# ADOPTION OF SOLAR WATER PUMPS IN TANZANIA

## THE FARMERS' PERSPECTIVES

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# ABSTRACT

*English*

In Tanzania, solar water pumps experience sparse uptake by smallholder horticulture farmers. Thus, there is a need to surface information about the conditions on-site and provide an improved understanding of early-state challenges as well as of the farmers' situations and expectations. Moreover, expected benefits require validation. In order to assess the potential impact of solar water pumps, a logical model is developed according to the theory of change leading to a results staircase, which links the desired impact with required interventions. Field surveys based on participatory rural appraisal, during which 12 farmers are repeatedly visited during 13 weeks, deliver in-depth information on farmer level. Thus, farmer profiles are created encompassing among others farming details and water supply information. It is found that what farmers value most in a water supply system is reliability, followed by low operational costs and simple handling – all characteristics of solar water pumps and drawbacks of fuel pumps. However, most farmers require financial service, which indicates the initial investment barrier. Logistic troubles due to Tanzania's vast area result in unsatisfactory quality of service and increased costs constituting additional challenges. Moreover, assessing the farmers' needs and providing a properly designed system proves to be particularly difficult. Insufficient quality of water sources and deficient briefing of customers complete the early-state barriers encountered. The severity of the barriers is highlighted by the limited progress experienced by the farmers on the results staircase. Nevertheless, the logical model is partly verified, indicating solar water pumps' aptitude to enable rural prosperity.

Keywords: Solar water pumps, solar irrigation, smallholder farmers, horticulture, theory of change, participatory rural appraisal

*Português*

Na Tanzânia, as bombas de água solares (BAS) são pouco utilizadas pelos pequenos horticultores. Para incrementar a sua utilização é necessário recolher informações sobre as condições no local, compreender os desafios, bem como as condições e expectativas dos agricultores. Para avaliar o impacto potencial das bombas de água solares, um modelo lógico é desenvolvido de acordo com a teoria da mudança, levando a uma escada de resultados, que vincula o impacto desejado às intervenções necessárias. Trabalho de campo baseadas em avaliações rurais participativas, durante as quais 12 agricultores são visitados repetidamente em 13 semanas, forneceram informações detalhadas sobre os mesmos. Foram criados perfis de agricultores, abrangendo, entre outros, detalhes agrícolas e informações sobre o abastecimento de água. Constata-se que os agricultores valorizam mais a fiabilidade do sistema de abastecimento de água, seguido por baixos custos operacionais e operação simples - características das BAS e que constituem inconvenientes das bombas de combustível. No entanto, a maioria dos agricultores requer apoio financeiro, o que constitui uma barreira inicial ao investimento. Adicionalmente, problemas de logística devido à vasta área da Tanzânia, resultam em qualidade de serviço insatisfatória e aumento de custos operacionais. Avaliar as necessidades dos agricultores e fornecer um sistema projetado adequadamente mostraram ser tarefas particularmente difíceis. A qualidade insuficiente das fontes de água e uma angariação deficiente dos clientes completam as barreiras iniciais encontradas. A severidade das barreiras levou a uma limitada melhoria de resultados. No entanto, o modelo é parcialmente verificado, indicando a aptidão das BAS visando a prosperidade rural.

Palavras-chave: Bombas de água solares, irrigação solar, pequenos agricultores, horticultura, teoria da mudança, avaliação rural participativa

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# LIST OF ABBREVIATIONS

| Abbreviation | Denotation |
|---|---|
| AC | Alternating current |
| BOS | Balance of system |
| CAPEX | Capital expenditure |
| CSP | Concentrated solar power |
| DAAD | Deutscher Akademischer Austauschdienst (German Academic Exchange Service) |
| DC | Direct current |
| EUR | Euro |
| GDP | Gross domestic product |
| GPS | Global positioning system |
| IOOI | Input, output, outcome, impact |
| LEIA | Low Energy Inclusive Appliances program |
| OPEX | Operational expenditure |
| PRA | Participatory rural appraisal |
| PV | Photovoltaic |
| RRA | Rapid rural appraisal |
| SHS | Solar home system |
| SMART | Specific, measurable, accepted, realistic, time-framed |
| SWP | Solar water pump |
| toe | Tons of oil equivalent |
| TAHA | Tanzanian Horticulture Association |
| TZS | Tanzanian Shilling |
| USD | United States Dollar |

# CHAPTER 1 – INTRODUCTION

Solar energy is by far the largest energy resource on this planet estimated up to approximately 50,000 EJ/year [1]. With the ongoing development of solar technologies, the exploitation of solar energy has experienced a continuous increase and is expected to continue rising [2]. Especially Africa has abundant solar energy resources, but electricity is only marginally generated from solar energy [3]. Tanzania itself receives an average daily global horizontal irradiation of between 1,700-2,400 kWh/m², surpassing the irradiation experienced in South Europe [4].

At the same time, 40% of the world's population is occupied in the agriculture sector – most living under indigent circumstances [5]. In Tanzania, 80% of the labour force is employed in agriculture [6]. Nevertheless, the country's potential in the agriculture sector is still not being exploited and is mainly set up by subsistence and smallholder farmers [6]. Despite the potential to improve harvest yields and increase farmers' resilience, a vast majority of the food crops are not irrigated and suffer from the climate's unpredictability [6], [7]. Utilizing the country's solar resources to decentrally provide reliable and sustainable energy for irrigation purposes is considered promising with expected benefits in farm yields and thus progressing rural prosperity contributing to the Sustainable Development Goals [5]. However, the spread of solar water pumps for irrigation is extremely small with studies being unable to detect solar water pump users in Tanzania, which highlights the need of action to enhance the market [8], [9], [10]. This was reinforced in a roundtable for solar water pump market development in Nairobi, Kenya, held by the Efficiency for Access coalition in 2018 [8].

## 1.1 Rationale

In order to progress the spread of solar water pumps in Tanzania, CLASP and Simusolar Ltd. conducted research activities for the LEIA programme from the Efficiency for Access Coalition. The research yielded the report Tanzania Market Snapshot: Horticulture Value Chains and Potential for Solar Water Pump Technology [8] delivering market intelligence on Tanzania's horticulture sector. During the research, information was collected from stakeholder interviews, focus group discussions and farmer survey questionnaires amounting to more than 500 participants in the Northern Highlands and the Central and Morogoro regions of Tanzania. The data facilitated the characterization of 407 horticulture farmers on the basis of farm size, crops cultivated, irrigation and water supply systems, financial parameters, and challenges faced. Thus, an improved understanding of potential customers as well as an estimate of the market potential was rendered possible. Moreover, market strategies including market segmentation possibilities and required actions are presented in order to progress the adoption of solar water pumps in Tanzania. [8]

Aiming to surface additional information about consumers, market challenges, and impacts of solar water pumps, additional field surveys in the three regions covered by the Tanzania Market Snapshot were scheduled. Besides gaining new insights, the field surveys were meant to verify and validate the findings presented in the Tanzania Market Snapshot. Therefore, the field surveys are supposed to encompass similar types of farmers. These are smallholder horticulture farmers in the regions named above with a farm size ranging from ¼ ha to 17 ha (the average being 3.4 ha) mainly operating within the horticulture sector and to different degrees market oriented with only 2% being subsistence farmers and half of the farmers pursuing off-farm income generating activities [8].

This work constitutes the report of the field surveys conducted from early March until End of June 2019 as follow-up of the Tanzania Market Snapshot. The research was performed as master dissertation and financed by the Efficiency for Access Coalition through CLASP – an overview of the expenditures is provided in Annex A. Additionally, the DAAD PROMOS programme provided financing for living expenses and travel costs to Tanzania.

## 1.2 Objective

CLASP and Simusolar developed the research questions, which were addressed in the Tanzania Market Snapshot, and which are also meant to be considered for the field survey. Taking into account the resources available for the field trials (including time and budget), the research questions were distinguished between those, which can be addressed in-depth, those which can at most be validated, and those which are unfeasible and are thus left unregarded. Table 1 shows the original research questions and the grade of attention payed to each of them in this work.

Summarizing, the goals for this part of the research are to validate prior findings on financial information (customers' willingness to pay, additional income and savings) as well as looking into the details of the farmers' needs, the characteristics farmers value in water supply systems as well as the challenges faced on using the solar water pumps and the benefits expected to be provided. Besides the research questions and the budget set for the field trials, only the available time of six months restricted the design of the field trials.

*Table 1: Consideration of the research questions for the field trials.*

| Research Questions | In-Depth | Validation | Not Considered |
|---|---|---|---|
| A. What factors do potential customers consider when purchasing an irrigation solution, particularly SWPs? Do these factors correlate with the top 6 factors uncovered in the study (namely cost and affordability, availability of the equipment and inputs, water source availability, simplicity of use, awareness about other irrigation technologies and area and reliability/efficiency of the irrigation solution.)? | X | | |
| B. How do consumers value capital expenditure vs. operational and other factors when choosing between diesel/petrol pumps and SWPs? Does this output concur with the study finding and any reasons for differences observed? | X | | |
| C. How many hours a day/days a year do customers use SWPs? How much would they use them if not constrained by cost and capacity? | X | | |

| Research Questions<br>Continuation | In-Depth | Validation | Not Considered |
|---|---|---|---|
| D. How much are potential customers willing to pay for SWPs in different use cases / farmer typologies? How much are they willing and able to pay for a deposit and monthly payments? | | X | |
| E. How much additional income or cost savings can be generated by a smallholder farmer who transitions to a SWP in different use cases/typologies? | | X | |
| F. What are other socioeconomic/development benefits from SWPs beyond higher incomes and reduced labour for irrigation? (e.g. education, health, safety, women's empowerment, business, access to credit/banking, reduced food waste) | X | | |
| G. What are the costs incurred by a company to acquire a new customer? | | | X |

## 1.3 Structure of the Report

Having set the objectives and presented the motivation underlying this work, background information on Tanzania is provided and the off-grid market discussed next. Afterwards, the technological, economic, and environmental aspects of solar water pump systems are presented focusing on the system's technical peculiarities. A description of the methodology applied in this work – the theory of change and participatory rural appraisal – completes the presentation of the expertise underlying this research. Thus, chapter three starts with its application developing a logical model of the cause-effect relationships conditioning Tanzanian smallholder horticulture farmers and of the concomitant potential impact of adopting solar water pumps. Based on this and using participatory rural appraisal methodology as the main pillar, the design of the field trials aiming to answer the research questions is developed. The realization of the field surveys together with the implemented changes of the initial designs are described next. Subsequently, the limitations of this research' scope determined by the available resources and sources of information as well as by the viability of activities are highlighted. After explaining the treatment of the collected information, the results are presented and discussed in-depth encompassing the farmers' characteristics, the farmers' expectations and their prioritization of a water supply system's properties, the challenges to adopt solar water pumps observed, and the solar water pump's impact achieved within the period of the field research. Finally, the future completion of the impact evaluation as well as promising further research areas are discussed before concluding with the main findings and insights that can help progressing solar water pump's spread in Tanzania.

# CHAPTER 2 – STATE OF THE ART

Providing contextual background information, this chapter presents the country in question, the research’ target market, technological and economic aspects on solar water pumps as well as sustainability issues, and finally the methodology applied during this work. Thus, the reader is able to put this work’s findings into perspective.

## 2.1 Tanzania Country Brief

Tanzania, approximately 1.5 times the size of the Iberian Peninsula [11], is located in East Africa bordering with Kenya and Uganda to the north, Rwanda, Burundi, and the Democratic Republic of the Congo to the west, and Zambia, Malawi, and Mozambique to the south, while facing the Indian Ocean to the east (cf. Figure 1). Being framed by Lake Victoria, Lake Tanganyika, and Lake Malawi, the country lies within the African Great Lakes region. Tanzania is home of a great biodiversity of both flora and fauna encompassing mountain regions such as Mount Kilimanjaro, numerous national parks among others the Serengeti National Park and the Ngorongoro Conservation Area, and coastal regions including the Zanzibar archipelago [12]. The country’s climate ranges from semi-arid and semi-desert over temperate and alpine to coastal and subtropical climate experiencing two diverse rainfall patterns [12]. While the northern region and northern coast face a bimodal rainfall (short rains from October to December and long rains from March to May), the southern, central and western regions experience one single rain season from December to April [13] – reaching an overall average yearly rainfall of approximately 1,000 mm [14].

*Figure 1: Map of Tanzania and surroundings [15].*

Since the formation of the United Republic of Tanzania in 1964 by the union of Tanganyika (sovereign state since 1961) and the People's Republic of Zanzibar (established in 1964 three months before the merging) [16], the country has been politically stable and a top recipient of international aid [12]. It reaches a Human Development Index of 0.538 (low human development) ranked 154th in the world [17] and is home of around 45 million people as of 2012 with Dar es Salaam as biggest city and economic driving power with 4.3 million inhabitants [12], [18], [19]. By 2018, Tanzania's GDP per capita has raised up to 1,050.68 USD (world: 11,296.78 USD) keeping an annual per capita growth of 2.115% of its GDP (world: 1.905%) [20]. Tanzania's economy is primarily based on agriculture, forestry, and fishing with a total share of 29.2% of the country's GDP by 2016, followed by construction with a 14% share [21]. The horticulture sector – horticulture crops including fruits, nuts, vegetables, seeds, roots, and ornamental plants but excluding e.g. maize, grains, and oilseeds [22] – experiences an annual growth rate of between 9% and 12% with an assessed value of at least 1 billion USD [8]. Maize however is by far the most frequently grown crop in Tanzania [6].

At the same time, Tanzania's energy sector is predominantly based on biomass, which accounts with 20.7 million toe to 88% of the total primary energy supplied in 2011, and depends on 1.6 million toe of fuel imports [23]. Most of the energy demand originates from the residential sector and is covered by household cooking (accounting for 80% of the sector's biomass used) [23]. As of 2014, Tanzania's per capita yearly electricity consumption of 104.79 kWh did not reach half of the low-income countries' average [23]. In total, 65% of Tanzania's electricity generation capacity is covered by thermal power plants (33% natural-gas-fuelled, 32% oil-fuelled), while hydropower contributes to 35% of the country's capacity [23]. In 2013, 91.96% of the installed capacity was allocated to the main grid, the rest encompassing mini-grids, SHS, and imports [23]. The state utility TANESCO owns Tanzania's main grid, while isolated mini grids and SHS help improving the electricity access in rural areas [23]. Overall, 32.813% of Tanzania's population had access to electricity by 2018 [24]. In rural areas, 64.8% of rural households were found to use solar power as energy source in 2016, while 34.5% obtained their electricity from the grid [25].

75% of Tanzania's population lives in rural areas surpassing Sub-Saharan Africa's average of 64% [12]. Generally, people have a life expectancy of 52 years (as of 2006) and are rather young with 44% being under 15 years old [12]. In 2007, primary school net enrolment reached 84%, and the completion rate increased to 85%. However, after completing seven-year primary school, only 25% enrolled into secondary school [12]. While primary school is taught in Kiswahili since 1968, the official language in secondary school is English – hence, the level of English spoken by the less educated part of the population is mostly rudimentary [26]. Kiswahili is Tanzania's national language, while English is a second official language intended for higher education, some industry sectors, and the higher courts. Additionally, almost each of Tanzania's more than 150 ethnic groups speaks its own language contributing to the country's cultural diversity [27].

## 2.2 Off-Grid Markets

The world's energy sector is dominated by centralized power generation from large power plants, electricity being distributed via extensive power networks to the consumers [28]. However, distributed energy generation is experiencing an increased attention [28]. In distributed or decentralized energy systems, small-scale power plants are usually situated close the location of energy consumption and often have no interaction through the main grid with other energy generating units [28], which is referred to as off-grid. Off-grid systems are mostly located in rural areas with no access to the country's main electricity network [28]. Globally, up to 1.5 billion people are estimated to lack access to electricity, most of them living in rural Sub-Saharan Africa and South Asia [29], [30], [31], [32]. In Sub-Saharan Africa, the number is expected to rise due to a population growth above the connection rates [32]. As of 2013, around 80% of the population in developing countries had no grid-connection and are attributed minimal prospects to obtain it [29], [33], [34]. Historically, rural areas have been predominantly electrified by grid extension and diesel stand-alone systems [32], [33]. However, grid-connectivity is in most rural areas economically unrealistic due to the characteristics of rural consumers such as low energy demand, low income levels, and wide scattering over large areas [29], [33], [34], [35]. Moreover, the installed capacity in developing countries is usually not sufficient to cover their entire population, and lack of resources and competing national objectives impede extensive rural electrification [31]. Nevertheless, access to energy is understood to benefit communities in social and economic aspects (i.e. empowering communities, creating job opportunities, promoting education, benefitting health, utilizing local resources, saving time, and reducing expenses), and decreasing costs for renewable energy systems are enabling new opportunities for rural electrification [28], [31], [32], [35]. Off-grid solutions are estimated to have provided 65% of the newly electrified population with access to energy in Sub-Saharan Africa [36]. Also, past experience with for instance mobile phones has shown that decentralized systems can successfully be adopted if appropriate conditions are in place [32].

Besides fuel-powered generators, renewable energy systems powered by solar, wind, hydro, or biomass are increasingly applied solutions [32], [33], [35]. When choosing an energy conversion technology, local conditions such as resource availability, available knowhow, and overall socio-economic conditions should be taken into account in order to provide the most appropriate, profitable solution [33], [35]. Stand-alone systems – particularly solar-powered – are the most frequently applied technology in recent electrification activities [29]. Solar PV systems (encompassing as standard a PV array, a charge controller, and often batteries for energy storage as well as an inverter for AC-loads) are often the most economical solutions for electrifying rural areas ahead of diesel generators thanks to the exceptional solar conditions in most areas [29], [30]. However, local circumstances such as governmental subsidies on diesel change the picture in many African countries [33]. So called solar home systems (SHS) are deployed commonly to provide basic energy access for lighting and possibly mobile phone charging and media appliances such as radio and television [32], [35]. Thus, SHS systems replace fuel-lighting, improving the air-quality in homes and decreasing health risks [37]. In many regions, solar irradiance is not sufficient to provide reliable energy access, which is why hybrid systems (mostly solar-diesel, but pure renewable hybrid systems with two or more energy sources are also possible) are an often preferred option providing a cost-effective but also ecologically optimised solution [29], [34]. For larger energy demands, isolated mini-grids (2-150 kWp) are attractive options [35]. Mini-grids consist of numerous consumers and usually several energy sources (jointly referred to as virtual power plant) connected by a basic network and operated conjunctly [28], [38]. Depending on the size, mini-grids can operate in low to medium voltages [38]. While mini-grids utilize energy resources more efficiently, reaching viability is challenging due to the associated high investment costs [35].

High initial investments are a common barrier especially for renewable energy systems, despite the high operation costs faced by consumers when using fuel-powered systems of up to 25% of their household budget [31], [32]. In order to decrease costs, policies such as taxes, tariffs, and subsidies can be adjusted restructuring financial resources or with help from the international society and from carbon finance [32]. Many countries have subsidies in place, but critics object that they often don't reach or even harm the poor [32], [35]. Further, more promising options include the expansion of financial services and the use of innovative business models [32], [33], [35], [37]. The need of financial services is outlined in many research studies with around 2.7 billion of the global population lacking access to appropriate financial services [32], [33], [35], [37]. Financial and business models include e.g. leasing of products, supplier credit-based sales, consumer credits from commercial banks, consumer credits from microfinance institutions, governmental-funded credits, lending group credits, and community based models for mini-grids, where committees act as electricity supplier and revenue management [32], [35], [37]. Alternative approaches aim to increase the consumer's ability to pay by promoting the productive use of electricity [32], [35]. The success of any intervention increasing the consumer's ability to pay or decreasing the costs of the system are expected to yield a great impact expanding the regions where solar stand-alone systems are the most viable solution [33].

Besides financial barriers, rural electrification also faces challenges in inconsistent governmental strategies (e.g. uncertainty regarding potential grid-connection), missing technology standards and inadequate system designs, logistics, available expertise and local capacity building, theft, and bureaucracy [28], [31], [32], [33], [35]. Therefrom derived approaches to promote electricity access encompass consistent policies and national targets, standardization, capacity building and consumer education, community involvement, bundling energy loads, and reaching out to early adopters [31], [32], [35]. A guideline for program developers and policy makers developed by Urmee [31] advises in detail on the individual steps to consider.

## 2.3 Solar Water Pumps

Solar water pumps, which can facilitate productive use of electricity, date back to the 1970s [39]. Since then, solar water pumping has developed significantly in terms of performance, economic parameters, and reliability of the systems, improving single components as well as optimizing the overall system composition. In the following, the technical options for solar water pumps are discussed before the development of financial parameters as well as business models are presented. Lastly, solar water pump characteristics in terms of sustainability are discussed.

