following section is not central to the overall objective of the research paper. Yet, it would be imbalanced not to acknowledge other technologies and/or practices that have had some historical impact on income and food security levels. Namely, options than can provide increased yields and are immune from erratic rainfalls. There are different set of technology options under consideration but also simple water retention and harvesting methods. Alternative energy sources for pumping groundwater are also briefly considered.

Accepting the idea that for any irrigation method to be effective the need for an ample supply of water is necessary, "the lifting of relatively small amounts of water for irrigation is generally regarded as the most promising" (Howes, 1982:3). In some cases, human-powered treadle pumps can be a suitable solution for pumping water because of the inherent low costs and no need for mechanics, spare parts etc. Another energy source used to pump groundwater is diesel-fueled motor pumps. However, several evaluations have shown that other human-powered methods of providing water supplies are not only cheaper but also more reliable than diesel engines (Carr, 1982:20). In addition, given the volatility and high long-run oil prices, diesel fuelled pumps are not an attractive energy option (although access to diesel fuel might not be an issue for villagers in the Kalale' District since it is situated only 30km from the Nigerian border). It is important to stress, the technologies considered in this section are for small scale farmers, thus large-scale methods such as building dams and canals (macro catchment techniques) are excluded.

Table 3 – Selected innovations that can improve water access and efficiency in agriculture

<table>
<tr><th>Technology or Practice</th><th>Example Locations</th><th>Conditions where consider appropriate</th><th>General Benefits</th></tr>
<tr><td>Manually operated pumps (foot/hand) that extract water from surface and groundwater sources</td><td>Bangladesh, India, Burkina Faso, Ethiopia, Mali, Malawi, Ghana, Niger, Tanzania and Zambia</td><td rowspan="2">Shallow groundwater or surface water available; small farm plots; semi-arid zones or areas with distinct dry seasons</td><td rowspan="2">1) Reduce water-carrying burden and risk of crop failure
2) Increase yields and allow diversification to higher-value crops for market sale
3) Increase income base and improve food security levels</td></tr>
<tr><td>Micro-irrigation using bucket kits, shiftable drip systems and micro-sprinklers, solar drip systems (debut in Benin and Burkina Faso)</td><td>Northwest, Central and Southern India, Nepal, Central Asia, China, Near East, semi-arid regions in South America and Sub Saharan Africa</td></tr>
<tr><td>Fog water collection using mesh nets</td><td>Peru, Chile, Nepal, South Africa</td><td>Upland areas with frequent fog periods</td><td rowspan="2">Simple techniques make fresh water available for irrigation year round, reduce groundwater extraction</td></tr>
<tr><td>Capturing surface runoff from “built” surfaces or rooftops, stabilization ponds, or small reservoirs</td><td>Beijing (China)
Lima (Peru)
Hyderabad (India)
Ubuntu (South Africa)</td><td>Rainfed, urban / peri-urban agriculture;
Rainfall runoff from greenhouses or other building structures</td></tr>
<tr><td>On- and off-farm rainwater harvesting</td><td rowspan="2">In low lying areas: “Fadama” in Nigeria
“Dambos” in Malawi, Zambia and Zimbabwe
“Tassa” in Niger</td><td colspan="2" rowspan="2">1) Where soil moisture is a limiting factor to crop production and where precipitation may result in topsoil erosion
2) Improve food security levels through effective soil and water management, retain soils and soil fertility and moisture</td></tr>
<tr><td>Terracing, vegetative barriers, recharge pits, and other methods</td></tr>
</table>

Source: Postel et al, 2001

Since short-term variability in rainfall affects soil moisture and plant bio-productivity, Mortimore (2001) argues that irrigation does not offer a general solution to low-bio-productivity – low in carbon, nitrogen and phosphorus (Mortimore, 2001) and therefore is not the only way to deal with water limitations (Uphoff, 2002). Nonetheless, it is important to note, "nitrogen and phosphorus are the principle soil nutrient deficits in most semiarid regions" (Lutz, 2002:43). As a result, although water retention practices have the potential to utilize rainfall most advantageously, where soils have high sand fractions, little clay and retain little moisture in the surface horizon" (Mortimore, 2001:236) these methods can be less effective. Parallel to water retention methods, micro-catchment techniques (such as on- and off-farm rainwater harvesting) also require a reflection on the soil-crop-water regime, stigmatized by the notion that soil need be moist and fertile if water is applied to it. In the frame of modernized irrigation systems, factoring the environment into crop performance is indeed a crucial element that requires examining the properties of soil fertility and water availability simultaneously (Davis, 1986). This concern is corroborated in Chapter 4.4.

The risk in entering too much into this discussion forces the need to acknowledge that with the exception of the treadle pump, the technologies and practices mentioned in Table 3 have not proven to solve the food security issues pertaining smallholder farmers in Sub Saharan Africa (FAO 1997, IFAD 2005). Although, to some extent, gains in productivities have been recorded, essentially, traditional irrigation techniques, such as total area flooding, have typically involved low frequency application of large amounts of water to reach excess saturation of soils (Wani et al, 2009). As a result, much water was wasted and land degraded (through water-logging and soil salinization (Nyamangara, 2009). Hand-watering also waste a lot of water and can cause soil leeching, not to mention the drudgeries involved in hauling water from the shallow tube wells, water tanks or rivers all susceptible to seasonal variations. Thus, for the purpose of this paper, none of these available options have attracted smallholder women farmers, and more importantly, helped them break the cycle of subsistence production. To this indictment, given the poor soils, drip irrigation is considered advantageous since small amounts of fertilisers can also be applied (a crucial component for the high yields along with the use of pesticides and improved seed varieties).