### 2.3.1 The Technology

There are different ways of harvesting solar energy in order to utilize its power, the most common being harvesting of thermal energy and using the photovoltaic effect, which directly converts solar power to electricity [40]. In the first case, the collected thermal energy can either be used directly e.g. for heating or hot water applications, or be utilized indirectly among others by converting it to electricity as is done with CSP technology (concentrated solar power) [41]. For water pumping applications, both PV and solar thermal technologies can be applied as displayed in Figure 2. Thermionic energy conversion is an emerging field of research and thermoelectric technologies reach very low efficiencies, which is why PV remains the only viable, commercial indirect conversion technology in the near future [42], [43]. Regarding the direct conversion technologies, the conventional designs – the Rankine cycle being the most frequently used, but Stirling engines the most promising option for small-scale systems – reach only low power outputs and low efficiencies limiting the application possibilities [44], [45], [46], [47]. Unconventional designs yield even lower outputs and efficiencies [44], [45], [48]. Overall, more research is required to realize the latent potential of solar thermal water pumps [49]. Thus, today's market is dominated by PV water pumping systems [50], which are the ones solely regarded in this work.

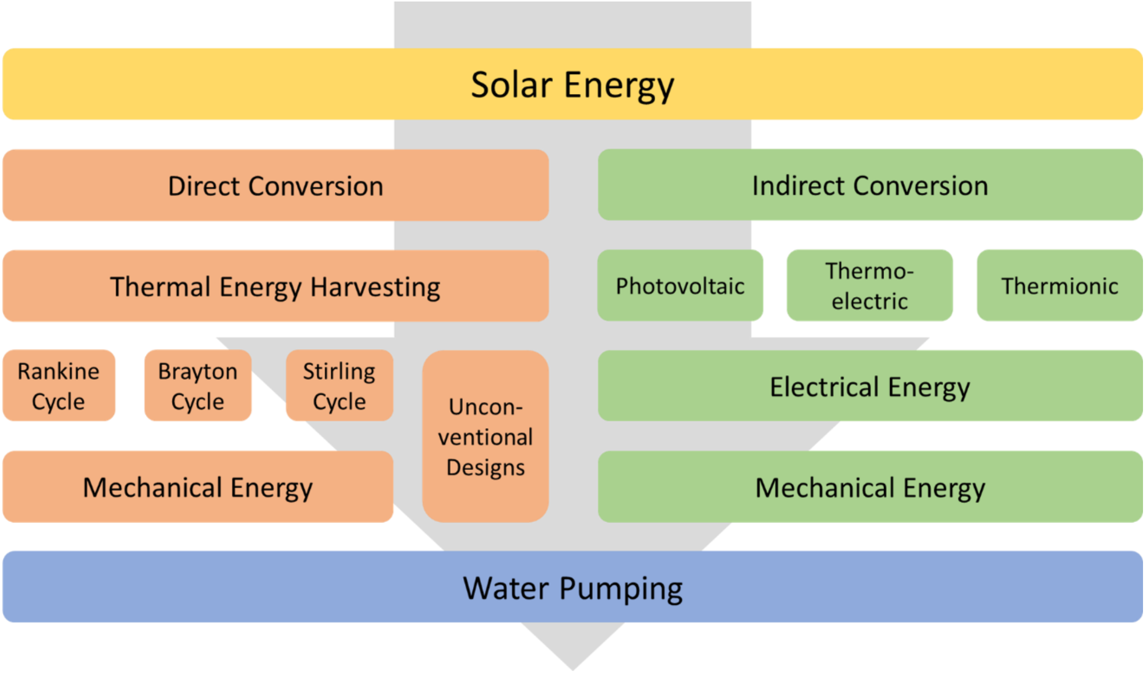


*Figure 2: Possibilities for solar water pumping (based on [45]).*

A water pump system powered by a solar PV system usually encompasses the standard components PV array, controller, electric motor (if an AC motor is used, an inverter is additionally required), pump, water storage tank, and BOS (e.g. wiring and piping) as shown in Figure 3. For solar water pump systems, there is often no limitation in available space, and costs can therefore be decreased by using polycrystalline PV modules. In order to maximize the energy obtained by the PV array, maximum power point tracking controllers are the state of the art. Usually, electric motor and pump are combined into one product, but can also be acquired separately. Generally, batteries are not needed in water pumping systems since storing pumped water in elevated tanks is a more economical storage solution.

Electric motors can be DC-, AC-, or multiple-phase AC-powered, however only the first two are used for solar pumping. AC-motors have a limited capability to operate at low speeds and require an additional inverter, which is why they are decreasingly used favouring high efficient DC-motors [46], [51]. Despite their higher costs, brushless DC-motors are replacing DC-motors with brushes, reducing the need of maintenance and thus increasing the system's reliability [46]. Additionally, permanent magnet and switched reluctance motors can be

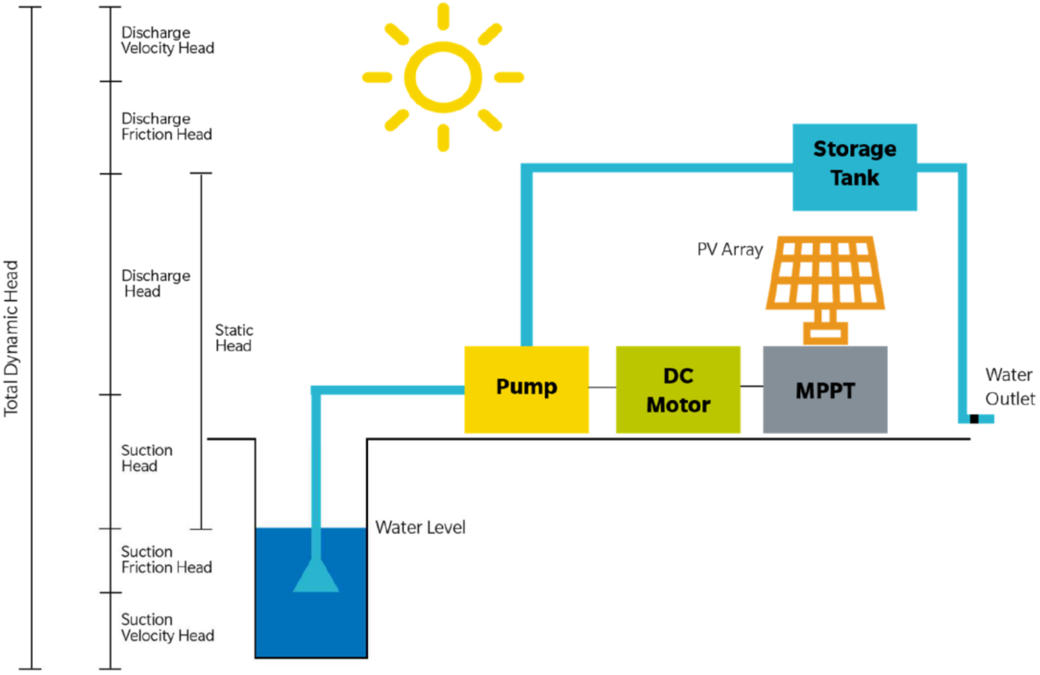


*Figure 3: Set-up of a solar water pump system [52].*

used for solar water pumping applications but require more complex control systems [46], [51]. Regarding the pump, there are mainly two different types that can be used in a solar water pump system – dynamic or centrifugal pumps and displacement pumps [46], [52]. In dynamic pumps, the centrifugal force generated by the pump's impeller is the driving force soaking in the water and expelling it with increased pressure and velocity [52]. They are able to deliver large volume flows and to operate also at low irradiation levels but with decreased efficiency [46], [52]. Furthermore, the volume flow is dependent on the total dynamic head of the system [46]. Displacement pumps on the other hand (e.g. screw and piston pumps) are characterized by a constant volume flow independent from the system's hydraulic head and by a high efficiency also far away from the normal operating conditions, but they overall deliver a low pumping volume [46], [52]. Nowadays, centrifugal pumps are the ones most commonly used for solar water pumping applications [46], [53]. As already mentioned, electric motor and pump are usually combined into one single system component and are realized as submersible, surface, or floating water motor-pump units – only surface units can have separate electric motor and pump [52]. For assessing the required pump characteristics, the water source and the conditions on-site have to be taken into account in order to determine which type of pump is needed (surface, floating, or submersible pump) as well as the power required to overcome the total dynamic head (static head and friction/velocity head, cf. Figure 3) and to deliver the required water flow. Taking into account the high variety of water usage (e.g. crop irrigation, livestock watering, and domestic use) and the changing conditions on-site with varying water sources, distances, and elevations as well as irrigation technologies (manual, flooding, sprinkler, trickle, and their respective versions [54]), designing a solar water pump system is a highly customer-dependent activity [55]. Moreover, the sizing of the solar array depends on the average solar irradiation on-site and the requirements of the pump chosen. Also dependent on the local climate, the size of the required storage has to be assessed in accordance with the expected irradiation and the average number of days per month not reaching a pump-dependent critical irradiance.

### 2.3.2 Economic and Environmental Aspects

Hand in hand with the technological progress, costs for PV modules have decreased in the past decades (cf. Figure 4) and are still decreasing, making solar water pumps an increasingly attractive solution [56], since the PV modules constitute one of the main matters of expenses – reaching above 50% of the system's total costs – alongside with the pump and the installation costs [39], [57]. Solar water pump systems are mainly competing with fuel powered pump systems, which are therefore used as reference to assess solar water pumps' financial and environmental aspects. Comparisons with grid-connected electric pump systems are not regarded here, considering that solar water pumps are intended as solution for grid-isolated regions, or in case that the grid's reliability is insufficient, and thus grid-connected electric pump systems are not an appropriate solution.

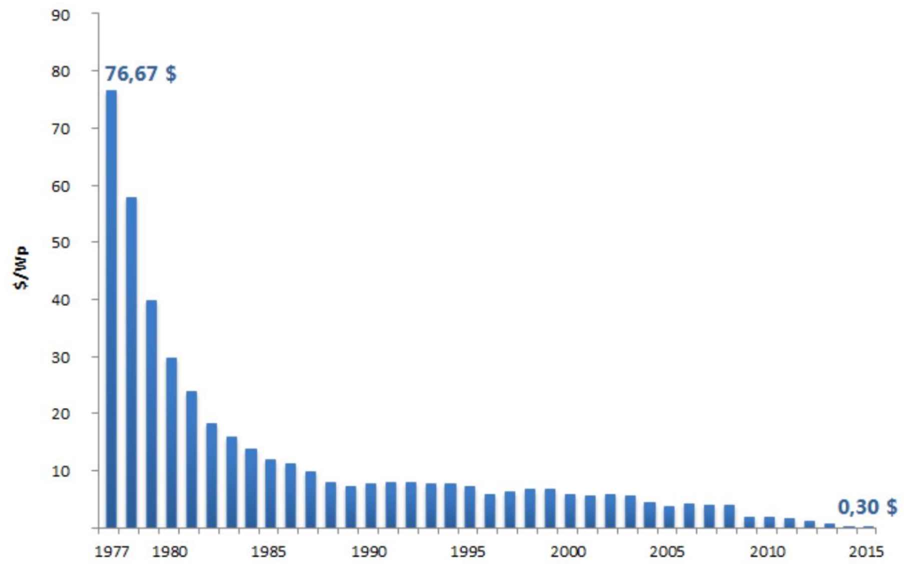


*Figure 4: Price development of crystalline silicon PV cells in USD/Wp (1977-2015) [58].*

Numerous studies have assessed solar water pumps' economic feasibility individually as well as compared to fuel-powered pump systems (diesel or petrol) under different conditions [36], [39], [47], [50], [52], [57], [59], [60], [61]. Compared with fuel-powered pumps, solar water pump systems are assessed as economically favourable [36], [39], [57], [61], and are generically found to be profitable with payback periods of less than six years [36], [47], [50], [52], [59], [60]. Profitability of a system can be assessed by evaluating the income generated by the farm [50], [59], [60] or by determining the electricity [47] or water volume unit costs [61]. While the first option is highly dependent on external factors, the latter ones don't consider the overall outcome and disregard important factors that might diminish the system's profitability. External factors found to impact the profitability of solar water pump systems are the area and type of soil irrigated (with a minimum area of farmland required), the types of crops cultivated, the irrigation system used, the therefrom resulting total dynamic head (largely influenced by the chosen water source), the water demand pattern originating from the crops cultivated and the irrigation system used as well as from climatic conditions, and factors out of the reach of influence as irradiation levels and interest rates for required credits [39], [50], [60], [61]. Moreover, a proper design of the system itself – especially proper storage sizing and the consideration of suitable oversizing – can increase a system's economic

viability [61]. Furthermore, the combination of drip irrigation and solar water pump systems has proven to significantly increase yields [50], [61].
However, the high initial investment of solar water pumps caused mainly by the PV sub-system constitutes a high obstacle for smallholder farmers and the importance of access to credit for the rural population is repeatedly highlighted [36], [39], [57], [59], [61]. FAO estimates capital costs of approximately 1,400 USD for a small-scale system in Kenya (300 W, submersible pump) including installation costs in mid-2017 [39], overall lying within the range of 400-3,000 USD for systems of 50-1,000 W found by the Efficiency for Access Coalition [62]. Besides improved access to credit, alternative business and financing models can contribute to overcome the initial investment barrier [39]. Promising alternatives to credits are for instance Pay-As-You-Go financing (widely used for SHS in Africa [63]) and contractor models, where the water supplied is sold as a service and the system itself remains in the ownership of the contractor [39].

In times of global warming, environmental aspects are gaining consideration and sustainable solutions are sought to mitigate climate change. Thus, the utilization of renewable energies such as solar are generically viewed positively and understood to reduce carbon emissions. Solar water pumps are often deployed in place of fuel-powered or grid-connected pumps preventing $CO_2$ emissions [50], [52], [64], [65]. In India, the unit costs for carbon emission prevention for systems of around 2 kWp is estimated to approximately 170 USD per ton of $CO_2$ when replacing diesel pumps and to around 400 USD/ton of $CO_2$ in the case of grid-connected electric pumps [64]. The overall potential of carbon emission mitigation appraised to 4-6% of India's total emissions [65]. China is currently emitting 33 tons $CO_2$ equivalents in 2005 due to water pumping for agriculture [66], indicating that the potential of solar water pumps for preventing $CO_2$ emissions should not be left unregarded.
However, "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" as defined by the Brundtland commission [67]. This implies that the impact of solar water pumps needs to be assessed beyond the capability to mitigate climate change and additional aspects such as the sustainable exploitation of resources need to be considered. Most critical is the exploitation of groundwater, which is expected to increase along with the spread of solar water pumps. In contrast to the case with fuel-powered pumps, the extractable amount of water is not limited by concomitant fuel costs in the case of solar water pumps [39]. Moreover, farmers using solar water pumps potentially expand their irrigated farmland and cultivate higher-value crops, which have often higher water demands, or they even provide water to neighbouring communities for domestic use and livestock watering [39], [68]. Deploying water-efficient irrigation technologies like drip irrigation can mitigate this problem, but it is not guaranteed [36], [39], [50]. Groundwater levels are already critical in countries like India and Morocco, which had subsidies for solar pumps in place [39], [68], [69], and unsustainable exploitation of groundwater accounts to almost 20% of the world's gross irrigation demand [39]. Tanzania holds around 10,000 $km^3$ total groundwater, which is average among Africa's countries, and is facing moderate to high groundwater drought risks in the Northern Highlands and the lake region as well as in the central-north and south regions, while the coastal, south-east, west and central-west are subjected to low risks [70], [71]. Taking the projected future climate development into account however, nearly the whole country is expected to face moderate to very high groundwater drought

risks [71]. Unfortunately, many feasibility studies for solar water pumps don't consider the use of water resources properly, potentially due to the lacking availability of detailed data and the difficulty of evaluating groundwater resources [68]. It is important to acknowledge that solar water pumps are both energy- and water-related applications, which on the one hand can favour a customer's access to energy, and on the other hand intensify water scarcity [36], [68].

Further possible negative impacts of solar water pumps include soil salinization due to improper irrigation management decreasing soil productivity and enhancing soil degradation [50]. Also, the cultivation of higher-value crops due to the increased water availability for farming leads to a higher use of nutrients and agrochemicals (e.g. fertilizers and pesticides) possibly constituting human health risk due to decreased water quality and affecting the ecosystem and its diversity, which can also deteriorate as a consequence of decreased water availability in the surroundings [50]. Additionally, irrigation is generally not recommended for high terrain slopes (above 8-15%, depending on the irrigation technology) due to the risk of soil erosion [50].

## 2.4 Methodology

Concluding this chapter, the methodologies applied in this work are presented – namely the theory of change and participatory rural appraisal. The theory of change is used to structurally evaluate the impact level reached, while participatory rural appraisal is applied during the field research for the collection of information on-site in an inclusive and equating manner.

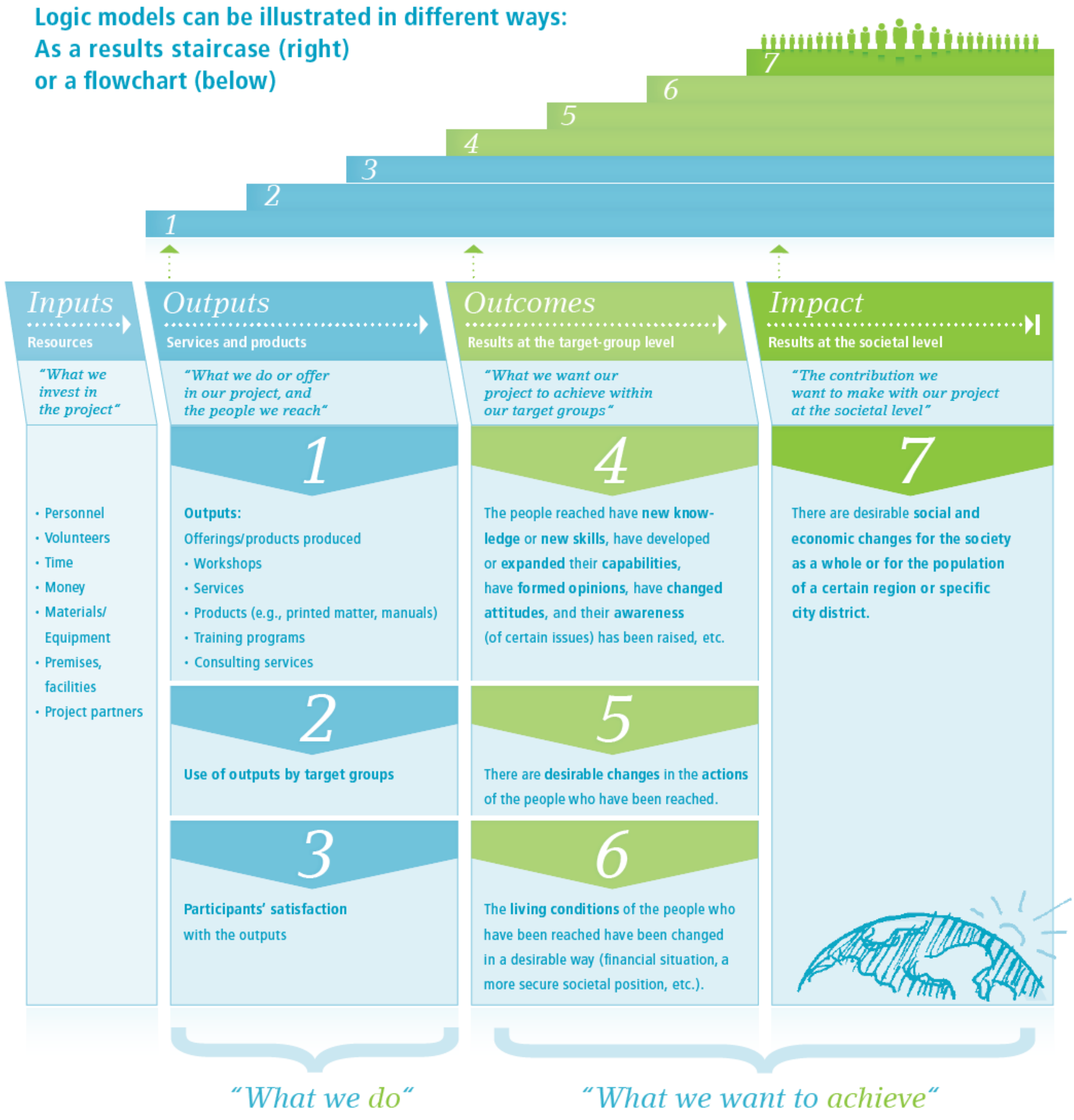
### 2.4.1 Theory of Change

"Theory of change is […] a comprehensive description and illustration of how and why a desired change is expected to happen in a particular context" [72]. Ensuing from this definition, theory of change (also named program theory, among others) can constitute a powerful tool for planning, monitoring, and impact evaluation [73], [74]. It dates back to the 1950's when D. Kirkpatrick developed the four levels of training evaluation – namely Reaction, Learning, Behaviour, and Results [75], [76]. For planning, the four levels are supposed to be used backwards from level four to level one in order to be able to develop a training, which yields the expected results [75], [76]. This idea was adopted by numerous researchers in the following years resulting in an increased focus on the logical chain, which connects an activity with its objective [75]. Eventually, the logical model was generalized encompassing the four levels Activities, Outputs, Purpose (i.e. desired outcomes that motivate the outputs pursued), and Objective (i.e. generic impact targeted, to which external occurrences may also contribute) [75]. In order to monitor and evaluate the progress and success of an intervention, multiple indicators are assigned to each level (the number of indicators required in each level varying from case to case) thereby completing the logical model [75].

The method used in this work is outlined by PHINEO in the Social Impact Navigator [77] and follows an adjusted logical model with the levels Inputs, Outputs, Outcomes, and Impacts aiming for impact evaluation of projects. While other theory of change approaches single out the activities to perform (e.g. the Swiss foundation Zewo [78]), PHINEO includes the services and products rendered within the outputs (cf. Figure 5), making an isolated consideration of the activities obsolete. As can be observed in Figure 5, PHINEO sub-classifies the main levels Outputs and Outcomes into three sublevels each. In terms of impact assessment, a more graduated logical chain is of great advantage since it allows a more detailed assessment of the level of impact reached. This additional graduation then generates a results staircase, which in the Social Impact Navigator disregards the inputs. However, the inputs required by a project are important in order to put the achieved results (Outputs, Outcomes, and Impact) into perspective and should therefore be monitored. In this work, the inputs are referred to as step zero. Following the inputs, PHINEO's approach defines step one as providing the services and products intended. The use of the services and products is observed separately in step two. The vital third step encompasses the acceptance of the services rendered and thus the participants' satisfaction. From there, the level of outcome is reached once the participants have successfully expanded their knowhow and their awareness as well as developed their opinions on relevant issues (step four). If the participants are able to translate the new knowhow and awareness into action, changing their behaviour and their range of activities pursued, step five is accomplished. As last step in the outcome-level, step six encompasses a change in the living conditions of the immediate target group. Finally, step seven – and therewith the impact-level – constitutes social and economic changes on community level exceeding the scope of the initial target group. Moreover, PHINEO suggests the use of SMART indicators (specific, measurable, accepted, realistic, and time-framed) for monitoring and evaluation. [77]

The Social Impact Navigator also provides a guideline to develop the results staircase. Firstly, it is advised to create a so-called problem tree linking observed effects with the root causes and other relevant challenges as well as with the underlying core problems. Thus, a holistic picture of the situation and concomitant challenges can be drawn, which – by inverting the challenges into opportunities and the root causes into potential – becomes a solution tree. The solution tree constitutes the positive scenario of the problem tree and then again serves to derive realistic project objectives. Due to the diverse levels of both a problem and solution tree, objectives for the different levels of the results staircase can be obtained. It is advised to create the results staircase backwards so as to obtain an impact-focused logical model. In order to reach a comprehensive results staircase, the whole process has to be iterated and reviewed by stakeholders and outsiders thus assuring a qualitatively satisfactory final logical model. [77]

The final logical model can then be used together with the SMART indicators to monitor and evaluate the progress reached after an arbitrary time period. The indicators have to be able to display both expected and unexpected, positive and negative results. Formulating questions that should be answered by the impact evaluation in each step of the logical model can help assuring the indicators' completeness. Moreover, baselines and target values are required in order to be able to assess if an objective is achieved. [77]



The people reached have **new knowledge** or **new skills**, have developed or **expanded** their **capabilities**, have **formed opinions**, have **changed attitudes**, and their **awareness** (of certain issues) has been raised, etc.

There are **desirable changes** in the **actions** of the people who have been reached.

The **living conditions** of the people who have been reached have been changed in a desirable way (financial situation, a more secure societal position, etc.).

There are desirable **social and economic changes for the society as a whole or for the population of a certain region or specific city district.**

Figure 5: PHINEO's logical model [77].

## 2.4.2 Participatory Rural Appraisal

The aim of this research of obtaining on-site information on farmers' level can best be reached when an actual engagement with the farmers is sought, and thus comprehensive information surfaced, which potentially encompasses also prior unconsidered areas. Participatory rural appraisal was found to fit best to these requirements ensuring an equitable interaction with the participants.

PRA originates from five different sources (activist participatory research, agroecosystem analysis, applied anthropology, field research on farming systems, and rapid rural appraisal), which influenced the development of PRA in diverse intensities. In the mid to late 1980's, participatory rural appraisal eventually evolved from rapid rural appraisal under the influence of the learnings from the other approaches to field research. While rapid rural appraisal emerged due to the need of more cost-effective methods and the discontent with processes and results of questionnaire surveys, PRA was enhanced by appreciating the participants' knowledge as well as the need of empowering the marginalized, thus shifting the researchers' role towards mere facilitators and catalysts – an influence from the activist participatory research. Agroecosystem analysis enriched PRA with visualization methodologies such as mapping, diagramming, and ranking. While the importance of behaviour, rapport, and field residence (prolonged interactions and observations) was adopted from applied anthropology, the field research of farming systems added the appreciation of rural people's experimental mind-set and their ability to carry out self-analysis. Thus, PRA and RRA are mainly differenced by PRA's empowering approach, where participants conduct their own analysis, while in RRA experts (outsiders) collect data from the participants and conduct analysis themselves later on. [79]

Field research with PRA is characterised by elementary principles. First of all, learning is reversed as to learn directly and on-site from local people appreciating their knowhow and experience, empowering them to conduct the research activities themselves analysing and ranking, and changing the researchers' role to that of a facilitator. Moreover, a PRA researcher listens instead of lectures, is unimposing instead of intimidating, and seeks diversity including the marginalized and looking for variability and possible ranges in order to learn from exceptions. Therefore, PRA is conducted with a great consideration of improvisation, being flexible to adapt on-site and pursuing to optimize the cost-benefit trade-off in terms of quantity, accuracy, and relevance of the information obtained. On the same time, iterations and cross-checking are indispensable to triangulate and thus verify and validate the findings. During PRA, researchers are expected to be self-critical and take personal responsibility as to use their best judgement and continuously improve by being aware of their own behaviour and regard mistakes and failure as opportunities to learn and to improve their work. Last but not least, sharing of information between the participants themselves as well as between researchers and participants is encouraged in order to maintain an inclusive and mutual beneficing environment. [80]

The PRA methodology was applied during this research with help of Drei Wellen's Toolbox for Exploration and Evaluation [81], which was made available by the co-author S. L. Brugger. Besides providing a comprehensive introduction into PRA, the toolbox presents specific methods with a guideline of when and how to apply each method. The presented methods encompass diverse ranking, visualization and visual-narrative methods, observation practices, as well as the appropriate use of questionnaires and good-interviewing practices [81]. For this work, activities based on daily routine schemes, flowcharts, mental mapping, pair-ranking, seasonal calendars, transect walking, and timelines were developed. Moreover, the best-practices for conducting each activity as well as for good-interviewing presented in the toolbox were followed.

# CHAPTER 3 – FIELD TRIALS

As described initially, the aim of this field research is on one hand to validate prior findings on financial information regarding the customers’ willingness to pay for a solar water pump system and possible additional income and savings resulting from its use. On the other hand, the purpose is also to look into the details of the farmers’ needs, the desired water supply system characteristics, and the planned and actual usage of the solar water pumps. Last but not least, a first assessment of the benefits provided by solar water pumps is to be conducted. In order to be able to access the information required to reach the research objectives, a pre-analysis of the research questions as well as an application of the theory of change model on solar water pumps is necessary. Thus, the exact information to obtain as well as the required frequency and points in time for collecting it is clarified before the start of the field research.

Additionally, a consent form was developed so that each farmer was able to state the extent to which data and material concerning him or her can be used. A blank consent form can be found in Annex B. All farmers agreed on the usage and storage of their anonymised data for this and further research. Most farmers also permitted the usage of photo material and footage. In this study, the identity of all farmers will remain anonymous although many had no objection to the publication of their identity.

## 3.1 Application of the Theory of Change

The methodology of the theory of change was chosen to evaluate the benefits provided by solar water pumps. Since the benefits and impacts of solar water pumps can only be unveiled after a period of time greater than that available for this work, an impact model was developed following the IOOI structure based on the theory of change as proposed by PHINEO in their Social Impact Navigator [77]. Thus, a guideline is created, which can be used for a future impact evaluation, but which also allows to determine the current level of impact since both short and long term benefits are considered. PHINEO proposes a more segmented and therefore detailed version of the impact model, namely the results staircase, which is developed taking into account diverse factors in order to obtain a logical model that is as complete as possible. However, completeness of the logical model cannot be ensured, and always when applied, possible additional factors should be taken into account and the model adapted. Furthermore, the importance of the individual factors will change depending on the farmer in question leading to diverse results staircases. In order to obtain a holistic results staircase, it is best to start by determining the existing problems building up a so-called problem tree. From there, the problem tree can be transformed to a solution tree, which contains the desired outputs, outcomes and impacts. From the solution tree, the individual steps of the results staircase can be extracted and after specifying them with indicators according to the SMART approach, the results staircase is obtained. [77]

The initial version of the trees and the staircase were rounded out after the experience from the field and with the knowledge gained during the farmers’ visits. Initially, issues like mobility, limiting markets, or security were not appropriately considered in the logical model. The final problem and solution trees can be found in Annex C.

The final results staircase presented in this work is meant to serve as guidance for the impact evaluation of solar water pumps for Tanzanian smallholder horticulture farmers. It might also be of use for applications with similar conditions as long as special caution is awarded to possible additional hurdles and indicators. The indicators used in this results staircase are based on the threefold service provided by Simusolar to its customers – ① the solar water pump system containing pump, PV panels, control box, and required wires, pipes, and other BOS equipment; ② a financial service to facilitate the purchase of the solar water pump system for low-income groups; and ③ knowhow in solar water pump technology, mainly in correct operation and required maintenance. Additionally, further possible services are taken into account, which according to the developed problem and solution trees would benefit the target group and enhance the impact reached. Initially, each indicator is attributed to a specific service only, while throughout the progress in the results staircase the measured changes stop being attributable to a single service only, and the indicators are used to measure changes arising from several or all services rendered.

It has to be pointed out that Simusolar is improving its services ongoing and the distinction between the offered and not-offered services might be outdated – e.g. Simusolar has started to offer support in agriculture via an experts' hotline. As can be observed when comparing the problem and solution trees with the results staircase, not all potential issues are tackled by providing solar water pumps and concomitant services. Depending on the specific situation of the farmer in question however, it can be sufficient to overcome the biggest hurdles in order to catalyse a development towards the aimed rural prosperity.

*Table 2: Theory of change - results staircase for solar water pumps for smallholder horticulture farmers in Tanzania.*

| | | |
|---|---|---|
| **INPUT** | Inputs ① - ③: Are offered by Simusolar;<br>Inputs ④ - ⑦: Complete the service provided. | ① SWP system ② financial service for SWP system purchase: on request payment by instalments ③ knowhow in SWP operation and maintenance<br>Potentially: ④ appropriate irrigation system ⑤ contact information of suppliers of quality agricultural inputs ⑥ knowhow in agriculture and land and water management ⑦ knowhow in complementary income generating activities |

| **OUTPUT** | **STEP 1** | **FARMER HAS A NEW WATER SUPPLY (AND IRRIGATION) SYSTEM** |
|---|---|---|
| | **S**pecific | ① New SWP system is installed ② if demanded, financial service is provided with purchase of SWP ③ farmer has been trained in SWP operation and maintenance<br>Potentially: ④ if required, an appropriate irrigation system is installed ⑤ farmer has contact information of input suppliers ⑥ agricultural training has taken place ⑦ training in farmer-specific, selected complementary activities has taken place |
| | **M**easureable | ① Installed system ② number and amount of instalment payments ③ time spent and material used by salesman to transfer SWP knowhow<br>Potentially: ④ installed irrigation system ⑤ contact information given to farmer ⑥+⑦ hours of training in each topic |

| | |
|---|---|
| **A**ccepted | Proposed indicators have to be accepted by all participants and rated as realistic to achieve |
| **R**ealistic | |
| **T**ime-framed | One week before and after installation of SWP system (financial service lasts for 6-24 months) |
| **STEP 2** | **FARMER USES THE INSTALLED SYSTEM IN A PROPER WAY** |
| **S**pecific | ① Efficient use of the SWP ② farmer makes use of financial service ③famer has a proper understanding of SWP<br>Potentially: ④ plants get sufficient water, water use is optimised ⑤ farmer has reliable suppliers for agricultural inputs ⑥+⑦ farmer has participated in trainings |
| **M**easureable | ①+③ Potential of SWP is exploited as needed (amount of water supplied) ② payments are being done ③ farmer maintains the SWP properly and has realistic expectations<br>Potentially: ④ amount of water used for irrigation compared to former amount and plants' needs ⑤ new suppliers used by farmer ⑥+⑦ participants of trainings |
| **A**ccepted | Proposed indicators have to be accepted by all participants and rated as realistic to achieve |
| **R**ealistic | |
| **T**ime-framed | Within first month after installation |

| **STEP 3** | **FARMER IS SATISFIED WITH THE NEW WATER SUPPLY (AND IRRIGATION) TECHNOLOGY** |
|---|---|
| **S**pecific | ① Sufficient water is supplied ② farmer agrees with amount of instalment payments ③ farmer knows how to maximize his benefits from the SWP<br>Potentially: ④ farmer is satisfied with irrigation method ⑤ farmer is satisfied with suppliers ⑥+⑦ farmer is satisfied with content and extent of trainings |
| **M**easureable | ① Amount of water supplied compared to old values; irrigation needs are covered ② payments are being done ③ farmer has identified potential to optimize the usage of the SWP<br>Potentially: ④ expectations are met (have to be assessed beforehand) ⑤ farmer keeps using new suppliers ⑥+⑦ farmer improves performance of complementary activities (may go together with STEP 4) |
| **A**ccepted | Proposed indicators have to be accepted by all participants and rated as realistic to achieve; as prerequisite, the farmers need to have realistic expectations – is it not the case, awareness and knowhow regarding SWP is indicated to be lacking |
| **R**ealistic | |
| **T**ime-framed | Within the first two-three months after installation |

**OUTCOME**

| **STEP 4** | **FARMER CULTIVATES (/IRRIGATES/USES RESOURCES) MORE EFFICIENTLY AND RELIABLY** |
|---|---|
| **S**pecific | ①-③ Farmer has adapted his farming activities in accordance with the available (amount, reach) water supplied by the SWP and/or enhanced the system (e.g. with appropriate water storage tank) yielding better harvest<br>Potentially: ④-⑥ farming activities are conducted with less resources and/or yield higher results → agricultural efficiency is increased by among others efficient use of water, quality agricultural inputs; farmer is more aware of water usage and possibilities to increase productivity and resilience ⑦ farmer expands his complementary income generating activities |
| **M**easureable | ①-③ Farming needs are met; comparing farm harvest before/after<br>Potentially: ④-⑥ amount of inputs used, water and time spent for irrigation, yield of each plant, measures taken to increase efficiency ⑦ compare income generated by additional activities and number of additional activities done |
| **A**ccepted | Proposed indicators have to be accepted by all participants and rated as realistic to achieve |
| **R**ealistic | |
| **T**ime-framed | After first (few) harvesting period(s) → 2-6 months after installation |

| **STEP 5** | **FARMER EXPANDS HIS/HER ACTIVITIES AND GENERATES HIGHER INCOME** |
|---|---|
| **S**pecific | ①-⑦ New crops are cultivated; effective and sustainable use of resources; additional income generating activities and new education activities are pursued; ability to withstand minor climate and market fluctuations |
| **M**easureable | ①-⑦ Compare type of crops and area cultivated; income generated from other sources; amount of income sources; time spent for education and further training, and people pursuing education activities |
| **A**ccepted | Proposed indicators have to be accepted by all participants and rated as realistic to achieve |
| **R**ealistic | |
| **T**ime-framed | After first few harvesting periods → 3-12 months after installation |

| **STEP 6** | **FARMER'S SOCIOECONOMIC SITUATION IMPROVES** |
|---|---|
| **S**pecific | ①-⑦ Increased resilience due to variety of activities and education: increased income (and sources of income); increased security (e.g. higher savings, increased access to credit); increased education level |
| **M**easureable | Farmer’s income and number of sources of income; level of savings, applicability for granting of credit, variety of cultivated crops, and agriculture-unrelated income generating activities; education level achieved by farm members |

|  |  |  |
|---|---|---|
|  | **A**ccepted | Proposed indicators have to be accepted by all participants and rated as realistic to achieve |
|  | **R**ealistic |  |
|  | **T**ime-framed | 1-2 years after SWP installation |

| **IMPACT** | **STEP 7** | **RURAL PROSPERITY AT COMMUNITY LEVEL** |
|---|---|---|
|  | **S**pecific | ①-⑦ Positive effects of farmer's development on community level (farmer's progress as catalyst) → increased microeconomic activities in the community, increased education activities/level, proper healthcare situation, efficient and sustainable use of resources |
|  | **M**easureable | ①-⑦ New installations of SWP, increased business activities and economic performance (exports out of the community) in the community, increased education level, reliable access to health services, amount of resources used, … |
|  | **A**ccepted | Proposed indicators have to be accepted by all participants and rated as realistic to achieve |
|  | **R**ealistic |  |
|  | **T**ime-framed | > 5 years after installation |

## 3.2 Design of the Field Trials

Taking also into account the results staircase developed based on the theory of change, the information to be collected is specified by breaking down the research question as displayed in Annex D. In order to obtain the identified information, two time-displaced visits of each farmer are required. Apart from visiting each farmer in the beginning and in the end, a visit in-between is scheduled in order to gain a deeper understanding of the adoption process of solar water pumps and use the time on the field as effectively as possible.

Thus, the field visits are separated into three separate rounds: an initial, a mid-line, and an end-line round. The purpose of having separate rounds to revisit farmers is threefold: to be able to gain insights into the different stages of the adoption of solar water pumps; to develop a better understanding of the farmers’ situations; and to provide a baseline analysis for a follow-up impact evaluation in future research. Moreover, visiting the same farmers up to three times throughout a period of three months allows to create rapport, and besides gaining deeper insights into the farmers’ day-to-day struggles, it enables to get first impressions on how solar water pumps can benefit smallholder farmers.

Thanks to the cooperation with the Tanzanian start-up Simusolar Ltd., it was possible to get access to Simusolar’s customer base and select 10-15 farmers based on the following criteria:

i. The installation of the solar water pump system happened not more than three weeks prior to the initial visit;

ii. The customer is using or planning to use the solar water pump for horticulture farming;

iii. The area used for horticulture is estimated to be less than 4 ha prior to the first visit;

iv. The customer is located within the following areas: Morogoro region, Central region, and the Northern Highlands.

By selecting farmers according to these criteria, the relevance of this research in reference to the Tanzania Market Snapshot is assured. Taking into account the limited availability of the farmers, 12 farmers were identified to match with above criteria. In order to ensure that the goal of surveying 10-15 farmers can be achieved, two additional farmers located in Pwani region next to Dar es Salaam, but fulfilling the first three criteria, were added as redundancy in case other farmers drop out. Due to the inaccessibility of two famers in the course of the field research (one in the Northern Highlands and one in Pwani), 12 out of the 14 potential farmers were visited – including one in Pwani. Thus, the aim to reach 10-15 participants was reached. The approximate location of the 12 farmers visited is illustrated in Figure 6. In addition to the headquarters in Mwanza (in the meantime relocated to Dar es Salaam), Simusolar has offices among others in Dar es Salaam, Morogoro, Singida, and Moshi, from which they serve the customers in the respective regions and supported this research with the regional staff.

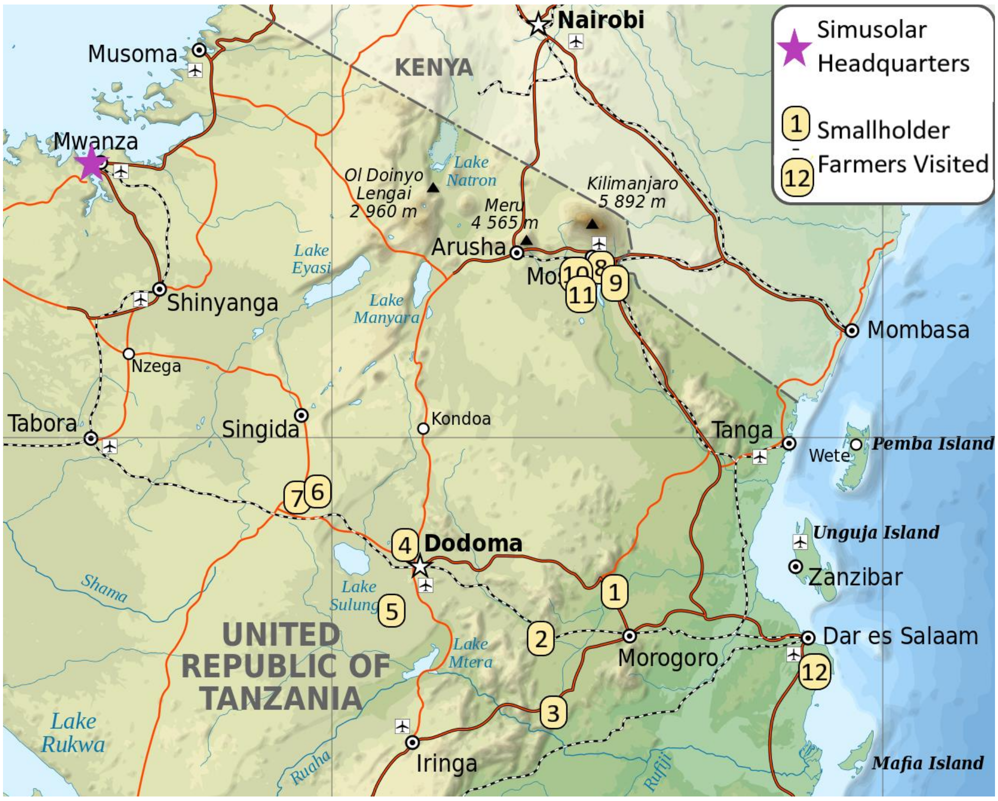


*Figure 6: Location of the 12 smallholder farmers visited during the field trials (customized [15]).*

For each round of the field visits, a scope of activities was developed in order to gain the information required to fulfil the purpose of each round, and thus reach the overall objectives. The hereafter presented plans for each round of field visits were developed immediately before starting each round. Thus, the field trials are planned with as much prior knowledge regarding local conditions as possible, minimising the need to adapt on-site – although not eliminating it completely.