Chapter three: Analytical framework

3.1 Defining "food security"

The production of food is a necessary condition towards ensuring food security (Mollinga, 2000:113). In turn, it has been shown that the availability of water, especially during critical cropping stages is a critical condition for optimal production yields. 'Optimal' within this context is considered as a state where food consumption is above minimum caloric requirements throughout the entire year. The term 'food security' is thus defined as according to

Mollinga (2000) "that every individual has physical, economic and environmental access to balanced diets, including the needed micro-nutrients and safe drinking water" (Mollinga, 2000:14). This definition is considered as a starting point for the analytical framework. The state of being 'food insecure' is precisely interpreted as a transitory but chronic state of being where rural communities are deprived by the needed micro-nutrients as well as safe drinking water.

The ability of individual women farmers to cope (i.e. their coping behaviour) during the dry season needs to be closely examined. The coping behaviour of women farmers (Gittinger, 1990) is limited to actions and strategies at the local level because of the limited access to resources, including information. Women have adapted to this systematic issue in many ways (by stretching their stores of staples or buying food at higher prices) but the underlying issue (a lack of micronutrient deficiency and lack of calorific intake) is not resolved. It has been mentioned that the scarcity of food is not only related directly to a physical shortage but also due to lack of accessibility and affordability.

It is important to stress, although in some cases there is plentiful production and availability of food supplies, the food and nutrition leevls may be undermined simply because women farmers do not "command the purchasing power necessary to buy a wholesome diet for the family food basket" (Mollinga 2000, p66). Given this scenario, ownership of the means of production (like irrigation systems) can provide a solution to stabilized and diversified crop production patterns all year round ultimately improving food security levels for women farmers and their respective households. Essentially, the potential to increase the rural purchasing power and expand women farmers' entitlement to food and nutrition can occur under three broad strategies proposed by Gittinger (1990) to improve food security at the household level which are examined in the study: (i) raising the level of income; (ii) varying assets and; (iii) changing structure of income (diversification of income base).

3.2 Measuring impact: improved income and nutrition levels

In Kalale' District, it has been observed that extended periods of droughts lead to diminished levels of household food consumption and a general scarcity of foodstuffs available in the community. Within this scenario, the research paper examines women farmers and their role in horticulture production. The reasons for this association with solar powered drip technology are because of their nutritional content (Van Koppen, 1998:38). As Weinberger and Lumpkin (2007) argue, when food consumption is below minimum caloric requirements during part of the year, "the interplay of the different micronutrients and antioxidants found in vegetables and fruits has important health impacts" (Weinberger and Lumpkin, 2007:1473).

Measuring impact becomes complicated because it does not only concern with the introduction of a new technology but also a strategy that seeks to develop horticultural systems as well as provide technical assistance on agronomic expertise. This situation complicates the study's conceptual framework as it seeks to evaluate the elements that have helped group-based women farmers adopt solar drip irrigation systems. In any case, two main indicators are used for measuring food security: increase in farm incomes (from the sale of vegetables) and nutrition levels (measured in calorific value of crops produced and the percentage consumed). The tangible measurements of basic indicators such as the incidence and severity of nutritional deficiency, morbidity and mortality rates, water supply and sanitation facilities, housing conditions, and education and health facilities are not available in the study under investigation. It is however accepted that, while income levels can be an important determinant for measuring food security, it is not a sufficient measure (Smith, 2004). For this reason, the following table illustrates how women manage to diversify their income bases by producing high-value crops which they can consume during the dry season.

Table 4 – Agricultural calendar of cropping season in Northern Benin

Month	D	J	F	M	A	M	J	J	A	S	O	N
	Dry Season						Rainy Season				Dry Season	
Cereal crops												
Sorghum								P			H	
Millet								P			H	
Maize								P			H	
Yam								P			H	
Cassava								P			H	
Vegetables												
Tomato				H						P		
Eggplant				H						P		
Carrots				H						P		
Pepper				H						P		
Green leave												
Amaranth				H						P		
Okra				H						P		

Key: H = Harvest; P = Planting

Basically, to understand the dynamics of the cropping stages, the agricultural calendar of cropping seasons depicts the crucial periods where harvests are done. Planting occurs in July. Weeding and thinning usually lasts until end of August. Harvesting of crops takes place in October / November leading to the dry season which commences in December / January until March / April. The agricultural calendar of cropping seasons comprises a mix of local crops cultivated in local fields and fruits and vegetables on the SMG.

3.3 Women's contribution to agricultural production and food security

The reassurance that the net benefits from the SMG are under strict control by women farmers stems from the fact that there is a local institutionalized NGO with precise contracts with the district council that adhere to pre-established agreements. These arrangements assure that all the production yields are appropriately managed by women farmers and that enough is available also for local communities. It is important to stress however that I will not devote enough time in elaborating the social relations of power inherent in the project – The relations among people and between people and artefacts (irrigation systems) are not dealt with as this would require a paper of its own. This point can be theoretically formulated and generalised by stating that "irrigation technologies have social requirements for use" (Mollinga, 1998:16).

From "subsistence" to "marketing" farming

In Africa, Asia and Latin America, high value crops are female intensive industries, with women dominating most aspects of production and processing (Weinberger and Lumpkin, 2007:1469). Indeed, the study under investigation looks at the role of women whom are largely producing for markets (about 80 percent of produce is sold). These markets hence need to be defined. To whom they are selling? What do they produce, what do they sell and during what periods of time. The paper acknowledges that further site specific research on these issues should be reviewed.

One other crucial aspect, which is particularly under studied, is the position of women farmers in their respective households. This is an important matter to consider when looking at the multiplier benefits the Solar Market Garden can have on the community. Although women confessed that the revenue generated from the gardens is their own, the role men play in the decision making process as to how to spend the money must be considered. The data available however makes it unrealistic to discuss the implications of the internal power dynamics within a household. Also, the fact that women farmers were not willing to talk about this situation can only but contribute to a generalization on the subject and therefore is avoided.