To be able to conduct the field research as planned, the mobility and the communication to the farmers had to be ensured. The latter was addressed by employing a full-time local interpreter, who apart from being experienced in interpreting, had agricultural knowhow and experience in field research as well as knowledge of how to interact with the local people. In order to reach the farmers – at times in very remote, rural locations – it was necessary to ensure a reliable and round the clock available mode of transportation. The fluctuating availability of the farmers required high flexibility in terms of mobility. This flexibility was not possible with Simusolar's vehicle fleet due to their high booking rate for other purposes such as sales activities and installations of solar water pumps for new customers. Therefore, it was necessary to rent a vehicle solely for the purpose of field research, which multiplied the costs incurred – cf. Annex A.

### 3.2.1 Initial Round of Visits

The aim of the initial round was to evaluate the customers' initial situation as a starting point of their experience with solar water pumps, ideally before the installation of the solar water pump system had happened. Expectations, potentials, and risks regarding the new technology were assessed conducting a combination of measurements, semi-structured interviews and participative rural appraisal activities that had been developed in order to reveal the desired information. When possible, the principle of triangulation was applied and information planned to be collected at least twice using different methodology or different sources in order to verify the collected data. The hereafter presented survey plan is to be understood as a flexible frame and was meant to provide a guiding thread for the field researchers. The activities were to be adapted according to the conditions found on-site to follow the natural flow, which automatically evolves in the course of field research. The farmers' initiative was to be encouraged and the schedule to be left open for changes initiated by the farmers and possible contingencies.

<u>Activity #1 – Mental Map (duration of approx. 20 min)</u>

As starting activity, the creation of a mental map by all the farm members jointly (including women and children) is proposed in order to collect basic information about the farm. The participants are to be asked to draw on the ground or on a flipchart paper the main sites of the farm without putting importance on accurate dimensions. While the mental map is created, the field researchers remain in an observatory role writing down information shared verbally by the participants. Once the mental map is completed, the participants present their result explaining every detail. If necessary, the field researchers can ask additional questions at this point of the activity. Based on the map created by the farmers, their social incorporation into the community can be visualised. Therefore, the farmers mark the people important to them (e.g. their customers, family, direct neighbours ...) on the map. The quality of interaction should also be recorded (reason for interaction, frequency ...).

The information that can potentially be revealed by this method includes at least:

- The number of people living on the farm including who they are (age, sex, responsibilities, level of education…)
- Area of the farm and its usage
  - → Types of crops cultivated and their area needs
  - → Types of crops desired for cultivation in the future
  - → Additional activities pursued in the farm besides horticulture
  - → Unutilized area and why it is not used
- Type of water source
- Type of current water supply system

- Neighbouring area and relationship to neighbours
- Social structure of the farm and its incorporation into the community

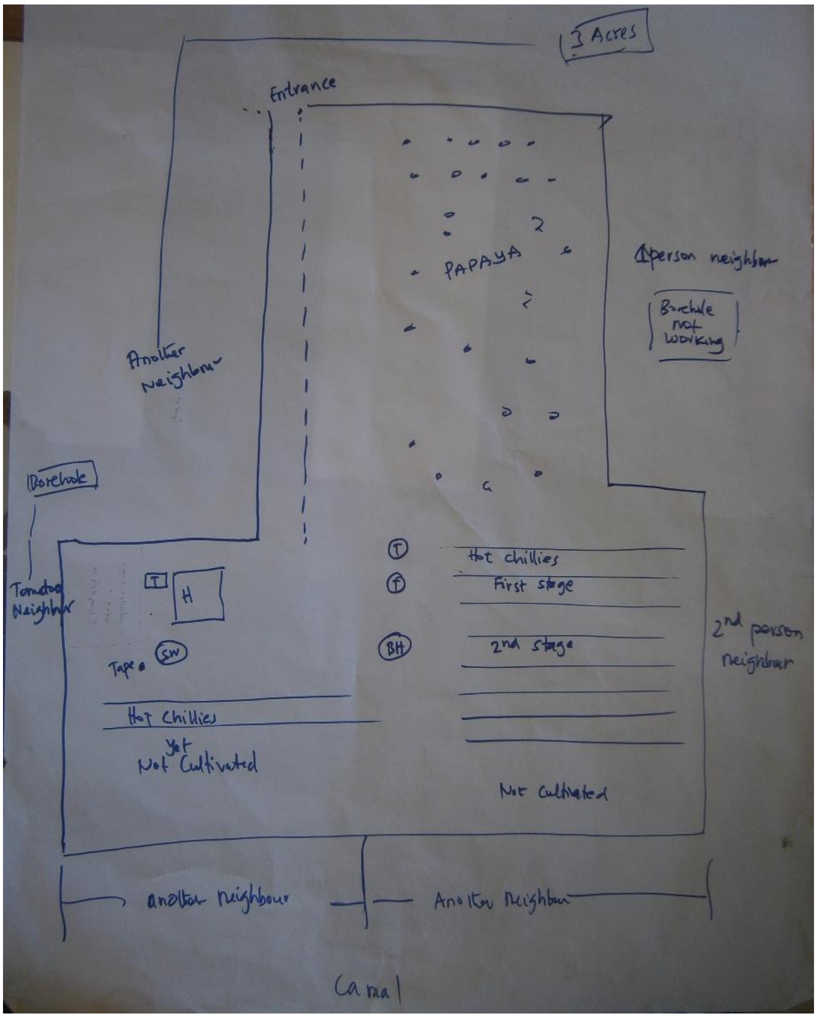


*Figure 7: Mental map of farmer nº 8, March 2019.*

Having a broad overview over the farm's size and activity spectrum, more specific information can be uncovered with the follow-up PRA activities. In addition, own measurements and activities are conducted and specific questions asked when appropriate situations emerge. The order of the activities can be changed according to the best fit in each specific case. However, in most cases it might be suitable to continue with the seasonal calendar, since it is best done with the whole group.

Activity #2 – Seasonal Calendar (duration of approx. 40 min)

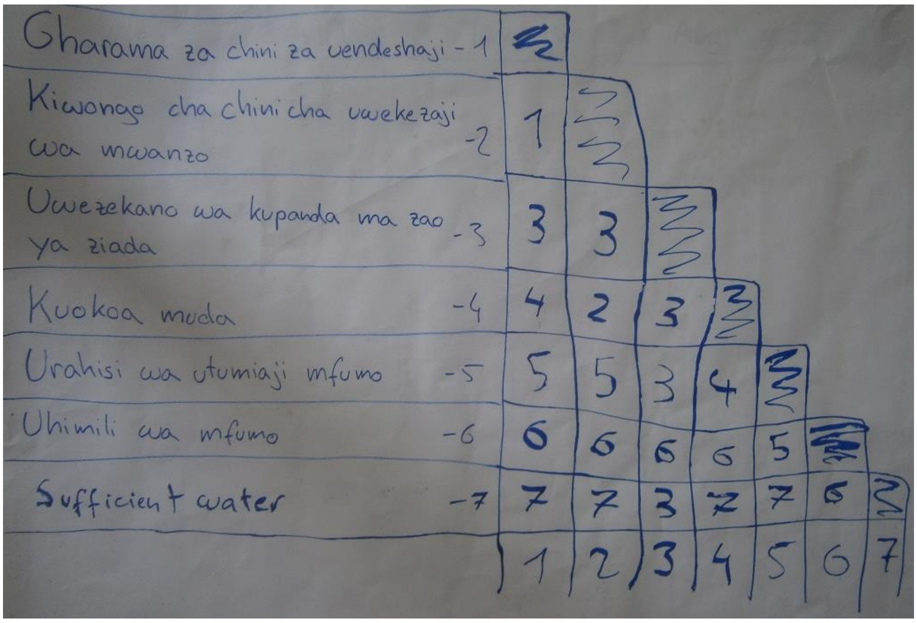
With the seasonal calendar, the farm's yearly cycle and its activities, potentials and dependencies can be grasped. The draft calendar presented in Table 3 should be validated with the participants before starting the activity – especially the seasons should be proposed directly by the participants according to the relevant time periods. While the calendar itself should only be filled with little stones, beans or peas to show the relative quantity, absolute numbers can be asked and noted separately when the calendar is presented. An example of the calendars obtained is shown in Figure 12, subchapter 3.3.

*Table 3: Proposed seasonal calendar for the initial round of field visits.*

| | **Dry Season** | **Wet Season** | **Dry Season** | **Wet Season** |
|---|---|---|---|---|
| | Jan Feb | Mar Apr May | Jun Jul Aug Sept Oct | Nov Dec |
| *Rain* | | | | |
| *Sun* | | | | |
| *Harvest Yield per Crop* | | | | |
| *Need of Irrigation* | | | | |
| *Availability of Water Source (Water Level)* | | | | |
| *Dependency on Climate (e.g. Rain/Sun)* | | | | |
| *Usage of Water Supply System* | | | | |
| *Water Supply System out of Function* | | | | |
| *Operational Costs* | | | | |
| *Maintenance Costs* | | | | |
| *Investments Needed* | | | | |
| *Income* | | | | |
| *Employment Situation* | | | | |

Activity #3 – Pair-Ranking (duration of approx. 30 min)

The pair-ranking activity is meant to address the farmers' prioritization of a water supply system's characteristics. Therefore, the field researchers start by making a list of the characteristic factors stated by the farmer. In order to obtain a complete list, the researchers begin by asking for the hoped-for benefits of the solar water pump system, followed by asking about the challenges the participant deals or dealt with the current system. The factors presented in the pair-ranking matrix in Table 4 should be included into the list, also if not mentioned by the farmer. Figure 8 shows a completed matrix, where the numbers in the squares represent the higher-valued corresponding characteristics.



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Gharama za chini za uendeshaji - 1 | | | | | | | |
| Kiwongo cha chini cha uwekezaji wa mwanzo -2 | 1 | | | | | | |
| Uwezekano wa kupanda ma zao ya ziada -3 | 3 | 3 | | | | | |
| Kuokoa muda -4 | 4 | 2 | 3 | | | | |
| Urahisi wa utumiaji mfumo -5 | 5 | 5 | 3 | 4 | | | |
| Uhimili wa mfumo -6 | 6 | 6 | 6 | 6 | 5 | | |
| Sufficient water -7 | 7 | 7 | 3 | 7 | 7 | 6 | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

*Figure 8: Pair-ranking matrix of farm nº 6, April 2019.*

Table 4: Proposed pair-ranking matrix for the initial round of field visits.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Low Operational Costs - A* | | | | | | | |
| *Low Initial Investment - B* | | | | | | | |
| *Possibility to Cultivate Additional Types of Crops - C* | | | | | | | |
| *Saving Time - D* | | | | | | | |
| *Complexity of Operation of System - E* | | | | | | | |
| *Reliability of System - F* | | | | | | | |
| *Other Factors Named by the Farmer - G* | | | | | | | |
| | *A*<br>*Low Operational Costs -* | *B*<br>*Low Initial Investment -* | *C*<br>*Possibility to Cultivate Additional Types of Crops -* | *D*<br>*Saving Time -* | *E*<br>*Complexity of Operation of System (and their Rating) -* | *F*<br>*Reliability of System (and their rating) -* | *G*<br>*Other Factors Named by the Farmer -* |

Activity #4 – Daily Routine (duration of approx. 10 min per participant)

In the optimal case, a daily routine plan is developed with each member of the farm individually. For the children, it can probably be best done with their mother or father. Depending on the number of people living and working on the farm and the time available, a feasible number of people has to be chosen. The importance of completing the daily routine with the different members of the farm is as follows:

*Main Farmer > Women > Additional Workforce > Children*

During the activity, which is done with each participant individually, emphasis should lie on water usage (e.g. irrigation) and education or income generating activities. Also, it should be asked how newly gained time would be used by each participant individually. Alteration of the daily routine throughout the year depending on the seasons should be checked before concluding the activity.

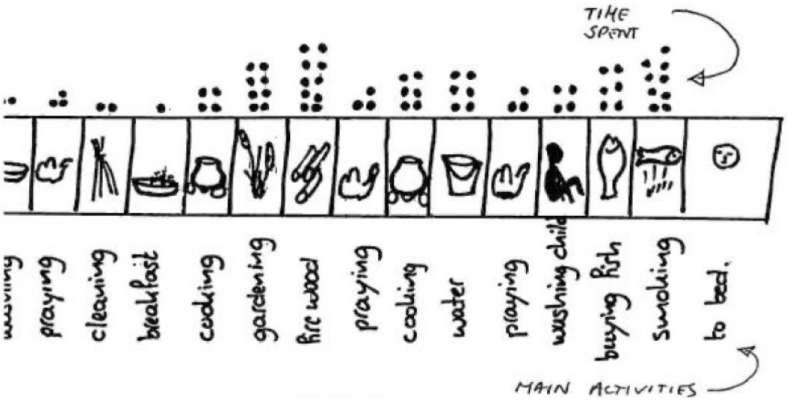


Figure 9: Exemplary daily routine depiction [82].

The following information can be obtained when the daily routine activity is done with the proper participants:

- Education activities
- Employment situation
- Usage of water system
- Points in time for irrigation throughout a day
- Labour and time demand for irrigation
- Women's role in the farm

Self-Conducted Activities by Researchers

Measurements and other self-conducted activities can be incorporated at any point of the field visit. They can be combined with a guided tour through the farm, which can be shifted towards a transect walk. During a transect walk, small maps of specific areas of high interest (e.g. water source surroundings; cultivated areas) and semi-structured interviews can be realised together with the participants, among others.

The following self-conducted activities are performed:

- Installing a water meter at the solar water pump;
- Measuring with the GPS mobile phone application GPS Tools 3.0.2.4 (designed and developed by VirtualMaze SoftSys Private Limited) the utilized area for horticulture as well as the unutilized area;
- Measuring the water level of the water source and check for primary water sources (refilling);
- Inspecting in person and taking photographs of
    - → Water source(s);
    - → Water supply system;
    - → Irrigation technology;
- Enquiring about further solar water pump suppliers in the region.

Semi-Structured Interviewing

In case the following questions don't arise by themselves during the field visit, they can be asked in a semi-structured interview e.g. as part of the guided tour through the farm as a transect walk. The formulation of the questions should be chosen according to the situation – generally, a conversation is to be sought, where the participant shares his or her knowledge without the wedging frame of a formal interview.

- How many people live on the farm, who are they, and which level of education do they have?
- Do you hire additional workforce? If so, during which time period and for what type of work?
- Which activities/responsibilities does/has each member of the farm?
- Which income generating activities do you pursue, and which would you like to pursue in the future?
- Which types of crops do you cultivate?
- Which types of crops would you like to cultivate in the future?
- How did you get to know about solar water pumps and which solar water pump suppliers do you know?
- How do you plan to use the new solar water pump [hours/day]; [days/year]?
- Which is/are your current water source(s) and why do you use them?
- How fast does the water source refill itself taking into account a whole year (dry and wet season)?
- Which costs occur when using the water source?
- Which costs occur when using your current water supply technology (e.g. for fuel)?

- How much energy or fuel do you need to operate the current water supply technology?
- Do you have access to credit and/or banking? If so, of what type?
- Within the local community/village, which is your role?

### 3.2.2 Midline Round of Visits

In order to learn which difficulties farmers might face while using the new water supply system, a midline/early evaluation is proposed. The goal of this step is to identify possible adoption difficulties of the new technology. Therefore, the performance of the system will be evaluated, and if applicable conducted measures for improvement identified and documented. Also, some of the collected parameters in the initial round can be re-collected to check for changes. Overall, this leads to a brief but comprehensive scope of activities:

1. Acquire missing information from the initial survey
2. Self-conducted activities by the researchers:
   - Take measurement from water meter
   - Take pictures of current status of crops/farmland
   - Measure cultivated area with GPS
3. Semi-structured interview:
   - Change in cultivation
     - → Area (size)
     - → Crops (status, variety, …)
     - → Irrigation (supplied vs needed)
     - → Dependency from rain?
     - → Harvest or expected yield (comparison with previous seasons)
     - → Reasons for changes
   - Usage of solar water pump
     - → Simplicity of use
     - → Time out of function and why
     - → Time of usage/day and days/week
     - → Struggles met
   - Expectations met
     - → Compare if reasons for purchasing were met (e.g. low costs, reliability, independency…)
     - → Are the problems with previous system passé?
   - Feedback from neighbours/community/society regarding solar water pumps
   - General changes
     - → Time and labour for irrigation
     - → Number of workers needed
     - → Time saved
     - → Sources of income
     - → Business opportunities (new ones identified, any newly realized?)
     - → New upcoming investments (other than already planned)
     - → New challenges
     - → Any unexpected benefits/changes

### 3.2.3 End-line Round of Visits

The overall solar water pump system’s performance is planned to be assessed after two to three months, when the new system has been operating long enough to reach normal operation state. Ideally, the time period between installation of the solar water pump system and the end-line evaluation is long enough to also observe an entire cycle of cultivation (from sowing until harvesting). If this is the case, the early benefits of the solar water pump system on the harvesting yield as well as on the required workforce and resources can be assessed. Due to the constrained timeframe, this cannot be guaranteed and will depend upon the farmer's cultivation range. In any case, an extensive assessment of the new system is conducted evaluating potential savings in water, workforce, monetary, and other resources. Additionally, changes in the daily routine and newly adopted activities will be documented.

Collecting Missing Information

Depending on the outcome of the initial and midline visits of the farmer in question, there might be missing data to collect and information to verify in order to complete the objectives of the field research. The collecting and verifying of data has to be incorporated in a suitable moment of the end-line visit.

Activity #1 – Transect Walk

To get an overview of the current situation of the farm, it is proposed to start with a transect walk. While walking through the farm, the farmer can explain the current status and the changes, which occurred since the initial and midline visits. The following questions and topics should be raised throughout the transect walk:

- Benefits experienced with the new solar water pump and their prioritization;
- Drawbacks experiences with the new solar water pump and their weighting;
- Check the farmer's understanding of the solar water pump technology including the proper operation and maintenance as well as his/her interest in potential co-benefits (e.g. usage of electricity for other purposes or usage of water for domestic use);
- How did farming change with the new solar water pump (e.g. preparing the farmland, irrigating…)? Did any new challenge arise? Check specially for changes in:
  - → The utilized area for horticulture;
  - → The unutilized area for horticulture and why it is unutilized;
  - → The variety of crops grown;
  - → The type of irrigation technology used;
  - → The dependency of climate.
- Perceived complexity of operation of the solar water pump;
- Time period in which the solar water pump was out of function due to maintenance, malfunction, or weather constrains;
- Perceived reliability of the new water supply system as well as problems faced regarding the overall system's reliability (leakages, supply shortage…).

Self-Conducted Activities by Researchers

As in the initial round, some information can be directly measured. The measuring can be incorporated e.g. into the transect walk.

- Reading the water meter and document the date of instalment and the date of reading in order to obtain information on the total water usage;
- Measure with GPS:
  - → The utilized area for horticulture;
  - → The unutilized area for horticulture.

Activity #2 – Matrix of Crops

In order to collect missing data, verify collected information, and document changes, a matrix of crops is prepared with the already collected data, discussed and completed together with the farmer. The matrix should contain the information as illustrated in Table 5 for the past year with a range of the potential spectrum to indicate the worst and best case scenarios.

*Table 5: Proposed matrix of crops for the end-line round of field visits.*

| *[in yearly values]* | *Total* | For each crop cultivated | Planned crops (as far as known) |
|---|---|---|---|
| **Cultivated area** | | | |
| **Farm income** | | | |
| **Price at the market** | | | |
| **Total yield** | | | |
| **Farm expenditures** | | | |
| **Employed workers** | *Amount + costs* | | |
| **Water needs and associated energy consumption** | *Amount + costs* | Qualitative | Qualitative |
| **Seeds used** | *Amount + costs* | Quantitative | Quantitative |
| **Chemicals used** | *Amount + costs* | Qualitative | Qualitative |
| **Fertilizer used** | *Amount + costs* | Qualitative | Qualitative |

Activity #3 – Water Usage Timeline

In order to understand and document the farmers' usage of the newly acquired solar water pump, a quick timeline can be drawn (cf. Figure 10) starting from the date of installation until the date of the end-line visit (horizontal axis). The vertical axis should be on the one hand the frequency of irrigation (once a day, twice a day…) and the amount of water supplied per irrigation, and on the other hand the total time the solar water pump was operating per day. A clear distinction between the usage of the solar water pump system and the irrigation activities has to be ensured in order to avoid misunderstandings. The level of detail of the timeline will depend on the farmers' retrospection capabilities and a broad overview is already sufficient.

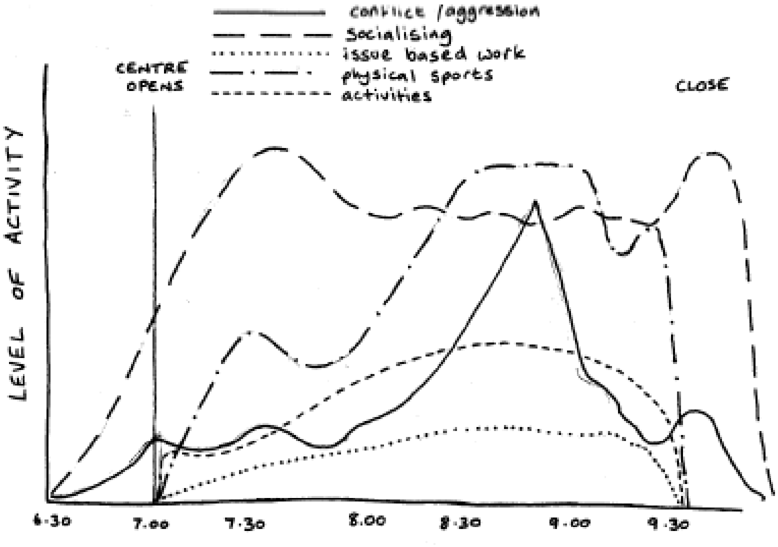


*Figure 10: Exemplary timeline with one y-axis only [83].*

Together with the reading from the water meter, this can yield valuable information on:

- The usage of the solar water pump in [hours/day] and [days/week]
- The water supplied by the solar water pump
- The water used for irrigation
- The frequency of irrigation (within a day and a week)
- The labour and time demand for irrigation

### Activity #4 – Flowchart of the Farmer's Expectations

In order to get a better understanding of the farmer's goals and the challenges faced as well as the potential and the effects of solar water pumps, a flowchart is to be created together with the farmer. The main aim of the farmer (e.g. a business opportunity) is placed in the centre of the chart, and the conditions required to reach the objective are put around it (separate flowcharts can be created if the farmer has various goals). Creating different levels shows how the specific objective can be reached and what needs to be achieved in order to reach the main goals. Once the main causal flow is set up, the farmer can elaborate on what was hindering its achievement so far and on the role the new solar water pump can play to reach his objectives.

With the flowchart, the following information can be gained:

- Business opportunities
- Challenges
- Potential of solar water pumps

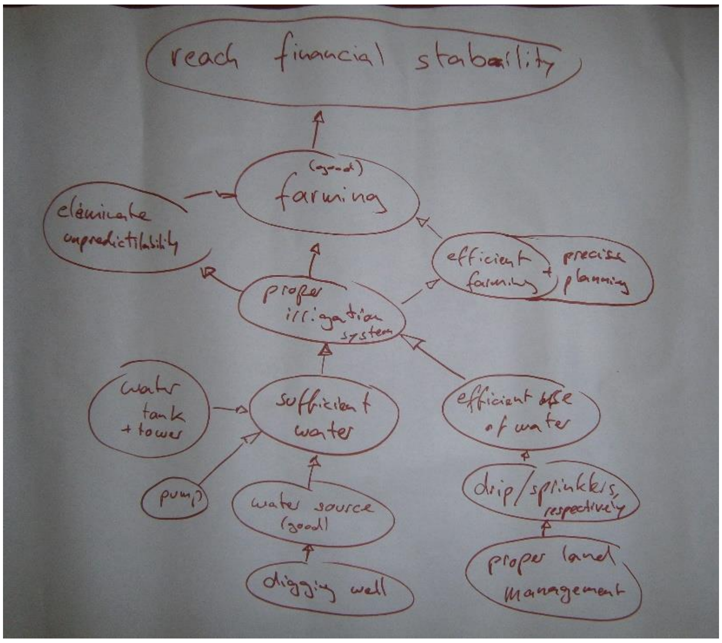


Figure 11: Flowchart of farmer nº 2, May 2019.

### Talking to Neighbours

In order to learn how solar water pumps are perceived by outsiders, it is proposed to get into contact with the neighbours and ask them about their current situation, especially about their water supply and irrigation situation, and their perception of their neighbour's new solar water pump. The interaction should be kept in an informal, conversational form of a semi-structured interview following the thread outlined with the following questions.

- What is your occupation?
- What water supply technology do you currently use?
- Do you have sufficient water?
- What challenges are you facing (in particular regarding water supply)?
- Do you have any plans on changing the situation and acquiring a new water supply or irrigation system?
- Do you know what a solar water pump is?
- Have you heard about your neighbour’s experience with the solar water pump?
- What are your thoughts about solar water pumps and would you be interested in purchasing one?

Semi-structured Interviewing

Finally, the remaining information to collect has to be asked either when seemed appropriate throughout the whole visit or at the end. In case any of the following information was not collected before the solar water pump was installed, both the information for before and after the solar water pump installation has to be asked in order to allow for a before-after comparison.

- Running costs (operation and maintenance);
- Income from other sources than farming;
- Business opportunities;
- Employment situation/additional workforce (type and time period of help);
- Sources of income;
- Access to credit/banking;
- Size and members of the family / people living on the farm;
- Activities and level of education of each member on the farm (incl. education activities);
- Women's role in the farm (responsibilities, activities…);
- Status within the community / relationship with neighbours.

## 3.3 In the Field

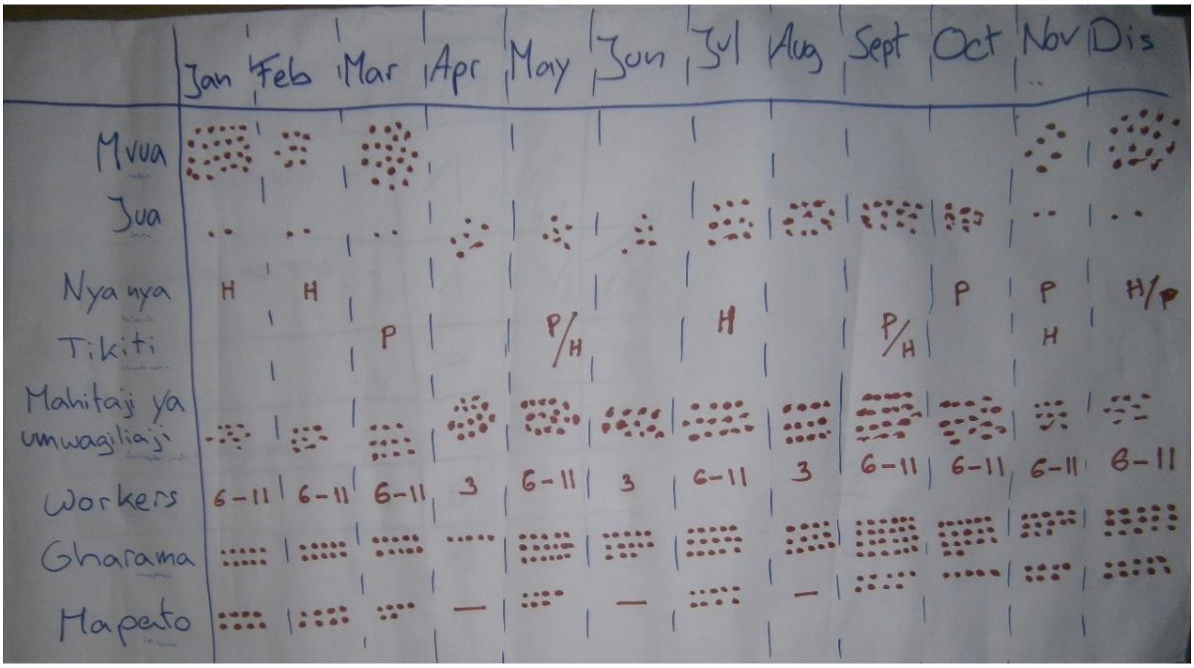
From the very beginning, the field trials were designed with the purpose of being flexible and adapting to the conditions on-site. As a natural consequence, many contingencies happened and multiple changes were implemented on the field last minute. These ranged from essentials as the number of farmers visited to details such as the order in which activities were conducted with each farmer. In the following, a broad overview of the conducted field work and therein implemented changes is given.

In total, 12 out of 14 farmers were visited within the scope of this research. The initial visits happened before or up to three weeks after the installation of the solar water pump. In a few cases, it was possible to combine the initial visit with the installation of the pump. Making two rounds of the route Dar es Salaam → Morogoro → Dodoma → Singida → Moshi → Dar es Salaam, it was possible to complete the initial visits within a period of four weeks. This way, it was possible to include the midline visits in the second round of the route while finalizing the initial visits of the last farmers. This implies that only the farmers, which were visited within the first round of the route, could be included into the midline round. In the end, three farmers participated in the midline round approximately two weeks after their initial visit. It was chosen to follow this procedure and reduce the number of farmers in the midline visits in order to remain within the limited budget and use the scarcely available time optimally. For the end-line visits, all 12 farmers were included again. Between the initial and the end-line visit of each farmer was a break of 7.5-11 weeks, slightly missing the intended eight-week threshold (two months) for three of the farmers from the second round of initial visits (farmers nº 3, nº 6, and nº 7).

Once on the ground, compromises had to be made on how to conduct the field research. With respect to the proposed PRA activities, the optimal procedure would include the involvement of all farm members in almost every activity. However, the amount of persons participating in the activities reflects on the required time to complete the respective activity. With the proposed scope of work, especially regarding the initial and end-line visits, there is a high level of active participation required from the farmers over an extensive period of time. To take up this amount of time was not possible with every farmer, and thus the number of participants for each activity had to be reduced. There was only a chance of including everyone in the activities at the farms with a low number of farm members. Thus, the PRA activities mental map, seasonal calendar, or matrix of crops had to be conducted with a reduced number of participants. Moreover, the available number of participants was restricted since the farmers often didn't live at the farm, and thus only a few of the farm members were at disposal during the field research. At some farms, the farm members would divide up between the activities (e.g. one farm member doing the transect walk and the mental map and another completing the seasonal calendar) so that each of them would remain with sufficient time to conduct their daily work. Also, some characteristic approaches of PRA such as using sticks to draw on the ground or qualitatively illustrate a quantity with beans were found to be time consuming, which is why the participants preferred to use more time-efficient means and draw directly with a marker on a flipchart and qualitatively illustrate a quantity with dots on paper. Also, stationary equipment is easily available and literacy levels are reasonable nowadays, making the initially planned ways of interacting obsolete and inappropriate. Despite the time constrains and thanks to the efforts taken as well as thanks to the farmers' hospitality, all farmers devoted at least half of their day to participate in the field research during each visit. To sustain the farmers' motivation and show the appreciation for their contribution, any possible form of support was rendered, ranging from giving a lift to technical support to connecting with potential customers or investors.

The order in which the different activities were conducted during the initial round of field visits varied from farmer to farmer. In most cases however, the visit started with a guided tour through the farm similar to a transect walk, during which the farmers introduced their farming activities. When thereafter continuing with the mental map, it was possible to recognise the different parts of the farm, ask specific questions and unveil information, which seemed irrelevant to the farmer as for example the extent of the unexploited farmland. This way, it was possible to gain a holistic overview and minimize the risk of missing information. Next, either the pair-ranking or the seasonal calendar activity followed – depending on the individual situation with the farmer. In many cases, it turned out to be better to close with the seasonal calendar and do the pair-ranking activity first since it became apparent that it required a lot of energy to fill out the seasonal calendar due to the level of detail required. The pair-ranking activity on the other hand was more straightforward and thus received positively.

During completion of the seasonal calendar, the atmosphere usually decayed and motivating the farmers for another activity was challenging. Regarding the information collected with the seasonal calendar, farmers nº 2 and nº 5 had just started farming, so that instead of information of the past year, expectations on the coming year were recorded. For farmers nº 3, nº 6 and nº 8, both past and expected farming information was collected since the past information alone did not suffice to cover an entire year. Generally, it has to be pointed out that farmers usually alternate the cultivated crops from year to year without a fix scheme trying out new crops and farming methods aiming to improve their yield. Only a few basic crops are cultivated every year in the same way by the individual farmer. Comparing different years is challenging due to the varying cultivation and potentially different climate conditions thus limiting the comparison's validity. Obtaining the information on the climate as well as the point of planting and harvesting different crops caused usually no struggle. In contrast, getting information on the yield, income and expenses was more challenging since not all the farmers were experienced and almost none kept records. Here, it was necessary to rely on approximate and – in case the farmer had just started – expected values. Regarding the employment situation, it varies on daily basis since most of the work is done by day-workers that are hired according to the present workload. That's why here, the seasonal calendar states a range in most cases. A particularly challenging information to obtain regarded the time period during which the previous water supply system was out of function. Exact statements on when and how often it was out of function were most of the times not possible to obtain and therefore left out of the matrix and noted down separately. In order to simplify the seasonal calendar, the operational and maintenance costs were put together and asked as one, and the investments needed and the dependency on climate left completely out of the calendar and asked separately. The availability of the water source was in all cases except one constant throughout the year, so that only for one farmer it was included in the chart. In the end, the implemented seasonal calendar looked in most cases as shown in Figure 12 and illustrated in Table 6.



| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mvua | | | | | | | | | | | | |
| Jua | | | | | | | | | | | | |
| Nyanya | H | H | | | | | | | | P | P | H/P |
| Tikiti | | | P | | P/H | | H | | P/H | | H | |
| Mahitaji ya umwagiliaji | | | | | | | | | | | | |
| Workers | 6-11 | 6-11 | 6-11 | 3 | 6-11 | 3 | 6-11 | 3 | 6-11 | 6-11 | 6-11 | 6-11 |
| Gharama | | | | | | | | | | | | |
| Mapato | | | | — | | — | | — | | | | |

*Figure 12: Seasonal calendar of farm nº 4, March 2019.*

*Table 6: Implemented seasonal calendar during the initial round of field visits.*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Rain* | | | | | | | | | | | | |
| *Sun* | | | | | | | | | | | | |
| *Planting and Harvest Point for Each Crop* | | | | | | | | | | | | |
| *Need of Irrigation* | | | | | | | | | | | | |
| *Employment Situation* | | | | | | | | | | | | |
| *Operational Costs* | | | | | | | | | | | | |
| *Income* | | | | | | | | | | | | |

In regard of the daily routine activity, it proved to be impracticable in the level of detail and in the way proposed initially. On a farm, the daily routine is only to a very small degree constant over the year. It changes distinctly from season to season and with the type of work required to be done each day. Generally, the farmers would only plan the upcoming day in advance. Moreover, the proposed graphical visualization of the daily routine constituted a challenge for the farmers. Therefore, the approach was pivoted after the first experiences, and the participant asked to narrate a typical day of farm work, so that the main steps of the daily routine (e.g. time spent on the farm, points of the day for irrigation, etc.) could be noted down without any graphical visualisation.

There were also some difficulties in terms of the activities and measurements that the field researcher himself was meant to conduct. While the measurement of the cultivated area was easily done with the mobile phone application GPS Tools (in addition to the obtained GPS location, the satellite picture helped reaching a higher accuracy), measuring the entire area was at times only possible via satellite picture since parts of the farms were not cleared and therefore couldn't be reached to obtain the exact GPS location data. The water source, the water supply system, and the irrigation technology were inspected and documented with photographs in all cases. The water level of the water source was on the other hand not possible to determinate, since most of the boreholes were closed and/or too narrow to use measuring tools. Since the exact depth is only of importance when the water level is documented over a long period of e.g. one year, it was decided to skip the depth measurements and rely on approximate statements by the farmers and technicians. For the installation of the water meters, which help measuring the usage of the solar water pumps, Simusolar agreed to take over and deploy its technicians for the installation. However, the customers' concerns that the chosen meters would limit the performance of their pump combined with unclear responsibilities and therewith unclear path of communication as well as logistic challenges resulted in four out of eight water meters installed – four farmers had no pump installed at the end of the field trials due to challenges with muddy boreholes, floods, and delayed payments by funders. The installed water meters were operating for 2.5 up to 9.5 weeks when read during the end-line round of visits.

The mid-line round of field visits was conducted as planned, with three out of 12 farmers visited in order to stay within the available budget and time frame. All measurements were done and water meter readings taken, apart from the reading at one of the farmers since there was no water meter installed. Also, all topics included in the scope of the proposed semi-structured interviews were worked through – although many were not relevant due to the little amount of changes occurred since the initial visit. Moreover, since many initial visits happened one to three weeks after the installation of the solar water pump, many challenges in adopting the new technology were observed already during the initial visit of the farmers. Thus, the aim of the midline visits was partly already covered by the initial visits. Nevertheless, the midline visits helped to yield additional insights and to gain an improved understanding of the diverse challenges for solar water pump adoption in smallholder horticulture farming in Tanzania.

The end-line visits were again more extensive and included, similarly to the initial survey, activities of the PRA methodology. The end-line visits usually began as planned with a transect walk through the farm since this was experienced to be more convenient during the initial round of visits. In-between, it was possible to include the readings of the water meters and – in case there was any change – measure the different areas. The order of the remaining activities varied, but most of the time the proposed order was followed continuing with the matrix of crops. After the experience with the seasonal calendar, it was surprising to see what level of detail the farmers were able to recall. It turned out that it was easier for the farmers to give information on more specific matters rather than estimating overall costs or yields. Combining both the seasonal calendar and the matrix of crops gives now a good overview on the initial situation of the farm giving a solid baseline for an impact evaluation. On the other hand, the timeline graph proved to be unnecessary and even impracticable. The information about the usage of the new solar water pump and irrigation practices was not available in such a level of detail since the farmers were only able to provide average numbers making the timeline redundant. In order to provide a higher level of detail, it is recommended for future research to use smart meters, which not only measure accumulatively the water flow but also the time periods of usage. For the research at hand, these meters were not available due to their higher costs and their lack of availability in Tanzania. Usually, the end-line visit ended with the creation of a flowchart of the farmers' goals and needs. Most of the farmers flourished when narrating about their aims and how they intend to reach them – the only challenge being catching the essence of their explanations in the flowchart (cf. Annex G). Only one farmer didn't see any point in the activity and was short in explaining his visions. After concluding the end-line visit with each farmer, the neighbours were sought in order to learn about their perception of solar water pumps. Often, the farmers joined in visiting their neighbours and supported by introducing one to another. In many cases though, the visit of the neighbours was skipped, since some of the farmers had no pump at the time of the end-line visit or had been barely able to use it, leaving the neighbours with no chance to experience the pump working and form an own opinion on solar water pumps. In other cases, there were simply no neighbours in the direct surroundings, making the activity obsolete.

## 3.4 Limitations

As mentioned earlier, the available budget and the given time frame combined with the distances to overcome to visit the farmers in the different regions constitute limitations to the research realized. Most importantly, they limited the extent of the field trials in terms of available time for each visit and the total amount of farmers visited. Since the aim of this work is to obtain insights from the farmer's level and improve the understanding of the situation on the ground, it was decided to keep the total number of visited farmers low (without undercutting the bottom limit of ten farmers) in order to maximize the time available witch each one for the PRA activities conducted during the visits, although compromises had to be made anyway regarding the number of participants in each activity. Thus, the results obtained in this research cannot be generalized for the entire Tanzanian horticulture market due to the low number of smallholder farmers visited and are therefore not representative. Moreover, some of the farmers included in the field research don't entirely fit to the predefined typology of smallholder farmers. Due to the limited available information about the farmers prior to the visits and its poor quality, six farmers turned out to cultivate a larger area with non-horticulture crops or to possess secondary farms. However, the solar water pump was purchased to provide irrigation predominantly to horticulture areas of typical smallholder size in all cases. Thus, the obtained results can be used to validate to a certain extent the findings of prior research studies. Moreover, they yield new insights from the challenges in the field, which can be subject of future research for validation of their relevance for the overall market.

Regarding the information obtained, the level of detail reached is outstanding despite the difficulties faced and the limited time available for conducting the PRA activities, which impeded a strict compliance with the PRA standards. Nonetheless, the information collected includes the farmers' individual views as well as their objectives and their subjective perceptions of the challenges in the field, thus reaching to the farmers' level and facilitating an improved understanding of the market. This implies that most of the information presented in this work represents the farmers' personal view and might fail to correspond with the overall situation or in extreme cases even the reality. The majority of the data is hence based on the individual expertise of the farmers and was not obtained directly. The accuracy of the individual information – especially regarding finances and water needs – cannot be guaranteed, but the overall picture serves nevertheless to understand the approximate situation on the field. Also, the local conditions at a farm can vary greatly from case to case reducing the relevance of single values and increasing the interest in potential ranges, which can be used to enhance the promotion of solar water pumps in Tanzania's horticulture sector.

In closing, it is important to point out that there are gaps in the information obtained. Apart from the already mentioned limitations, obtaining information on finances was in some cases not possible due to the taboo-like perception of financial issues as long as a certain level of confidence is not reached. This level of confidence was not always achievable, and in these cases it was decided to renounce from querying in order to sustain the rapport and not affect the remaining research. Moreover, language and culture barriers might have interfered with the information obtained despite the efforts taken, the use of PRA methodology, and the support of a local interpreter. Also, this work does not address the sustainability of solar water pumps, which especially in terms of groundwater depletion risk is of particular importance.