As mentioned previously the ownership of capital equipment as well as over land is an obvious component to examine when looking at the enabling environments that dictate women farmers' general risk averseness. The motivation of women farmers to produce for market sale also needs be considered. Uphoff (2002) argues that if women cannot afford the means of production, this aggravates the extent of food unavailability, resulting in heavy debts in the long-run. Indeed, the confidence of women farmers to invest in complementary inputs (fertilisers and pesticides) is directly correlated with whether they have a secure access to water resources and in tandem, can claim the associated benefits from horticulture production. Weinberger and Lumpkin

(2005) argue that increasing horticulture production can potentially foster a "marketing farming" approach. This is due to the high profitability of horticultural crops. At the same time, however, the authors believe that without market information on vegetable prices, availability of good quality seeds and access to markets (which are usually thin in rural areas), taking up these crops can be risky. Generally, we must consider that women farmers are risk-averse on the one hand, but their comparative advantage for producing horticulture is greater as land is scarce and labor is abundant.

Chapter four: Findings

4.1 Findings

Although most of the literature available on technological innovations such as drip irrigation has so far focused mainly on its hardware aspects and associated economic advantages (Mollinga, 2000), few studies have shown that solar-powered drip irrigation systems can be a cost-competitive technology. Furthermore, the financial viability of irrigation technologies has been scarcely examined within the context of group-based women farmers. This cost-benefit strictly analyses the three pilot projects (two SMGs in Bessassi and one in Dunkassa). The first part of this section seeks to identify the tangible costs of the project. The second part considers the technical and economic costs and benefits and the third section mentions the environmental issues of the solar drip system. It is important to stress that these are "the non-economic and non-quantifiable values" (Gittinger, 1972:15) and therefore an attempt to quantify these would be unrealistic.

To recall, the garden is 0, 5 hectare in size. Thus, with about 33 women in total, each woman farms her own 120m² plot. The remaining plot is farmed collectively. Socioeconomic surveys conducted by IREEP concluded that each SMG supplied an average of 1.9 tonnes of produce per month. The specific quantities sold for each specific vegetable were not available (Mr. Bonraima Abdoulaye, personal communication, September 3, 2011). Essentially, the FSE report says that income levels increased for 70 percent of the women in target groups by US$0.69 per day. This income has been reported to be spent mostly on the purchase of staples, pulses, legumes as well as the rabbit farming activities initiated by the women.

In Dunkassa, local women farmers were much more involved in the study to facilitate the organization of the meetings and data gathering. About thirty-three women took part in the interview, but just like in the other two villages the president, treasurer and secretary of each group were mainly responding to my questions. This is an interesting fact that tells us about group organization as well as the inherent hierarchies within the group association – a president, secretary and treasurer are chosen for the decision-making of all aspects regarding the SDI system. Moreover, two members in each group are trained in all aspects of vegetable seeds production, garden bed preparation and other on-farm related activities.

In summary, women participating in the SMGs have reported in interviews that they spend up to 50 percent less time working on their current plots than they had hand-watering their previous plots. Furthermore, they report they spend time in more income-generating activities – including seed replication for sale to other farmers, or rabbit farming (as extra income has allowed women farmers to invest in a big shelter for rabbits and hence diversify their income base). Essentially, the results from interviews conclude that women engaged in horticultural production have increased their income levels by selling a large amount of their produce either at nearby market towns or at the garden site.

4.2 Cost-Benefit analysis

The findings of the study are related to data that supports indicators of improved income and nutrition levels; however the numerical figures may vary, depending on various costs such as hydrogeological analyses, on-farm activities and operation and maintenance costs. The analysis was carried out using both primary and secondary data available. It shows that at present, a solar-powered drip irrigation system is not economically viable for women farmers without subsidies (grants) to finance the initial capital costs. This rationalized judgement is based on answers retrieved by farmers that were asked to list the vegetables they used to grow, the ones they grow with the support of the drip technology and the vegetables that they can successfully replicate. In addition, they were asked to state expenses related to complementary inputs such as fertilisers, pesticides and improved seed varieties. On the bright side, the income generation opportunities and the associated benefits accrued to the local economy manifest in terms of capacity building of industries required in the construction, maintenance and operation of the system as well as the local studies performed prior to the drilling for groundwater. These benefits cannot be monetized but need to be recognized.

Due to the scarce availability of empirical data on the specific case study, the research does not go into depth with Gittinger's model for assessing the impact of agricultural projects. Farm gate prices, shadow prices and relative prices of complementary inputs are not known from an 'official' source. Prices of these components were only obtained from women farmers and thus are "analytical generalizations" rather than factual (reliable) data. Taking into account that this technology made its debut in West Africa in 2007, the costs of the three pilot projects were not defined properly. No previous experience was available to provide a benchmark for establishing a suitable financing scheme for women. In the three SMGs, the costs were not pre-decided but rather elaborated on the basis of women's actual ability to pay with the on-going of project activities (Robert Freling, personal communication, 9 August, 2010).

While the project turns on a fairly sizable initial capital investment, a convenient starting point for establishing the period of the analysis is the technical life of the major investment item (Gittinger 1976:87). The price of materials for constructing the reservoir (water tank) and fencing, the solar pump, the drip system and the solar panels are US$3,000, US$2,500, US$2000 and US$7,400, respectively. The drilling and the forage (including hydrogeological studies) cost another US$7,000 amounting to a total of US$22,000. The table below summarizes the capital costs:

Table 5 – Capital costs of SDI system

Capital items	Production costs	O&M costs	Frequency (year)	Total costs
12 Solar Panels each 175W (total 1.2kw)	US$7400	US$300	15	US$7700
Solar pump set	US$2500		10	
Drip system	US$2000	US$5000	5	US$13000
Reservoir (water tank) and fencing	US$3000		10	

CASH FLOW = GROSS RETURN *less* CAPITAL ITEMS, INPUTS AND TAXES *less* LABOUR AND MANAGEMENT COSTS

The operation and maintenance costs (O&M) are subject to variation in the three SMGs. The frequency is the estimated time after which capital items need to be replaced. Labour costs (extension services and support of technicians) amount to about US$8,000 per year including the costs of installation (salaries and wages), drilling and other hydrogeological studies. Considering that the area is isolated and segregated from big cities (but also from small towns), transportation costs to and from the village need to be evaluated.

Mechanism of cost recovery

Taking into account that this was a pilot project, after four years of experience on the field, and an increase in local expertise (a crucial factor that is not given as much importance in this paper as it should be due to time and word limitations) women have now learnt the correct crops to grow, the correct crops to replicate, as well as securing markets and access to them. A willingness to make the transition from "subsistence farming to marketing farming" has also been observed in the women farmers. All these factors were non-existent in the first year of project implementation and now contribute to their rural development.

The mechanism for possible cost recovery is simple. The amount women can contribute to the communal pot and opt for a long-term financing scheme should take into account how much women make from the sale of horticulture crops. At present, it has been agreed that, given the high production yields, the money going in the communal pot is too low and the percentage of income per farmers should be increased to 400 CFA (US$0.82) per week.

After one year of project duration, women farmers have earned about US$7-8 per week (by selling about 80 percent of produce). Moreover, their respective households have consumed, on average, 1-2kg of their own production (including tomatoes, carrots, aubergine, amaranth and okra) per week. After the first year, each SMG supplied an average of 1.9 tonnes of produce per month (Burney et al, 2009). It is important to stress, since most of the activities were performed during the dry season, other agricultural related activities and production (on their fields) were not affected. Thus, their production yields for staple crops are taken as an average and not considering the fluctuations in yields due to erratic rainfalls. Income levels increased for 70 percent of women in group by US$0.69 per day. This income has been reported to be spent mostly on the purchase of staples, pulses, legumes as well as on rabbit farming (protein during the dry season) and purchase of fertilisers (NPK) and pesticides (about 2,000 CFA per week, about US$4).

The net revenue from the SMG after the first year of operation was approximately US$2 per m^2 of garden, meaning one woman was making an average of US$250 per year from her $120m^2$ plot. Based on the FSE report, assuming that women have steady revenues from the sale of horticulture crops of about US$10,000 per year (Burney et al, 2009), the value of the investment, or the payback period is worked out to equal six to seven years (using business as usual scenarios). Previously, it was mentioned that women are financially responsible for the maintenance of pumps. The operational costs are financed by the communal pot, a small plot collectively farmed by all women participants. Women deposit 100 CFA (US$0.20) per week in the communal pot and after four years of project activities, there are approximately 280,000.00 CFA (about US$600). The revenues from this garden bed are exclusively used for costs related to the SMG.

The solar pump and drip system requires high start-up costs but both pumps and pipes have an expected durability of about five years. The assumed lifetime of solar panels instead, are calculated to last a minimum of fifteen years (et al, 2009). When comparing costs, since the majority of women farmers in villages use traditional techniques (hand watering), it would make sense to evaluate the non-monetary benefits that the SDI system can ensure. The most crucial point here is that the high up-front costs illustrated in the cash flow as they are derived for project analysis do not include the noncash elements, and therefore it may be unrealistic to assume that "accounting costs and benefits" (Gittinger, 1972:66) exemplifies the value of the project investment.

4.3 Techno-economic considerations

The drip irrigation system is at the heart of the SMG. Drip laterals, filters, taps and connectors are used that provide maximum longevity (Adrien Namur, personal communication, September 6, 2011). The drip laterals are made of thick-tube, rigid polyethylene (see figures below). The lateral pipes (left) have emitters every 30cm, with small labyrinth filters (right) at each dripper to prevent clogging and maintain pressure. All these 'sophisticated' components however are difficult to obtain because of the remote location in which Kalale' is situated. The problem of repairing parts however as still not occurred as the system has been running for now only four years.

Figure3 – Drip laterals and labyrinth filters

At the initial stages of the project, the water source for the drip system in the village of Bessassi was taken from a nearby river. Subsequently, it was realized that the open water source caused a set of technical issues that had not been taken into account at the implementation stage. Firstly, since the river is populated with crocodiles, metal could not be placed in the water due to sacred considerations for crocodiles. This meant that the material for this site had to be changed. In addition, a local ritual had to be performed before any equipment was placed in the water. Furthermore, the water quality from the river contained sand particles which would enter into the pipes consequently eroding the plastic drip lines. Moreover, this same 'dirty' water was ending up watering the crops. For these reasons, after the second year of project duration, water was not taken from open sources (neither wells which usually are not deeper than 10m and are above the water table therefore affected by seasonal variations). The system now necessitates that the water source is extracted from below the water table, the strata of soils and below the rocks thus avoiding impact on renewable water resources stored in groundwater aquifers (Hollerman et al, 2010).

Some cultural issues also affected the decision to source from a closed source. Before the SMG site was implemented, neighbouring women villagers would wash their clothes downstream, but soon after project completion (late 2007), women starting washing clothes upstream. This affected the water quality due to the chemicals that would flow downstream. The reason for this change in behaviour of nearby villagers is still unknown but it is argued it was done out of spite from the neighbouring women villages who were not benefitted with the project (Adrien Namur, personal communication, 5 September 2011).

4.4 Factoring the environment into crop performance

From a scientific/biological standpoint, determination of the productivity potential of a crop requires a thorough understanding of crop growth and development. These in turn are dependent on several climatic, hydrological, physiological and management factors (IFAD, 2005). The major factors affecting crop growth are radiation, temperature (yield determining), water, nutrition (yield limiting) and pests and diseases (yield reducing) (Wani et al 2009:74) and yet this research limits itself in assuming that of prime importance for plant growth are rainfall and soil moisture storage.