# CHAPTER 4 – RESULTS

The findings resulting from the field research can be allocated to four different areas. On the one side, there is detailed information about the farmers' initial situation before obtaining a solar water pump, which improves the understanding of the farmers' needs, and which can be used as a baseline for a future impact evaluation. Furthermore, the farmers' prioritization of a water supply system's characteristics is analysed and the approach for assessing purchase drivers as presented in the Tanzania Market Snapshot [8] applied. Thirdly, the close interaction in the field with the farmers as well as with Simusolar allowed to identify early-state barriers to the adoption of solar water pumps in Tanzania's smallholder horticulture market. Last but not least, the farmers' progress on the theory of change model is assessed to better understand the potential of solar water pumps.

## 4.1 Processing of Data

The results presented in this work are based on the information collected during the field trials as well as on information provided by Simusolar regarding their products and services as well as their customers. Since Simusolar offers financial services in terms of payments of their products by instalments to its customers, they collect the required information to assess eligibility and repayment risks. This information was made accessible for this research and helped to verify the information collected in the field as well as to complete information gaps. In addition, weather data from the nearest weather station as provided by the FAO in CLIMWAT 2.0 (available under [84]) and comparative theoretic data of the crops' irrigation demand is added to offer a point of reference.

The comparative crop irrigation data is obtained by following the FAO crop water requirement guidelines [85], which are implemented in the freely available GIZ-FAO tool SAFEGUARD WATER – Water Requirement Tool from the Toolbox on Solar Powered Irrigation Systems (SPIS) on energypedia.info [86]. Here, the crop's water needs are approximated by calculating the reference evapotranspiration of well-watered green grass of 8-15 cm height using the Blaney-Criddle method and the climate data from the nearest weather station provided in CLIMWAT 2.0 [84], [85]. With the reference evapotranspiration as baseline and the respective crop factors as well as the length of the crops' respective growing periods – both obtained from the FAO database or if missing from research papers [87], [88], [89] – the crops' specific evapotranspiration parameter is calculated [85]. Taking into account the area used for each crop, the farmer's cultivation scheme, and the average rainfall in the region in question, a theoretic irrigation demand of a farmer's land is obtained [85]. However, the resulting water needs have to be treated with caution since the farmer's cultivation scheme might not fit optimally to the average climate recorded by the nearest weather station, and therefore the calculated values might be overestimated. Moreover, farmers usually adapt their cultivation scheme according to the prevalent climate conditions aiming to reduce their irrigation needs. Also, relevant data such as the soil's qualities and regional variation of crops' characteristics are not considered yielding to inaccurate results.

Once all the data is collected, internal and inter-farmer cross-validation helps to eliminate erroneous values. Then, key indicators such as aggregates, normalized, mean, median, maximum, and minimum values are calculated, and a structure to logically organize the data is created. From there, before-after comparisons and farmer-specific analysis can be conducted, conclusions be drawn, and the data be used e.g. as baseline for an impact evaluation. Due to the low number of participants and the resultant unrepresentativeness of the data, comparisons between the farmer types and correlation analysis are of little use without being able to verify the findings with a representative pool of participants.

The data obtained by the pair-ranking PRA activity requires an additional processing step as compared to the rest of the collected data. In order to be able to use the information of the 14 different ranking matrices (cf. Annex F), each matrix has to be evaluated individually and the scores obtained by each factor aggregated. Since not all factors were surveyed the same amount of times in each matrix, it is necessary to normalize the scores obtained in each matrix over the respective number of incidence. Thus, the overall score as presented in the subchapter 4.3 is calculated my summing up the factors' normalised score reached in each farmer's pair-ranking matrix reaching overall scores within the range of 0-14. The normalised score is obtained by dividing the number of times a factors "wins" against another factor within one pair-ranking matrix by the total amount of factors considered in the respective matrix subtracted by one.

$$A\ Factor's\ Overall\ Score = \sum_{Matrix\ 1}^{Matrix\ 14} \left[\frac{amount\ of\ "wins"}{total\ amount\ of\ factors - 1}\right] \tag{1}$$

## 4.2 Farmer Profiles

In order to learn about the farmers' situation and enable a better understanding of the conditions on-site, it is vital to provide a structured and easy-to-grasp overview without withholding important details. Therefore, as starting point, a profile of each farmer visited and his or her initial situation prior to obtaining the solar water pump is created.

### 4.2.1 Scope

The two-page farmer profiles, which can be found in Annex E, contain the most essential information such as the size of the farm and average climate data from the nearest weather station, and at the same time they provide a detailed overview of the farming activities thanks to the matrix of crops, which constitutes the second part of each profile. Thus, it is possible to detect the diversity of Tanzania's smallholder horticulture market while understanding the specific conditions on-site.

Each profile comprises information on the farm area and its use as well as on all farming and any further income generating activity and the resulting average yearly income. It depicts all farm members i.e. the main farmers and permanent workers as well as the seasonal day-workers, which are hired as needed, and who are often people from the same community living close to the farm. Beyond that, the water situation is detailed referring from the sources of water over the former water supply system and irrigation technology up to the new solar water pump system purchased by the farmer. To better understand the climatic context of the farm, average weather data from the nearest weather station as provided by the FAO in CLIMWAT 2.0 [84] is illustrated combined with the farmer's perceived intensity of rainy and sunny periods as captured with the PRA activity of the seasonal calendar. This way, the average official weather data is put into perspective with help of the subjective and time-specific account of the climate at the very location of the farm. The first part of a farmer profile is finalized with the specification of the farming challenges and the current aims of each farmer complemented with the envisaged steps required to reach these objectives. Additional framing information such as the education level of the farm members, their preferred sources of information, and their involvement in the local community are provided together with further remarks.

As already mentioned previously, the matrix of crops constitutes the second part of each farmer profile. The structure of the matrix of crops remains mostly as used in the end-line visit but is enhanced by including theoretical data on the crops' water demand and by calculating missing totals and adding information obtained at other points of the field trials.

*Table 7: Matrix of crops as included in the farmer profiles.*

| Matrix of Crops | Total | Crop #1 | Other crops |
|---|---|---|---|
| Area | *Cultivated area in [ha]* | *Area in [ha]* | ... |
| Total yield/year | - | *In locally used unit* | ... |
| Price at market | - | *[TZS / above used unit]* | ... |
| **Income from farm** | ***Yearly total in [TZS]*** | ***Yearly total in [TZS]*** | ... |
| Daily water demand | *Farmer's estimates and GIZ-FAO tool total in [m³/day]* | *GIZ-FAO tool value in [m³/day]* | ... |
| Expenditures for irrigation | *Daily* | – | – |
| Payed workers | *Number & wage* | – | – |
| Seeds used | *Yearly expenses in [TZS]* | *Yearly amount & expenses in [TZS]* | ... |
| Fertilizer used | *Yearly expenses in [TZS]* | *Yearly amount & expenses in [TZS]* | ... |
| Chemicals used | *Yearly expenses in [TZS]* | *Yearly amount & expenses in [TZS]* | ... |
| **Expenditures for farming** | ***Yearly total in [TZS]*** | ***Yearly total in [TZS]*** | ... |

### 4.2.2 Farmer Characteristics

In order to provide a deeper understanding of the situation on-site as encountered during the field trials, a range of selected farmer characteristics are presented in this section. So as to obtain a more detailed picture of the respective farmer conditions, please refer to the farmer profiles in Annex E – a short overview is presented in Table 8.

The surveyed farmers pursue differing objectives with their farming activities. For five of the participants, farming constitutes the main source of income (defined as first objective; farms nº 1, nº 3, nº 9, nº 10, and nº 11), while four participants practice farming as second source of income (defined as second objective; farms nº 2, nº 4, nº 6, nº 7, and nº 12). Interestingly, another three of the visited farms were started as a retirement plan (defined as third objective; farms nº 5, nº 8, and nº 9). Here, all the farm owners are currently employed in governmental institutions (or have just retired), and thus have a stable financial situation from which to develop a farm, which can provide them with a reliable additional income once retired. Farm nº 9 is both listed in the first and third objective since the farm has been for four years on the farm manager's hands, whose main income yields from farming. Now that the farm owner is retiring, he wants to manage the farm himself and work together with the

*Table 8: Overview of surveyed farmers.*

| **Farm** | Region | Farming Objective (regarding income) | Farm Area [ha] tot./cult./hort. | Cultivated Crops hort. / non-hort. | Water Source | Formerly Used Technology |
|---|---|---|---|---|---|---|
| 1 | *Morogoro* | *Primary* | *2.0/1.6/1.6* | *5/1* | *Borehole* | *Grid-connected electric pump* |
| 2 | *Morogoro* | *Secondary* | *3.2/1.2/1.1* | *0/1* | *Hand-dug well* | *None* |
| 3 | *Morogoro* | *Primary* | *4.0/2.0/2.0* | *4/1* | *River* | *Petrol pump* |
| 4 | *Central* | *Secondary* | *4.0/0.8/0.8* | *2/0* | *Borehole* | *Diesel pump* |
| 5 | *Central* | *Retirement plan* | *20.2/2.8/1.6* | *0/1* | *Borehole* | *None* |
| 6 | *Central* | *Secondary (farming group)* | *8.1/1.2/1.2* | *1/1* | *Borehole* | *None* |
| 7 | *Central* | *Secondary* | *20.2/8.1/1.4* | *6/3* | *Borehole* | *Diesel pump* |
| 8 | *Northern Highlands* | *Retirement plan* | *1.2/0.8/0.8* | *2/0* | *Hand-dug well* | *Petrol pump* |
| 9 | *Northern Highlands* | *Retirement plan / Primary* | *8.1/1.6/1.6* | *4/1* | *Hand-dug well* | *Petrol pump* |
| 10 | *Northern Highlands* | *Primary* | *1.6/0.0/0.0* | *0/0* | *River* | *Petrol pump* |
| 11 | *Northern Highlands* | *Primary* | *8.7/8.1/4.0* | *6/1* | *River* | *Diesel pump* |
| 12 | *Pwani* | *Secondary* | *4.0/0.8/0.8* | *2/0* | *Borehole + river* | *Diesel pump* |

current farm manager to run the farm jointly in the future. Since the current situation of farm nº 9 was developed by the farm manager, the farming situation is attributed to him and therewith to the first objective. However, the solar water pump system was purchased by the farm owner and the initiative came from himself since his preferred solution of utilizing wind energy was not feasible due to a lack of companies with the required knowhow. Farm nº 6 is a special case, since it is run by a local farming group consisting of a family of six members and three befriended villagers – the occupation of the group members ranging from farmers over teachers to doctors. This is a unique set-up within the surveyed farmer-pool, where formally unused land is utilized by experienced farmers supported by the financially well-positioned members of the farming group. Additionally, farm nº 7 has to be singled out from the second objective group. Here, a nursery school and a primary school are run for the local children complemented with a farm to support the school with an additional source of income as well as directly with farm goods.

The experience in farming goes hand in hand with the farming objectives. Apart from farm nº 7, which is being run for already ten years, all farmers pursuing the second or third objective have very little farming experience having just started farming at most one year prior to the initial visit. In contrast, farmers pursuing the first objective have a farming experience of four up to 19 years. Only farmer nº 3 has little experience of two years horticultural farming.

A close correlation can be observed between the level of education of the participants and their farming objective. While all the participants who do farming as second source of income or as retirement plan completed higher education, the farms serving as main source of income are run by farmers who at most completed secondary school. As partial exceptions, farm nº 1 (pursuing the first objective) and farm nº 4 (second objective) are singled out. In case of farm nº 4, where father and son manage the farm jointly, the father completed secondary school and the son university studies on bachelor level. In farm nº 1, the wife, who dropped out of school after primary school, is the main farmer being supported by her husband, who obtained a university

degree in agriculture and animal husbandry in Italy. In case of farm nº 6, which is run by the farming group, the level of education varies from member to member reaching from primary school up to university.
Taking the educational background only into account, in three quarters of the visited farms there is at least one farm member who pursued higher education. This leaves only the farmers nº 3, nº 10, and nº 11 with limited educational background. Considering that the farmer nº 10 and farmer nº 11 were reached via the Tanzanian Horticulture Association (TAHA), which supports the farmers in the purchase of the solar water pump by taking over the initial deposit, only one farmer who lacks higher education, was reached directly by Simusolar. This indicates the difficulty of reaching low-educated farmers with an innovative solution, which moreover implicates a high initial investment.

In addition to farming, all participants pursue further income generating activities – be it as primary, secondary, or otherwise further source of income. As already mentioned earlier, all participants who pursue farming as a retirement plan have a reliable main source of income from their employment in governmental institutions (or the therefrom originating pension). At the farms nº 2 and nº 12, the main source of income is also obtained from employment in the same governmental institutions – in case of farm nº 12, this applies for both husband and wife. In the farming group of farm nº 6, four members are currently receiving a reliable salary from their employment as nurses, doctors or teachers. All the farmers pursuing the third objective have an additional income from an own business ranging from tailor businesses to shops for agro-inputs, which are run without exception by the wife while the husband is managing the farm. Two farmers pursuing the second objective also have own businesses – farm nº 4 a timber business, which is run by the wife and provides the main income, and farm nº 12 a barber shop. Moreover, the wife of the farm manager of farm nº 9 owns a tailor business, and also farm nº 1 gets additional income from an own business. For latter, the husband is running a bar in the village. Farm nº 1 additionally gets income from food processing, an activity pursued by the wife within the local women's association. The wife of farmer nº 11 is also doing food processing but by herself as her main income generating activity providing the second income of the household after the husband's farming. This indicates that food processing can be an attractive complementary source of income, as is reinforced by another three farmer's plan to add value-adding processing (including packaging for increased durability) of their harvest to yield higher prices at the market (farmers nº 1, nº 3, nº 10). The other farmers pursuing the first objective (nº 10 and nº 11) rely as well on a secondary income from the other marriage partners, who work in a local restaurant and a local market, respectively.
Other sources of income of varying importance are keeping poultry (farms nº 1, nº 3, nº 4, nº 9), keeping livestock (nº 9, nº 10), renting one's own tractor to neighbours (nº 11), selling water to the neighbours for watering their livestock (nº 5, nº 6) and domestic use (nº 6), real estate property (nº 2) or affiliated institutions (nº 7). Moreover, farmers pursuing the first objective yield additional income from secondary farmland, which due to the nature of the land distribution is located off-site. Thus, the secondary farmland requires its own irrigation system and is not intended to be supplied by the newly purchased solar water pump. This is the case for the farmers nº 1, nº 2, and nº 10, farmer nº 1 owning three additional farmlands, of which two are currently exploited. Moreover, some members of the farming group of farm nº 6 own individual farms.

In respect of the financial situation of the farmers, which is influenced by numerous factors as the farming and non-farming income generating activities or the available resources in terms of inputs, knowhow, and climate, the obtained information is to be viewed with care as explained in the subchapter 3.4. Especially individual values are possibly highly inaccurate, rendering indicating correlations inopportune since it would lead to ambiguous results. This is why here merely an overview of the overall situation is outlined instead of looking on the farmers' individual financial parameters.

As is shown in Figure 13, the participants' yearly income amounts to between 8.4 million TZS and 60 million TZS, translating to approx. 3,650 USD and 26,050 USD, respectively – considering the exchange rate from June 24th, 2019 (the end of the field trials), of 1 USD to 2,303.39 TZS [90]. The mean yearly income lies at 23 million TZS (approx. 10,000 USD) and the median at 22.8 million TZS (approx. 9,900 USD). At that, the farmers hold savings from none at all up to 20 million TZS (approx. 8,700 USD) while facing yearly expenses of up to 48 million TZS (approx. 20,800 USD). The running expenditures caused by the formerly used water supply system are considerable reaching a median of 35% of the farm's total OPEX. Eliminating these expenses by using a solar water pump is therefore expected to provide a remarkable relief to the farmer's financial situation – provided that, in case that the farmer is not able to cover the high initial investment by himself, a suitable payment by instalments solution is found. In case of the farmers visited, the initial deposit payed for the solar water pump accounts to between 0.9 million TZS and 1.65 million TZS (approx. 390-715 USD). The total price to pay for the solar water pumps reaches from 6.12 million TZS until 8.31 million TZS (approx. 2,650-3,600 USD), which results in a total amount of 5.22 million TZS up to 6.66 million TZS (approx. 2,270-2,900 USD) to pay in monthly instalments. In total, the expenditures to purchase the solar water pump sum up to an average of 42% of the farmers' yearly income.

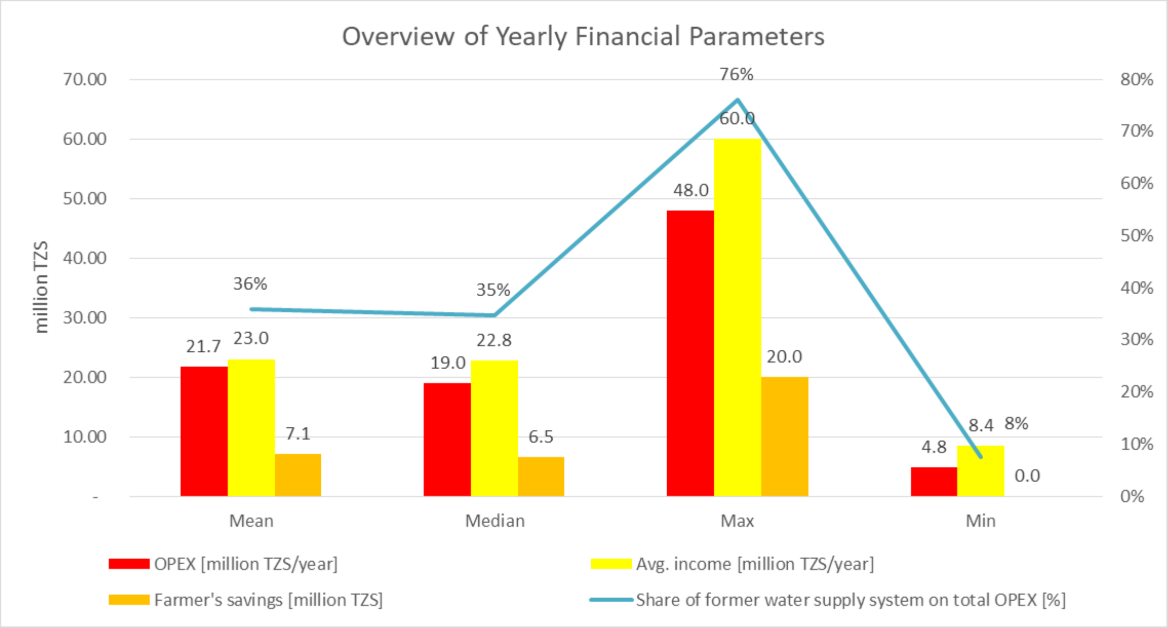


*Figure 13: Overview of yearly financial parameters.*

Looking closer to the farming details, which yield the above described parameters, the utilized area as well as the cultivated crops are of great interest. The cultivated area as measured with the GPS mobile phone application varies from 0.81 ha up to 8.10 ha reaching a maximum share of 93% of the farmland. In average, 41% of the farmland is cultivated – both by horticulture as well as non-horticulture crops. Seven of the visited farmers stated that the reason why they don't cultivate their entire farmland is because they are gradually increasing the cultivated area in order to keep costs manageable, while other four explicitly named insufficient water for irrigation the reason for having unexploited farmland. The remaining farmland of farmer nº 12 is of low quality and therefore has to rest in-between seasons limiting the area, which can be cultivated at a time. The farmers visited are altogether currently cultivating or planning to cultivate a variety of 21 different types of horticulture crops and seven non-horticulture crops (cf. subchapter 2.1 for the definition of horticulture). At that, each farmer grows a maximum of six types of horticulture crops and three non-horticulture crops without exceeding the total amount of nine types of crops in total (without taking into account secondary farms). The median of horticulture crops cultivated amounts to two different types, while as median only one non-horticulture crop is cultivated. The by far most popular horticulture crop grown is the tomato, being cultivated by five of the 12 visited farmers. Additionally, five other farmers are planning to grow tomatoes in the near future. Onions, papaya, and banana follow with four farmers each. Banana is mostly grown for own consumption, which explains that only one more farmer wants to cultivate banana in the future, while three farmers plan to grow onions and papaya. Water melon is another important horticulture crop, although it's currently only cultivated by two of the farmers. However, water melon is after tomato the most popular crop for the future with four farmers planning to add water melon to their cultivation scheme. In respect of the non-horticulture crops, maize and sunflower are cultivated by four farmers each. One more farmer is planning to grow maize in the future, making maize a similarly important crop for horticulture farmers as water melon, onion, and papaya. This reflects the overall importance of maize in the Tanzanian agriculture sector as mentioned in subchapter 2.1.

In their farming activities, the farmers rely on three different types of water sources: boreholes, hand-dug wells, and/or rivers. Most commonly, farmers use a borehole of 70-140 m depth as primary water source (a total of six farmers), while hand-dug wells and rivers are both used by three farmers each as primary water source. Of the 12 visited farms, a secondary water source is used only in farm nº 12 – namely a small river. Since this river does not provide sufficient water year-long, the farmer had a borehole drilled additionally, which is now serving as primary water source. All the farmers visited claim that their primary water source is available year-long without perceivable decrease in the extractable amount of water. No statements can be given in regards of the sustainability of the water sources' exploitation – therefore, a more extensive examination of the water sources is required than what was possible throughout this field research.