As mentioned previously, in Northern Benin annual rainfall is erratic and has been predominantly below average since the 1970's (Hollermann, 2003). At the regional level, water scarcity related issues are heightened in the Northern areas because with respect to the South of Benin where two rainy seasons exist, the growing season in the North is blessed by only one rainy season (Van Liere, 1993:59). This unimodal and arid climate shapes the soil characteristics (also due to lower rainfalls measured in precipitation levels) which are low in nitrogen, phosphorus and potassium contents, making it low in its cation-exchange capacity (CEC) – the relative ability of soils to store one particular group of nutrients (Wani et al, 2009). Thus, to help adapt to this arid climate and soil, vegetable seeds were supplied with the assistance of ICRISAT for the first two years. This is also one of the reasons that constitute the elevated costs. During the first two years of project duration ICRISAT provided seeds with high first generation yields but with very poor yields in their second generation. Therefore, this situation inevitably affected the ability of women to replicate certain seed varieties

Ecological issues regarding water availability

A hydrological analysis prior to drilling is performed by a local hydrologist and a local drilling company. Chats with SELF's engineer confirm the associated financial and technological constraints that hinder the development and exploration of groundwater (Hollermann et al, 2010). In addition, there is no certainty as to whether there will be long term effects on the water source. The recharge rate of the water is slow, but at the same time, it is believed that the amount of water taken is relatively little, and as an added measure, a marginal amount is always left as a secure rate of extraction. For example, if studies say that at a certain point, $5m^3$ of water can be taken, the head flow of the system will take $3m^3$ and leave $2m^3$ for security. This is an attempt to minimize the ecological damage (at least in the short run) that the system might have since only the amount of water needed for the crop is to be lifted thereby not altering the renewable groundwater resources of the area (Cuadros et al, 2004:466).

It is also important to stress, that since the deeper water source is of good quality, this same water source can also be a source of potable drinking water for the entire village. This certainly does affect how much water is taken but it is considered accordingly with the required amounts needed. This is the case in both Bessassi and Dunkassa village. The only difference is that in Bessassi the same forage manages to irrigate $24m^3$ of water to two 0,5 hectare fields as well as approximately 10,000 gallons of clean, drinking water. The key point here is to demonstrate that the ecological relations to production are indeed considered.

Soil degradation and micronutrient deficiency

ICRISAT adopts Integrated genetic and natural resources management as its overarching research strategy (Wani et al, 2009). The aim is to combine tested methods of crop commodity research (for example double crossing hybrid seeds or gene mapping) as the basis to improve food availability in drought-prone areas. The provision of improved seed varieties is an important component to consider in the project because of the need to accompany them with high use-levels of fertilisers and pesticides, as well as other potential long term ecological effects.

Lakshman (1993) argues that these higher yielding hybrid seeds should be evaluated because of the need to accompany them with chemical fertilisers. Ultimately, "improved seeds can provide high yields and create scarcity at the same time". To cite the Vitamin A "iron deficiency" example in Punjab (also in this case, ICRISAT was pioneering the improved varieties). Lakshman (1993) clearly states how fruit of lessons learnt from the technical package deployed for farmers under the Green Revolution should firstly, and more importantly, give weight to the "soil-crop-water" regime and see what possible long-term ecological effects can improved crop varieties have on soil qualities (Shiva, 1998) – other than the high use of fertilisers (NPK) and pesticides (Venkatesh, 1994). The research cannot go into depth regarding this dilemma as it would require a paper of its own.

Chapter five: Conclusion

There is a stable ground to assume that drip technology optimises the use of water and increases yields, but some of these benefits are not quantifiable. Although, the water-saving capacity augments among those water-intensive crops like vegetables (Narayanamoorthy 2004, p128), the net gains in water saving capacity are estimations in most cases and in others simply incomparable because previously those vegetables were not grown in the current local environment. Moreover, it is difficult to calculate the net returns from solar-powered drip irrigation since solar panels (and other capital costs) are not financed by women farmers. The fact that the most expensive component of the system is funded through donor schemes raises difficulties on two levels, the socioeconomic and the political. At the socioeconomic level, understanding how much the women value this system is impossible due to the nature of the project. Therefore is it difficult to ascertain whether women farmers are accepting and adopting the system because it is (to an extent) free. In any case, the reflections on the extent to which women farmers are willing to pay for the system is not possible to perceive (given my position as a representative of a specialized UN agency) and the time constraint. It becomes complicated also at the political level as it raises issue on how to assess the nature of the funds made available for this project and therefore who is associated and liable for the long-term costs of the system. More specifically, who will burden the costs of new solar panels, hopefully about fifteen years down the road?

I would like to stress that the study is essentially a project and therefore must have a project life. However, in development there is neither beginning nor end to improve the standard of living of poor rural communities. Thus, the goal of the project should not be concerned with identifying tangible benefits, but more widely, to understand whether the drip system can actually contribute to better income and nutrition levels.

Based on rationalized judgments and analytical generalizations, this paper would lose much credibility if it would not cite the issues occurring at present in South Asia, namely in India and Bangladesh. *The Lancet*, a British medical journal, reported last year that about 77 million Bangladeshis had been poisoned by arsenic – the largest mass poisoning in history. This was the result of villagers pumping up groundwater from ever deeper aquifers. The same poison is now entering crops and more of the food chain. In this sense, the scale and magnitude of the technology must be evaluated against the future ecological impact it can have. This statement gives light to the general controversies inherent in developmental projects that have short term (important) gains however at the expense of detrimental natural resource bases in the long run. On the bright side, it is evident that the project places environmental sustainability (especially for one of the main assets of smallholder farmers – soil) as a core priority in their agenda. The gradual switch from inorganic fertilisers to organic pesticides and fertilisers derived from the trees of neem is a practical example to the commitment in managing natural resource bases.

5.1 The Forgotten workers

It is important to note, increasing agricultural productivity and income for the majority of these farmers, most of who cultivate on less than two hectares of land, is a relatively untapped opportunity for finding practical solutions to improving agricultural yields and hence rural poverty (IDE, 2002).

Although the expensive hardware components are not indebted onto women farmers, at the same time, the project does not underestimate the possibility that somehow, women farmers are empowered with higher incomes and new market opportunities which ultimately benefit the entire community. To an extent, parts of the semi-structured interviews have led to this conclusion. The incomes generated from the sale of horticultural crops have put in motion a series of entrepreneurial activities such as vegetable seeds production, rabbit farming as well as other recreational activities.

At present, SELF has received funding from USADF for the deployment of eight new SMG sites in eight new villages in the Kalale' district. Local staff from ADESKA will collaborate in the construction and maintenance of the solar drip system. Two solar technicians have already been trained and two more will be trained. Two women farmers from each women's group have been trained on aspects of vegetable seeds production / nurseries activities etc. The key point here is acknowledging the long-term strategic plan of SELF – to teach ADESKA everything from supplier side commercial aspects to maintenance and technical knowledge on system. SELF has been building the capacity of ADESKA in order to construct and maintain solar powered drip irrigation systems. The long-term strategic plan is to deploy all responsibilities to ADESKA, from knowing the technical design of photovoltaic systems (include procurement of project equipment) to the training of solar technicians and installation management. ICRISAT is also actively involved in contributing agronomic expertise, reservoir and drip system design, and training on aspects of vegetable seeds production for women producers as well as for local NGO.

Thus, as one may infer, the technology is not directly provided to women farmers, but are deployed in such a manner that the local NGO is directly involved and acts as a service provider. The local economy therefore benefits as a whole as the need for local solar technicians / engineers, hydrogeologists, and construction workers for the required labour work increase. To consider is the construction of the water reservoir, fencing and other related capital equipment requiring civil works.

5.2 The Way Forward

Financed by the World Bank in order to achieve adequate food security levels in this drought-prone zone, the PILSA program although today has been abandoned, gave rise to the possibility for a stronger organization at grass-root level for women farmers which in turn, have given them the possibility to connect in a network of information and resources. Indeed, one may argue that the greatest obstacle is a lack of symmetric information in rural communities. In conclusion, the study reveals that given the social, technical and organizational arrangements, women have extensively contributed to vegetable farming on small garden plots. The following elements have contributed to a better understanding of the link between access to water resources and improved income and food security levels:

- Household survey and field level data throughout the first year of harvest
- Household income and nutritional intake (measured in diversification of income bases and amount of crops produced, calculated in tons)
- Horticultural systems (leap from subsistence to marketing farming)
- Hydrogeological studies for water quality (factoring environmental concerns in project decision making)

The emphasis of this paper is on the social and economic impacts of the technology on women farmers engaged in horticulture production. How much women value the system is interpreted in terms of their opportunity cost in managing the land. That includes preparing the bed, weeding, ploughing and other agriculture-related activities. They are not paid for this work, but in exchange they feel, since they are doing the agricultural work, that as a group they own the SMG (Mr. Bio Wade Seydou, personal communication, September 6, 2011). The patterns of ownership for land are thus reflected not through a financial disbursement, but recognized by institutional structures such as the local NGO and the district council because of the work done for raising the value of that land (SMG) by women.

This gives way to discovering an alternative financing scheme comprising of monetary and non-monetary costs. Within this time framework women farmers will have learnt the production system (from nurseries activities to market penetration and sale). The six-year period entails that women will have enough annual savings to pay for all the complementary inputs such as fertilisers, pesticides and improved seed varieties as well as for the maintenance of the system. For example, in the village of Bessassi, the rooftop of the water reservoir needs to be replaced as well as the ladder and the fencing (which have been damaged by local livestock). The payback period however does not include the repayment of the capital costs highlighted in table 5.

This paper has tried to evaluate the potential of drip irrigation for women farmers within a specific agro-ecological environment. The case study has realized that the diversity in the physical conditions of land, current agricultural practices and the embedded social relations (Howes, 1982) are all inherent factors that need to be factored when appraising technological innovations. Substantially, there are favourable parameters to tapping groundwater but since it is an expensive procedure, the project is undoubtedly out of the reach of poor farmers with low capital investments. Thus, it is believed that without the aid of grants and/or subsidies, the expected potential (in terms of improved income and nutrition levels) of solar powered drip irrigation system are limited and constrained by the inherent social relations in which they are borne.

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Annex I – Questions asked to women farmers during interviews

Information on project (why it exists?)

1. What problems are you confronted with during the dry season?
2. How did you use to water crops?

1. Did SELF/ADESKA approach you or did you find out about this technology from elsewhere?
2. In what ways does the local NGO help you?
3. Who has helped you form groups (i.e. how do you exist today as an association)?
4. How many women farmers are part of the group?
5. Do you fully know about the total costs of the system (including transportation, operational, maintenance and labour costs)
6. Who is responsible for preparing garden beds (ploughing, tilling the land etc.)
7. Are there any duties and responsibilities among the group?