The daily extracted amount of water by each farmer is difficult to assess, since measuring equipment was not in place before the beginning of the field trials. Some of the farmers have a rough idea of their water needs, which they acquire by tracking how often they have to refill their water storage tanks throughout the day. However, water for irrigation is often supplied directly from the well additionally to the water taken from the tanks. Thus, counting the "amount of tanks used" usually underestimates the actual water demand. In order to verify the farmers' estimates and obtain a rough idea of the water demand of the farmers, who had no notion of their water consumption, the GIZ-FAO tool SAFEGUARD WATER – Water Requirement Tool [86] is used to assess the water demand (cf. subchapter 4.1). Overall, the thusly obtained maximum water needs range from 85 $m^3$ to around 200 $m^3$ per day, disregarding farms nº 7 and nº 11, which account for a more than double as large cultivated area and thus require accordingly more water. In comparison to the farmers' estimates, the deviation is remarkable, with theoretical values in average three times higher than the farmers' respective estimate. While theoretical values don't necessarily represent the reality (cf. subchapter 4.1), the farmers' estimates often don't consider the water needs of all current and future crops and are especially in case of unexperienced farmers error-prone. Despite the inaccuracy of the theoretical water requirements, the high deviation indicates the farmers' unawareness of their own needs

Providing satisfactory irrigation represents a big challenge for various reasons. Most prominent are the high costs of operation of the former water supply system (mentioned seven times by the farmers) and the difficulties to maintain and repair the system in terms of both costs as well as logistics and knowhow (three times). In one case, the quality of the water source posed an obstacle, since the borehole in question was too muddy to operate a water pump and therefore would have required a regeneration. Due to financial reasons, a new hand-dug well was created instead. As stated by Simusolar, poor-quality water sources with dirty or even muddy water is one of the most frequent reasons for pump failure. Overall, the farmers' former systems suffered from breakdowns in average 1.2 times per month – for electric, grid-connected pumps mostly due to frequent grid blackouts of several days. Fixing a defective pump could take up to three weeks according to the farmers' experience. As an extreme example, farmer nº 12 had to replace his fuel pump three times within a year.

Besides providing sufficient irrigation, the farmers visited experienced a series of diverse challenges opposing their farming activities. The final farm revenue depended highly on the available market price, which can fluctuate significantly throughout the year and even make harvesting unprofitable in first place. For instance, farmer nº 10 refrained from harvesting the cultivated eggplants due to the low market price in place. Mobility to reach a wider market as well as irrigation to enable counter-seasonal farming are two modifiable factors to mitigate the market limitations as identified by the farmers during the PRA flowchart activity six and 14 times, respectively. Additionally, value-adding processing of the harvest is an attractive option to obtain higher prices at the market, as explained earlier. As a consequence of limiting markets, poor-quality inputs such as seeds, chemicals, or fertilizers impede efficient farming. Moreover, the harvest can heavily be affected by extreme climate conditions such as overly strong rains and excessive sun irradiance, fungus and insects, or even monkeys and other animals eating up the harvest. All these hurdles are intensified by a difficult access to information and often lacking knowhow in best practices for irrigation and farming as a consequence.

Access to information is obtained by most of the farmers on average via three and up to five different sources. Half of the farmers use governmental agriculture offices and friends and family as source of information. Fellow farmers, the internet, and NGOs are also popular within the surveyed farmers and are used each by four of the participants. Three of the visited farmers are members of TAHA, which constitutes an additional source of information. Furthermore, two other farmers are members of local societies. Media such as radio and TV and extraordinary sources of information such as trade fares are used scarcely by one farmer each. Two farmers rely little on external information and preferably learn by doing – the trial and error approach. Interestingly, many of the customers' neighbours learned about solar water pumps thanks to the newly installed solar water pumps in their neighbourhood. Considering also that the field survey participants rarely knew any another solar water pump supplier besides Simusolar, word-of-mouth recommendation can be of high value – by the end of the field research, two neighbours had purchased a solar water pump as a consequence of their neighbour’s experience.

## 4.3 Farmers’ Perspectives

So far, a general account of the farmers’ situation has been given, which is useful to grasp a holistic picture of the conditions on-site and serves as a baseline for future impact evaluations. Beyond that, a goal of this work is to unveil information on farmer-level regarding the motivation of adopting solar water pumps. This is accomplished by looking closer on the relevant characteristics of water supply systems for the visited farmers as well as on the prevalent purchase drivers.

### 4.3.1 Relevant Characteristics of a Water Supply System

In order to assess the importance of a water supply system’s characteristics, the PRA pair-ranking activity was conducted with each surveyed farmer. Here, the farmers prioritized individually a predefined set of factors, which describe potentially important characteristics of a water supply system. To ensure that no relevant characteristic is left unregarded, the farmers were asked to name the most important qualities of a water supply system according to their experience and understanding prior to conducting the activity. Thus, it was possible to add further factors to the pair-ranking matrix in case they were missing. As already explained in the subchapter 3.2.1, six standard characteristics (Roman numbering) were always considered. Additionally, eight further factors (Arabic numbering) were mentioned by different farmers and taken into account in the respective farmer polling.

i. Low Operational Costs
ii. Low Initial Investment
iii. Possibility to Cultivate Additional Types of Crops
iv. Saving Time
v. Simplicity of Use
vi. System Reliability
7. Independency from Electricity Provider → named by farmer nº 1
8. Independency from Money for Irrigation → named by farmer nº 1
9. Low Maintenance → named by farmer nº 1
10. Paying Only Once for Irrigation → named by farmer nº 1
11. Independency from Seasons → named by farmers nº 2 and nº 6
12. Supplying Sufficient Water → named by farmers nº 3 and nº 6
13. Increased Production → named by farmers nº 6 and nº 8
14. Less Workers Required → named by farmer nº 10

As can be observed when comparing the characteristics, not all of them are independent from each other. For instance, the characteristics i. Low Operational Costs, 8. Independency from Money for Irrigation, and 10. Paying

Only Once for Irrigation are related to each other to some extent. Having low operational costs can yield independency from money for irrigation, same as paying only once for irrigation. A similar case occurs for vi. System Reliability and 9. Low Maintenance, since requiring low maintenance is one of the factors contributing to the reliability of a system. Furthermore, there is also a relation between 11. Independency from Seasons and 12. Supplying Sufficient Water. Only if sufficient water can be provided, independency from seasons can be reached. This on the other hand, can lead to an increased production, which constitutes characteristic number 13.

In addition to the interrelations between the individual characteristics, it has to be kept in mind that the standard characteristics i-vi were considered throughout all farmers, while the characteristics 7-14 were only considered when mentioned by the respective farmer. Therefore, a comparison of the additionally named factors with the standard characteristics is not possible within this work. The importance of the additional factors 7-14 for the farmers, who named them, can be obtained from the respective pair-ranking outcome as presented in Annex F, where the additional characteristics are compared with the standard characteristics. Generally, the fact that the additional factors were explicitly named by a farmer suggests that at least for him/her it is a relevant characteristic. However, this is the sole point of view of the farmer in question.

The obtained results yield some new understandings considering the present assumptions regarding the desired benefits in water supply by smallholder horticulture farmers. So far, low operational costs were understood to be the greatest values added by a solar water pump [8]. However, the reliability of the water supply system is by far the most important characteristic identified by the surveyed farmers. Seven of the 12 farms ranked the reliability of the system into the first position, reaching a mean position of 1.79. Comparing the reliability of the system with the next-ranked characteristic, the overall score is nearly double as high. Such a clear outcome indicates that the reliability of the water supply system is a characteristic that could help promoting solar water pumps, and it should therefore be granted proper attention. However, it is recommended to validate the outcomes of this work with further research with representative groups of participants.

In second place, low operational costs reach a tie with the simplicity of use. Both are factors that are characteristic for solar water pumps and can therefore help increase the interest in them if advertised effectively. However, the reached score by the second-placed characteristics is only one point higher than the forth-placed and less than two points above the fifth-placed. Thus, the ranking of the characteristics apart from the system reliability is equivocal and likely to change with a different set of participants.

*Table 9: Ranking of the system characteristics on a scale of 0-14.*

| Ranking | System Characteristic | Overall Score |
|---|---|---|
| **1** | **System Reliability** | **11.578** |
| **2** | **Low Operational Costs** | **6.573** |
| | **Simplicity of Use** | **6.573** |
| 4 | Possibility to Cultivate Additional Types of Crops | 5.462 |
| 5 | Saving Time | 4.867 |
| 6 | Low Initial Investment | 3.943 |

### 4.3.2 Prevalent Purchase Drivers

While the PRA pair-ranking activity yields a good overview of how farmers envision their optimal water supply system, there might be differences between the farmers’ requirements on a system and the factors they actually consider when it comes to make a purchase decision. In case of the surveyed farmers, all of them had already purchased a solar water pump at the point of the initial visit, even if some did not have yet the pump installed. Therefore, the presented ranking constitutes the farmers’ requirements on a water supply system rather than the purchase decision drivers. This is can be clearly recognised when looking closer on the financial factors.

The operational costs are ranked high in the PRA pair-ranking outcome, but the initial investment is on the last position. This doesn’t fit to the fact that nine of the visited farmers opted for payment by instalments. The three farms that bought the entire system at once were the farming group of farm nº 6, where the financial power of nine group members is added up (moreover, they had taken a bank group loan to prepare the land for farming and to secure a reliable water supply), the school of farm nº 7, which is supported by an affiliated institution, and the farmer from farm nº 5, who apparently is in a financially comfortable situation taking into account that he purchased 20.24 ha of land in the past two years. Moreover, in the PRA flowchart activity, nine participants explicitly named capital as a requirement for reaching their objectives, which is indicative of the importance and the limiting potential of financial factors. Taking all of this into account, it becomes apparent that the initial investment is a major factor for the purchase decision process. The height of the initial investment required will likely determine if a farmer opts to purchase a solar water pump, while other factors such as the reliability of the system, simplicity of use, or operational costs will attract the farmer’s interest in the first place. This observation is in accordance with former findings presented in subchapter 2.3.

Operational and maintenance costs are by themselves a very important characteristic of water supply systems. Besides the high placement of operational costs in the PRA pair-ranking and the explicitly named maintenance needs, the difficulties to properly maintain the system in terms of required knowhow, availability of technicians and spare parts, and the concomitant great costs were named by three of the farmers when asked about the challenges they faced with their former water supply system. Overall, eight farmers were facing challenges to irrigate and farmer nº 10 had even completely put farming on hold since he had no financial resources to ensure proper irrigation. It is clear that financial factors play an important role in purchasing and operating water supply systems. Solar water pumps are on the one hand convenient due to their low operation and maintenance expenditures, on the other hand however, they face a great obstacle due to the high initial investment needed. This is no news (cf. subchapter 2.3), but is once again validated with this research. Simusolar’s financial service and its high uptake within the surveyed farmers show how the obstacle of high acquisition costs can successfully be overcome.

Looking closer on further potential purchase drivers, the categorization approach of smallholder horticulture farmers into six different categories is applied as proposed in the Tanzania Market Snapshot [8] in order to differentiate the farmers according to their main drivers for acquiring a water supply system. Studying the data of over 400 Tanzanian horticulture smallholder farmers, the six categories cost-driven, distribution-reliant, water conscious, effortless, unaware, and technical farmers were proposed. The different categories offer the possibility to address the solar water pump market in diverse, category-specific approaches. This way, more target group tailored, and thus more effective market strategies are possible. [8]

The characteristics of the surveyed farmers of this research were compared with the reference farmer characteristics of each category as stated by the Tanzania Market Snapshot in order to assess the application of the categories for the surveyed farmers. In accordance with the reference characteristics of each farmer category, six questions were developed as to facilitate the categorization. In addition to the six questions, the prioritization of the desired water supply system characteristics resulting from the PRA pair-ranking activity were taken into account.

*Table 10: Farmer categorization matrix with reference values from the Tanzania Market Snapshot [8].*

| | Cost-driven | Distribution-reliant | Water conscious | Effortless | Unaware | Technical |
|---|---|---|---|---|---|---|
| Q1: Which is your current water source for irrigation? | *Hand-dug well (7 m depth)* | *Surface water* | *Surface water* | *Borehole & hand-dug well* | *Surface water* | *Hand-dug well (22 m depth)* |
| Q2: How far from your fields is the water source you use for irrigation? | *272 m* | *463 m* | *811 m* | *157 m* | *157 m* | *157 m* |
| Q3: How much water do you use for irrigation? | *2,216 l/h* | *1,961 l/h* | *3,026 l/h* | *2,453 l/h* | *1870 l/h* | *2,665 l/h* |
| Q4: Which means do you currently use to access the water from your water source? | *Manual* | *Diesel pumps* | *Canals* | *Mechanical, manual* | *Canal* | *Diesel pumps* |
| Q5: Why do you use this means to access the water from your water source? | *Cost* | *Availability* | *Matches the water source* | *Simple, matches target area* | *Known* | *Increasing production, simple, saving costs* |
| Q6: Which source(s) of information do you use to get to know e.g. the latest market prices or newly available technologies for farming? | *Peers, marketing groups, co-operatives* | *Downstream market players (retailers, middlemen, wholesalers)* | *Downstream market players (retailers, middlemen, wholesalers)* | *Government* | *Media* | *Peers, downstream market players (retailers, middlemen and wholesalers)* |
| System characteristics score as weighted in the PRA pair-ranking activity. | *Mean of OPEX & CAPEX* | | | *Mean of saving time & simplicity of use* | | *Mean of reliability of system & increase cultivation* |

While categorizing a market in order to be able to individually address certain groups can be a helpful approach, fitting the surveyed farmers into one category only turned out to be impracticable. A farmer's answers covered at least three different categories, which renders a clear categorization impossible. Moreover, the second question regarding the distance to the field combined with the standard characteristics is an inappropriate tool for categorization at least for the surveyed farmers. The highest encountered distance between water source and field was with 57 m slightly above one third of the lowest reference distance of all categories and therefore doesn't really fit into any of the categories. Similar accounts for the third question of the farmers' water demand for irrigation. Considering the theoretical water demands, no farmer has a demand within the range of 1,870 l/h and 3,026 l/h as provided by the reference characteristics. All farmers account for water demands of above

5,000 l/h assuming a daily pump operating time of 12 hours. This raises the question whether the distance between water source and field as well as the water demand for irrigation is actually an appropriate indicator for any of the proposed categories. The given range by the reference characteristics is too narrow and the differences within the different categories too small taking into consideration the characteristics of the surveyed farmers. However, no well-founded conclusion can be drawn on this regard due to the low number of farmers considered in this work.

However, it is possible to determine a farmer's correlation with the different categories. The reference characteristics as presented in the Tanzania Market Snapshot come along with corresponding correlation factors, which indicate the significance of the factor in question. These correlation factors range from zero to one and can be used to weight the characteristics of assessed farmers in order to be able to categorize them more accurately. Thus, it can be observed that some questions are of more importance than others. Interestingly, the categories can be identified with varying accuracy. While the correlation values of the cost-driven and water conscious categories reach a remarkable average of 0.83, the effortless and unaware categories have a very low average correlation value of around 0.5. The technical and distribution-reliant categories lie in-between with average correlation values of 0.62 and 0.67, respectively. Overall, this means that especially the categorization in the effortless and unaware categories has to be viewed with care.

Taking into account the given correlation factors of each reference characteristic and leaving out questions two and three for the reasons stated before, the correlations as shown in Table 11 are obtained. Within the surveyed farmers of this work, five highly correlate with the distribution-reliant category and three each with the cost-driven and the technical categories. Taking into account the secondary correlation, another three farmers can be numbered among the distribution-reliant category. Four farmers are attributed to the technical, three to the effortless, and two to the cost-driven categories. When considering also the tertiary correlation, three additional farmers each are numbered among the cost-driven, effortless, and technical categories as well as one each among the distribution reliant and the water conscious categories.

*Table 11: Farmers' correlation to the purchase driver categories from the Tanzania Market Snapshot.*

| Farmer | Main Correlation | Secondary Correlation | Tertiary Correlation | Relative Difference | |
|---|---|---|---|---|---|
| | | | | 1st/2nd | 2nd/3rd |
| 1 | *Cost-driven* | *Distribution-reliant* | *Effortless* | ✓ *57%* | ✓ *21%* |
| 2 | *Cost-driven* | *Effortless* | *Technical* | ✗ *7%* | ✗ *3%* |
| 3 | *Distribution-reliant* | *Technical* | *Water conscious* | ✗ *9%* | ✓ *64%* |
| 4 | *Distribution-reliant* | *Technical* | *Effortless* | ! *11%* | ✗ *2%* |
| 5 | *Cost-driven* | *Effortless* | *Technical* | ✗ *3%* | ! *10%* |
| 6 | *Effortless* | *Cost-driven* | *Technical* | ! *10%* | ! *19%* |
| 7 | *Technical* | *Distribution-reliant* | *Effortless* | ✗ *1%* | ✓ *33%* |
| 8 | *Technical* | *Distribution-reliant* | *Effortless* | ✓ *22%* | ✓ *21%* |
| 9 | *Technical* | *Cost-driven* | *Distribution-reliant* | ! *17%* | ! *10%* |
| 10 | *Distribution-reliant* | *Technical* | *Cost-driven* | ✓ *29%* | ✓ *26%* |
| 11 | *Distribution-reliant* | *Technical* | *Cost-driven* | ✓ *37%* | ✓ *30%* |
| 12 | *Distribution-reliant* | *Effortless* | *Cost-driven* | ✓ *31%* | ✗ *6%* |

Overall the technical category is the most frequently featured with a total of ten out of 12 farmers, which shows that the farmers surveyed have a clear objective of increasing their productivity by switching to a reliable water supply technology. The distribution-reliant category follows with nine farmers but with a greater appearance as main category and with 23% a greater relative difference to the secondary category as compared to the technical category (13%). Thus, the distribution-reliant category is assessed to be of slightly higher relevance as the technical category within the surveyed farmers (cf. Table 12), which highlights the importance of the distribution channels in place. The farmers' dependence on existent suppliers and their product portfolio is again affirmed when taking into account that only four farmers knew any other solar water pump supplier besides Simusolar. Nevertheless, the importance of financial factors as well as their limiting impact needs to be kept in mind, considering that the cost-driven category reaches third place with a total of eight farmers. The effortless category is also noticeably represented within the surveyed farmers, however the relevance of this category is ambiguous due to the low correlation values of its reference characteristics. Moreover, it is noteworthy that the representation of the water conscious category is very low with only one farmer tertiary correlated to it. In future applications of the Tanzania Market Snapshot categories, it should be observed if this occurs repeatedly, and if so the definition of the category should be reviewed to assess its relevance. The low correlation of the surveyed farmers with the unaware category (missing in the top-three ranking) makes sense considering that the surveyed farmers all managed to acquire the information regarding solar water pumps and have acquired one.

Looking on the relative difference between the primary and secondary as well as between the secondary and tertiary correlation (cf. Table 11), it becomes obvious that the number of relevant categories for each farm varies significantly. While for some farmers (e.g. farmer nº 1 or farmer nº 11) the correlation with the primary category is significantly higher than the correlation with the secondary or tertiary category, other farmers (farmers nº2, nº 4, or nº 5) show very similar correlation levels for the three main categories. When addressing individual farmers, it might therefore be necessary to consider one, two, or more categories depending on the correlation characteristics of each farmer, combining the strategies proposed in the Tanzania Market Snapshot [8]. Especially when a farmer is attributed to the effortless or unaware categories, it is important to consider further categories due to the low classification accuracy of these two categories.

Comparing the rankings for the surveyed farmers of the water supply system's most important characteristics and of the purchase drivers according to Tanzania Market Snapshot categorization approach as done in Table 12, a similar weighting can be observed. Besides the distribution-reliant and unaware categories, the remaining categories can all be associated to corresponding system characteristics, and therefore their respective weightings can be compared. When disregarding the distribution-reliant category (no linkage with any system characteristic), the technical category is ranked first, same as the corresponding characteristics combined (system reliability and possibility of cultivating additional types of crops). Low operational costs and low initial investments combined are ranked after the combination of simplicity of use and saving time, resulting in an inverted order compared to the equivalent cost-driven and effortless categories. Overall, the similar rankings indicate that relevant system characteristics are connected to prevalent purchase drivers. However, purchase drivers go beyond a farmer's valued characteristics and are prioritized slightly different.