Information on Solar Market Garden (SMG)

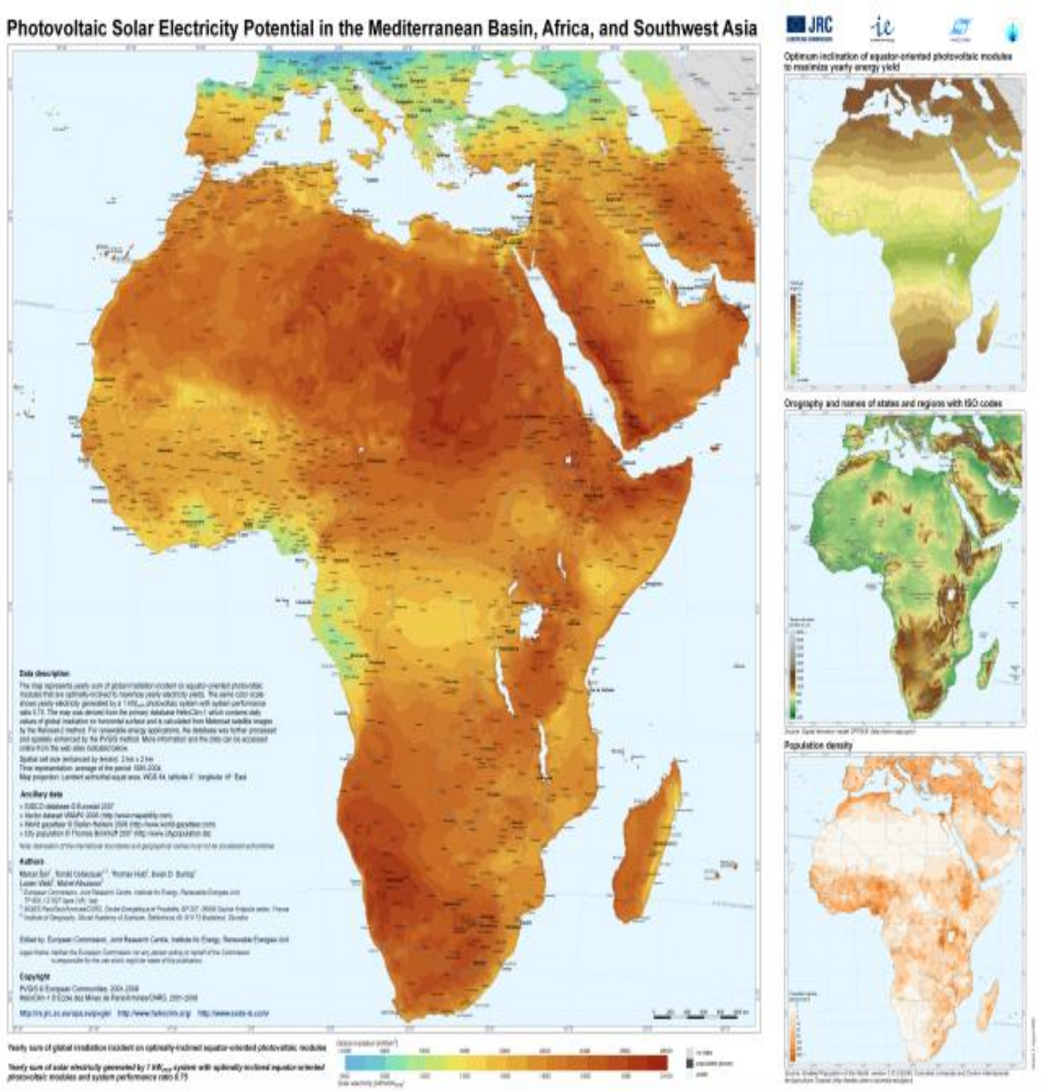
8. Which crops are locally grown? Which new crop varieties have been introduced in the local environment?
9. What crops are you successfully producing on gardens?
10. What type of fertilisers do you use?
11. Do you apply to all crops, have some crops been infested with pesticides? Snails,
12. Who taught you how to replicate seeds and align the drip lines and pipes etc. How do you prepare garden beds?
13. In what other aspects have SELF, ADESKA and ICRISAT trained you relating to garden activities?
14. How many women are trained in vegetable production (nurseries activities)?
15. Which vegetables seeds do not replicate?
16. What role (upkeep procedures) do you have to undertake?
17. How do you get your produce to markets (or do people come and buy the produce here at the SMG site)?

Economic well-being (factors affecting cash outflows and inflows)

18. How much is the increase in yields with the adoption of the SDI system?
19. How much produce is kept for home consumption and how much is sold at market?
20. Where do you sell your produce? Do you go to nearby market towns?
21. Why do you buy seeds every year? Doesn't that bother you?

22. What other benefits have you gained from this water-labour saving technology?
23. How did you come up with the idea to engage in rabbit farming?
24. How much money is in the communal pot at present (that is, nearly four years down the road)?
25. How are revenues from the sale of horticultural crops spent?
26. How much of your income do you spend on fertilisers, pesticides and improved seeds?
27. Have any of the women ever quit the group and therefore abandoned the SMG project without having contributed to the communal pot?
28. Does it occur that certain women fail to pay on a weekly basis in the communal pot? What happens?
29. Are there any sanctions present for women who don't pay in the communal pot?
30. How much money is in the communal pot today?
31. In fifteen years (hope even later) the solar panels will need to be replaced. Who do you think will need to pay for these? Are you willing to take up such substantial investment?

Annex II – Map of photovoltaic solar energy potential



Annex III – Planning of field visits to Kalale' District

Planning of Field Visit	
Date	Activities
Thursday (01/09/2011)	• Route between Cotonou and Parakou • General discussions with the solar engineer from SELF, Mr. Adrian Namur
Friday 02/09/2011	• Route between Parakou and Kalale' • Meeting with Mr. Namur and Mr. Bio Seydou Wade Doukago, Executive Director of local NGO, ADESKA • Visit SMGs in Bessassi
Saturday 03/09/2011	• Visit Women's group of Kalale' Centre • Meeting with Mr. Bonraima Abdoulaye, member of the administrative council of IREEP • Visit Women's group of Kidaroukperou
Sunday 04/09/2011	• Visit SMG in Dunkassa • Group based interview with Women's group of Dunkassa • Visit Women's group of Peonga • Briefing session with Mr. Namur
Monday 05/09/2011	• Visit SMGs in Bessassi • Meeting with Mr. Zackary, solar engineer and technician of ADESKA • Group based interview with Women's group of Bessassi
Tuesday 06/09/2011	• Debriefing session with ADESKA and SELF representatives • Route between Kalale' and Cotonou

Annex IV – List of women farmers in Bessassi during group interviews

BAH SAHA Bona
BAH KOTO Gaya
BONI Nagado
CHABI Wonkoutê
KIPASSI Gnogoua
WINCHABI Zénabou
OROU SANNI Natian
SANNI OLY Bona Ganni
SANNI OLY Gnongbea
SOUMAILA Alima
SOUMAILA Amina
IMOROU Adissa
ASSOUMA Adissa
BONI Gnongbea
ORU BAH Fati
WASSO Woura
SARE Koto
BAH WOURE Satou
BALAKI Gnon
ISSIFOU Bona
Kona Amina
MAMA Adissa
CHABI Sakina
SANNI OLY Sala

Annex V – List of interviewees and research informants

Met with:

- Mr. Bio Seydou Wade Doukago (executive director of ADESKA)
- Mr. Bonraima Abdoulaye (member of IREEP, administrative council)
- Mr. Adrien Namur (Solar engineer / technician for SELF)
- Mr. Zackary (Solar engineer / technician for ADESKA)
- Accountant for ADESKA

Phone calls with:

- Robert Freling (executive director SELF)
- Dov Pasternak (leading agronomist for SMG concept on behalf of ICRISAT)
- Jennifer Burney (PhStanford University - FSE)

Annex VI – General information on Solar Market Garden project

General Information					
Village name	Bessassi	Dunkassa	Kidaroukperou	Kalale' Centre	Peonga
Current situation	Two SMGs working since 2007	SMG working since 2007	Forage has been drilled for water supply. SMG will be completed by 2012	Premature stage. Women's group has been identified SMG will commence in 2012 (along with other five villages)	Same situation as in Kalale' Centre
Number of women farmers in SMG	31 and 35	38	27	Not available	
Number of women present in interview session	Total of 28 women representin g both SMGs	17	15	7	
Technical and Economic Information on SMG					
Water source	Initially surface water, now ground-water	Groundwater	Groundwater	In all new villages it has been decided that water source will be groundwater	
Communal pot	200,000.00 CFA	280,000.00 CFA	N/a	N/a	N/a
Vegetables under cultivation with SMG	Tomatoes, carrots, aubergine, amaranth and okra	Tomatoes, carrots, aubergine, amaranth and okra	N/a	N/a	N/a
Vegetable seeds for replication	Amaranth, okra, eggplant, papaya	Amaranth, okra, eggplant, papaya tomatoes	N/a	N/a	N/a

Annex VII – Photos of the Solar Market Garden

Annex VIII – Profile of Solar Electric Light Fund (SELF)

The Solar Electric Light Fund (SELF) is a non-profit organization founded in 1990. SELF is dedicated to advancing the use of solar energy in the developing world. Their projects have demonstrated that small, decentralized photovoltaic systems can significantly break the cycle of subsistence production and gender inequality while fostering an agri-business approach for rural smallholder farmers.

SELF has been active at the village level for twenty years in twenty countries. They have developed an effective and sustainable project model that brings immediate, tangible results to the most disadvantaged people. Their goal is to empower people in developing communities by providing sustainable and targeted electrical energy sources to reduce poverty by improving health, education, water supply, communication and security for individual families and communities.

In 2003, SELF brought solar power to three villages in Jigawa State of Northern Nigeria. Each village was equipped with solar arrays for a water pump, school; clinic, mosque and a micro-enterprise centre housing six small businesses. In the Himalayan Kingdom of Bhutan, SELF worked in partnership with the Royal Society for the Protection of Nature (RSPN). The project had two objectives – to improve the quality of life among villagers in the region and to help the endangered ecosystem imperilled by deforestation, caused in part by people seeking fuel wood for cooking and lighting. In Brazil, SELF worked with the Native Cabocio Indians to implement solar power for water pumping, refrigeration of vaccines and snake bite serum, and for connecting to the Internet via satellite for telemedicine, distance learning in class-rooms, and development of eco-tourism and e-commerce opportunities. SELF has also deployed solar home systems (SHS) to 41 homes in the coastal village of Panama, South-eastern Sri Lanka. In 1997, SELF spun-off a for-profit affiliate, the Solar Electric Light Company (SELCO), based in Bangalore, India, whose goal would be to sell solar home systems in the states of Karnataka and Andhra Pradesh. SELCO has achieved modest success, selling about 130,000 SHSs in India.

It is essential to note that SELF's projects address vital needs including household lighting, water pumping and purification, vaccine refrigeration, micro enterprise, and modern communications. SELF typically functions as project manager or implementer by playing a leading role in the following tasks: bringing partners/participants together; listening to the community and local stakeholders through meetings, surveys and interviews; formalizes project design and proposal writing; technical design of photovoltaic systems; procurement of project equipment; training of local solar technicians; installation management; capacity building of local partners; evaluations and reporting.

Partnerships

SELF has built a strong web of partnerships. Their partners include:

L'Association pour le Developpement Economique, Social, Culturel de Kalelé (ADESKA) is the local development association based in Kalelé, and the on-the-ground project administrator, overseeing the recruitment of and contract administration for project employees, and serving as the liaison among all international project partners.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) monitors and supports the emergence of agricultural markets through activities such as providing market information and marketing extension although it is actively involved in project implementation, contributing agronomic expertise, reservoir and drip system design, training and capacity building for the women farmers, and data collection and analysis ideas.

The Center on Food Security and the Environment at Stanford University (FSE) is a research centre that seeks to simultaneously generate solutions to global hunger and environmental degradation. A research team from FSE oversees the monitoring and impact evaluation and contributes to project and research design.

L'institute pour le Recherche Empirique d'Economie Politique (IREEP), a Cotonou-based research firm, maintains a network of well-trained enumerators and a staff capable of organizing and executing surveys and interviews around the country. IREEP has helped finalize the baseline socioeconomic surveys, translated them into local languages, and administered the questionnaires.