*Table 12: Comparison of the rankings of the system characteristics and the purchase drivers.*

| Relative Score | System Characteristic | Purchase driver category | Relative Score |
|---|---|---|---|
| ***100.0%*** | ***System reliability*** | ***Distribution-reliant*** | ***100.0%*** |
| ***56.8%*** | ***Low operational costs*** | ***Technical*** | ***99.2%*** |
| ***56.8%*** | ***Simplicity of use*** | ***Cost-driven*** | ***80.7%*** |
| *47.2%* | *Possibility to cultivate additional types of crops* | *Effortless* | *68.1%* |
| *42.0%* | *Saving time* | *Unaware* | *23.7%* |
| *34.1%* | *Low initial investment* | *Water conscious* | *18.2%* |

### 4.3.3 Relevance of Solar Water Pumps

During the PRA flowchart activity, the relevance of solar water pumps for the farmers was outlined very clearly. The goal of the PRA flowchart was to retain the farmer's objectives as well as what the farmers assume to require in order to reach their goals. As can be observed in the 14 created flowcharts attached in Annex G, solar water pumps were explicitly named in 12 cases as one of the requirements – the remaining two participants more generically stated "water" and "proper infrastructure", in both cases including irrigation. Naturally, this also includes the water supply system and thus their solar water pumps. Five of the farmers went even further and detailed how the solar water pump is supposed to assist them in reaching their aims. They expect the pump to help them reduce their need of fuel and/or workforce and thereby reduce their expenses. They named the solar water pump the "critical point" (flowchart nº 6.1) and a "multiplier" (flowchart nº 2.1) when aiming to reach community learning and prosperity. This is a direct indicator of the importance that solar water pumps can have within smallholder farmers' undertakings and should be utilized to raise awareness and promote the technology. Moreover, taking into account the characteristics of solar water pumps as presented in the subchapter 2.3, the PRA flowcharts also show that many of the solar water pump characteristics are of importance to farmers. For a start, 12 participants stated sufficient water supply as a requirement to achieve their goals. While a satisfactory water supply can also be reached by other means than a solar water pump, potential alternatives face limitations, which don't exist for solar water pumps. In regard of mechanical and manual pumps, the amount of water supplied depends on the manpower and time available. The need to assign manpower and time for water supply limits automatically the farming activities, which can be pursued by the respective farmer. The other alternatives as fuel or electric pumps don't draw manpower or time resource, however the amount of water supplied is limited by the amount of energy (electricity or fuel), which can be purchased by the farmer. Thus, a properly designed solar water pump is more likely to reliably provide a sufficient water supply. In point of fact, reliability is a challenge mentioned by seven participants in their flowcharts, while another four farmers explicitly aim to reduce costs to reach their goals. The PRA flowcharts are thus verifying the outcome of the PRA pair-ranking activity, where reliability was identified as prime factor followed by low operational costs and simplicity of use, and indicate the importance solar water pumps can bear for smallholder horticulture farmers.

## 4.4 Adoption Barriers

Besides the high potential of solar water pumps, the field trials unveiled many difficulties in satisfying the needs of solar water pump purchasers. By the end of the field trials, only one participant (farm nº 8) had been using his solar water pump for an extended period of time without facing any challenges. Two other (farm nº 12, farm nº 7) faced minor issues but were also able to operate satisfactorily their solar water pumps for an extended period of time. All the other participants faced diverse challenges in obtaining and operating their solar water pumps as well as in ensuring sufficient irrigation for their farming activities. Since the obstacles encountered surpass by far the expected difficulties, the following subchapter elaborates this further.

### 4.4.1 Main Early-State Challenges

Challenges in logistics were the most prominent to be observed. They mainly originate in the immense area of Tanzania and the limited amount of Simusolar branch offices, leading to great areas that each branch office has to cover. Of the surveyed farmers, the closest one is located 43 km from a Simusolar office, the furthermost one lies 276 km from a local branch. Simusolar staff has to travel on average 129.75 km to reach their customers. Taking into consideration that only three farms are situated directly next to a paved road (another four lie less than 5 km from a paved road) and that distances of up to 80 km have to be covered on unpaved roads, the accessibility of customers is a big challenge for Tanzania's smallholder farmer market. The fact that two potential farmers were left out of this work due to non-accessibility of the farm highlights the severity of this obstacle (during the rainy season plenty of unpaved roads become impassable even with all-wheel vehicles, cf. Figure 14). Moreover, some areas of the country suffer from heavy flooding during and after the rainy season, as can be seen in Figure 14.

*Figure 14: Left: Impassable unpaved road after the rainy season. Right: Flooded area surrounding farm nº 10. (Both in the Northern Highlands, Tanzania. June 2019)*

The long distances to the customers are reflected on the service delivered. Since the staff tries to optimize the travelling time and distance in order to keep expenses down, they might be urged to carry out tasks fast and under stress as to prevent a second journey to the same customer, which potentially leads to lesser-quality service. Moreover, farmers might have to wait until nearby customers have also to be visited in order to get their solar water pump system installed, maintained, or repaired. However, instalments and repairs of solar water pumps are usually time-critical due to the importance of irrigation (and consequently of a functioning water

supply system) for farming as long as there are no rains. Thus, the customers' happiness and the reputation of solar water pumps is highly dependent on the quickness of response to malfunctions.
The speed of response relies furthermore on the availability of spare parts and the system's individual components. While most of the spare parts and components can be purchased in the main Tanzanian cities (Dar es Salaam, Mwanza, and Arusha) and to a lesser degree or for significantly higher prices in other cities (Morogoro, Dodoma, and Singida), the pumps as core components of the system have without exception to be imported. Thus, their availability depends on the companies' stock management and the response time to replenish stocks reaches weeks. In order to handle bottlenecks in pump availability, the observed solution was to offer the customer in question to deploy another type of pump until the ordered pump is available. This way, the consequences for the customers are mitigated.

Apart from logistics, great challenges were observed in terms of need assessment and the subsequent design of the solar water pump system. First and foremost, assessing the farmers' needs is a highly challenging task since even the farmers themselves often don't know accurately enough what they need. This is most apparent when it comes to the water needs. Five of the visited farmers had no notion about their water demand for irrigation, and one additional farmer only irrigated the seedlings and didn't know how much water irrigating the whole farm would require. For the four experienced farmers with an estimation of their water needs, the theoretical water needs accounts to 220% of the farmers' estimates, while unexperienced farmers estimated their water requirements five times lower than the theoretical values.
Besides of the amount of water required, four farmers struggled to irrigate the entire farm with their new solar water pump due to insufficient reach. The pump's power turned out to be insufficient to overcome the total dynamic head increased by the use of a drip irrigation system (which was the case in three farms) or flooding irrigation method (one farm). Here, a more tailored technical solution is required, where the specific conditions of the farm in question are taken into account. Of these four farmers, three needed to enhance their systems with additional panels (another farmer also needed additional panels), while the forth farmer is still using his fuel pump to pump the water from a pond he uses as water storage to the drip irrigation system. Summarizing, the initially installed systems of five of the 12 visited farmers did not satisfy the customer's needs. Moreover, another three farmers had just started using the solar water pump system at the end of the field trials while two more farmers had not received their system at all due to missing payments by TAHA (TAHA supported farms nº 10 and nº 11). For these five farmers, it is not possible to draw any conclusion on the suitability of the designed system. In terms of installation, it was also observed that the solar panels were not always located and/or oriented ideally in order to maximize their power output. In a few cases, the solar modules were installed in locations where they would be shaded during some parts of the day. Moreover, the ideal orientation of the modules (north, approx. 5° inclination [91]) was rarely complied with, thus debilitating the systems' performance. In order to overcome these challenges in assessing the farmers' needs and properly designing and installing the solar water pump systems, it is advisable to deploy technically trained staff (engineers or especially trained technicians), who know how to assess a farmer's needs and subsequently find the best technical solution. Once the best technical solution is known, the technical experts can discuss with the sales officers and/or the customer

how the final system should look like in order to find a compromise of technical optimisation, economic optimum, and customer satisfaction.

Also worth mentioning is that Simusolar limits its service to the pump, the solar PV panels, and required BOS – no storage of any kind is provided. Half of the visited farmers already owned water storage tanks, all the other had to purchase storage tanks by themselves, which per se is no drawback. However, the farmers might lack the required knowhow to acquire a suitable storage system and install it properly, which can then lead to water supply shortages and discontent with the purchased solar water pump system. Two of the visited farmers expressed their discontent of receiving no support in setting up a suitable water storage system.

Beyond logistic and technical challenges, difficulties in communicating with the customers were encountered throughout the field trials in all surveyed regions. The difficulties can be ascribed to misunderstandings, insufficient information conveyed, or even untruthful statements given. Latter was the case with one sales officer only, who solely took interest in acquiring new customers and would therefore sacrifice the service rendered by raising unsustainable expectations and spreading misinformation on a system's potential performance. This affirms the need of qualified – and trustworthy – staff. Deploying both technical experts and sales officers would drastically decrease the risk of misinforming customers.

Although the farmers when asked assured to have been informed adequately about their solar water pump system both in terms of operation and maintenance, it was observed that their understanding was at least partly deficient. The struggles of farm nº 9 with their system is one clear example. In order to secure the PV modules against theft, the customer enclosed his PV arrays with massive frames, which also covered a small stripe of PV cells on all four module edges as shown in Figure 15. Combined with significant dirtiness of the modules, the created shade caused the system to fail working in an intermittent way, as if it had a loose contact. After rearranging the frame in a way that it wouldn't shade the PV cells anymore, the issue was successfully solved.

*Figure 15: Partially shaded, dirty PV modules in the Northern Highlands, Tanzania. April 2019.*

Misunderstandings between customers and sales officers were observed several times. Exempli gratia, farmer nº 11 was frustrated because the installation of his solar water pump system was delayed (it did not happen throughout the duration of the field trials) although he had finished all required preliminary work. Expecting to get his new system, the farmer had created a barricade along the river bordering his farmland in order to prevent the river to flood his farm and impede the installation of the solar water pump system. In order to proceed with the installation however, TAHA had to pay the deposit as agreed between farmer, TAHA, and Simusolar. Until the end of the field trial, no payment by TAHA happened, and thus Simusolar was not able to install the system. The farmer however was not aware of the missing payment and believed that the heavy floods in the surrounding area – although his farm was saved from flooding thanks to the barricades – were the reason for Simusolar not arriving for the installation. Had he known about the actual reason, he might have been able to contribute in finding a solution or at least renounce from creating the barricades in order to allow the floods to water his farm. Overall, proper communication is an essential factor to prevent solar water pumps providers to gain discredit and therewith hamper the spread of solar water pumps.

Last but not least, the security of the system's components is a matter that should not be underrated. Most farmers are aware of the risk of theft and secure the equipment as done in farm nº 9 and by enclosing the borehole with brickwork and a locked trapdoor. In farm nº 2, the only measure taken was to deploy a security man to mount guard over the solar water pump. As a consequence, the pump got stolen when the security man was absent for a short while – luckily, the farmer managed to recover the pump. For farm nº 3, a submersible solar water pump was used in a river without any diversion to protect the pump from the river's currents and instead fixed with a rope. However, during the rainy season the river level and the current intensity increased that much that the rope broke and the pump got flooded away.

### 4.4.2 Insights into the Field Work

Concluding the presentation of the identified adoption barriers for solar water pumps, a detailed account on the individual experience of two different farmers is given. This storytelling is meant to provide a deeper comprehension of the challenges to provide satisfactory service with solar water pump systems.

Farm nº 3 lies directly at the paved road south of Morogoro, close to Mikumi. On the way to another customer, Simusolar sales officers were thus able to spot several solar modules on his main house's roof, which remained there unused after the farmer's failed attempt to set up a solar water pump system by himself. The PV modules raised the curiosity of the sales officers, and a short visit revealed that the farmer's fuel pump had broken down three months earlier and that the farmer was thus expecting farming losses without having any irrigation possibility left. A short demonstration of the pump's capability reassured the farmer that the products delivered by Simusolar do actually work. Due to the urgency of his case, the farmer pushed Simusolar to install the system as soon as possible even before signing any contract. In rural Tanzania, it is common to close business deals only with a handshake and without any written agreement. Thus, when contracts are required by one party, they are often signed without thorough reading and without understanding all sections of the contract – an incident, which also happened in this case.

The solar water pump system was then installed as proposed by the sales officer, placing a submersible pump in the middle of the river only fixed by a rope to a nearby tree as shown in Figure 16. Also, the sales officers refused to integrate the farmer's own solar modules in the system since Simusolar was only offering standard packages back then and including external solar modules would compromise the company's two-year warranty on their systems. The standard package with three solar modules barely delivered enough power to irrigate the entire farm, but in order to include a forth module the farmer was asked to pay for it separately. Due to his limiting financial situation, he refused to pay for the additional panel outside of the agreed payment plan for the standard system. Instead, he reinforced his request to utilize his own solar modules. After conferring with its management, Simusolar agreed to check the unused solar modules for usability and in case of a positive result to integrate the farmer's modules in the system.

*Figure 16: The submersible pump lying in the river is only fixed with the yellow rope in Morogoro region, Tanzania. April 2019.*

Before the modules could be checked, the rainy season arrived increasing the river level and the current intensity thus flooding the farmer's newly acquired pump away. This generated new disputes putting the plans of checking the old panels on hold. While according to the terms of contract the equipment's security lies within the responsibility of the farmer, farmer nº 3 entirely relied on the experience and knowhow of the deployed staff. The farmer's doubts on the adequacy of the pump's mounting were ranked as irrelevant and neglected by the staff responsible. After this event and due to the farmer's missing understanding of the contract details and Simusolar's guidelines, his trust in Simusolar's credibility was debilitated and he altered his conduct starting to accuse Simusolar and threatening the staff to a point that they felt unsafe returning to the farm. On the other hand, the staff failed to recognise the lack in understanding on the farmer's side making mediation necessary. Only after making the farmer understand Simusolar's limited manoeuvring room and reinitiating communication between both parties, Simusolar agreed on compromising and disregarded the liabilities as appointed in the contract to the farmer's benefit due to their deficient service of properly installing the solar water pump and agreed on providing the farmer with a new pump under exceptional terms.

At farm nº 9, the installation had to be postponed after the technician realized on arrival that the structure for the solar modules did not provide sufficient space for all modules. It was missed to inform the farmer how much space was required for the instalment of the solar modules. Thus, the system's installation was delayed by shortly over a week until the farmer had constructed a new structure for the installation of the solar modules. Once the installation was concluded and the technicians had left, the farmer proceeded to securing the solar modules with an iron frame to prevent theft. As already mentioned, the additional framed shaded the edges of the PV cells impairing the system's ability to operate. Although the source of malfunction was easy to resolve, the farmer had to wait for a couple of days until the branch's technician was in the neighbourhood for another customer due to the relevant distance from the local branch to the farm of more than 100 km.

Once the system was properly set up and working, the farmer realized that the power was not sufficient to reach the entire farm. Due to the existence of monkeys nearby the water source that eat up the crops cultivated significantly decreasing the harvest, the farmer opted to mainly cultivate the opposite-located farmland. Reaching the far off farmland with earth canals, which are used by the farmer for flooding irrigation, requires considerable power that the installed solar system was not able to deliver. Thus, the farmer changed his farming habits and started creating more narrow canals, which were able to reach a great rate of the farm. Nevertheless, the farmer realized that he might need to change to a more efficient irrigation method in order to be able to optimize the usage of the solar water pump system but was struggling to obtain information. Moreover, the farmer faced struggles irrigating with the solar system due to the cloudy climate at this time of the year. The fact that he lacked any water storage only complicated the situation further. By the time of the end-line visit, the farmer had purchased a water storage tank of 10,000 l capacity and was about to install the tank. However, he was concerned about the limited potential to store water to overcome cloudy weather periods. Also, he was missing knowhow on how to best install the water storage tank and was not aware of the necessity to set up the storage at a minimum height in order to assure a minimum reach of the water and render redundant an additional pump between storage and farmland.

## 4.5 Impact Evaluation

The farmers' experience with solar water pumps was very diverse as is evident from the information presented so far. In order to provide a holistic overview and showcase potential benefits of solar water pumps, an impact evaluation following the logical model of the results staircase developed in subchapter 3.1 is conducted. The developed results staircase covers a large period of time of several years until the potential impact is reached. However, the duration of the field trials, which accounts up to 12 weeks after the installation of the solar water pump systems, should be sufficient to experience the achievement of at least the first two steps, which are expected to be reached within the first month after the system's installation. Furthermore, steps three and four are expected to be realized within two to three and two to six months after installation, respectively and could therefore be observed during the field trials as well.

Recapping, the service provided by Simusolar to the visited customers comprises inputs ① - ③, namely the solar water pump system itself combined with the option of payment by instalments (financial service) and necessary knowhow in operation and maintenance of the solar water pump system. Step 1 of the staircase "Farmer has a new water supply system" constitutes that the inputs were actually delivered to the customers. This was not the case for all the customers visited. While farm nº 10 and farm nº 11 were not yet provided with a solar water pump system by the end of the field trials as explained in subchapter 4.4.1, farm nº 2 only partially reached Step 1. While the customer's payment by instalment was already in place, the system's components were delivered, and the customer was informed on how to properly operate the system, Simusolar was unable to complete the instalment of the system due to the inadequacy of the borehole in question and the need to secure an appropriate water source as explained earlier. Apart from farm nº 10, farm nº 11, and partially farm nº 2, all remaining customers managed to reach Step 1 within the duration of the field trials.

In Step 2, the customers are supposed to be using the installed systems in a proper way, meaning that they are efficiently using their solar water pump systems, that if applicable they make use of the financial service offered, and that they have a proper understanding of their solar water pump system and are maintaining it correctly. Most of the customers that had previously reached Step 1 managed to properly use and maintain their system identifying potential to optimize its usage. Thanks to the simplicity of use of solar water pumps, the only encountered obstacle to efficiently use the system was a deficient installation of the system as discussed in the subchapter 4.4.1. This was the case for the farms nº 1, and farm nº 3. At the end of the field trials, the system on farm nº 1 was not operating properly due to the orientation of the solar modules, which were facing west and were thereby unable to properly collect the solar energy in the mornings and thus maximize the energy provided for running the solar water pump. The situation at farm nº 3, where the pump got flushed away, was extensively presented in subchapter 4.4.2. The remaining customers of the farms nº 4, nº 5, nº 6, nº 7, nº 8, nº 9, and nº 12 were all able to properly use and maintain their systems. Only farm nº 9 has to be singled out here due to temporary improper maintenance. Simusolar had maintained contact with the farm owner only, who was informed about the proper use and maintenance of solar water pumps. However, he didn’t pass on the information to the farm manager, who was the one in charge of operating and maintaining the system. This had no consequences on the operation of the system due to its simplicity of use, but proper maintenance could not be upheld. This is why dirty solar modules were observed at farm nº 9 during the midline round (cf. Figure 15). By the end of the field trials however, also the farm manager knew how to properly maintain the system. Moreover, he had realized that he needed to add a water storage tank in order to optimize his usage of the solar water system – similarly, farmer nº 12 realized that changing from using a pond as water storage to an elevated tank would improve his water supply system by making an additional fuel pump redundant.

Reaching Step 3 goes along with being satisfied with the services provided. Achieving this already proved to be a hurdle for the customers visited. While customers nº 1, nº 2, nº 3, nº 4, nº 10, and nº 11 didn’t manage to efficiently use their system (if existent) and thus naturally were unsatisfied at the end of the field trials, also customer nº 9 was not entirely satisfied. As mentioned earlier, his system was not able to supply the entire farm with water due to the limited power of the system and the irrigation method used. Yet, he started adapting his irrigation practices by using more narrow canals, which allowed him to increase the reach of the system, and by starting to enhance the system with an elevated water storage tank that he purchased shortly before the end-line visit. This is remarkable, since he was thus partly accomplishing Step 4 (adapting his farming activities) without having completely reached Step 3. Customers nº 4, nº 5, nº 6, and nº 12 weren’t completely satisfied with their received services by the end of the field trials either. Farmer nº 4 just got his system upgraded with additional five panels one day after the end-line visit. His initially installed solar system did not match his needs – the outcome of the unreliable sales officer as explained in subchapter 4.4.1. Thus, while he had operated the initial system for several weeks cultivating a reduced area of his farm, he was not able to assess the upgraded system yet. Similar accounted for farmers nº 5 and nº 6, who were only farming for around one week and thus not operating the pumps long enough to be able to evaluate their performance. Customer nº 12 on the other hand was using his system for ten weeks, but failed to be fully satisfied due to the water storage in place, which impeded him to get completely rid of his fuel pump since he required it to pump the water from the pond to the farmland. Only customers nº 7 and nº 8 were entirely satisfied with their services received by the end of their field trials. They were both able to supply sufficient water for their current activities, were happy with the payment by instalments and had realistic expectations on their opportunities with the solar water pump system. Farm nº 7 for instance knew that they would need additional solar modules in order to be able to expand their irrigation activities or to decrease the impact of cloudy periods on their water supply security.

Evaluating if these two farmers had managed to reach Step 4 was not possible within this field research. In order to assess whether the farmers are cultivating more efficiently and reliably, it is necessary to observe an entire season from sowing to harvesting. The time available proved to not be enough to conduct such an assessment. Farmer nº 8 was just starting harvesting and had no final yield yet, which could have been assessed. At farm nº 7, harvesting had not yet started at the point of the end-line visit. Taking into account that the initial visit only rarely coincided with the crops' sowing and that the growing period of the crops encountered lasts in average 19 weeks (calculated based on the data available in the Water Requirement Tool [86]), it is no surprise that more time is required in order to monitor an entire season.

Overall, the progress achieved on the results staircase varied highly within the visited customers (cf. Table 13) – some completing the entire output scope, while others not even reaching the first step. This short assessment showcases how the theory of change can be applied to structurally highlighting the level of impact reached once a coherent logical model is developed. It cannot yield any outlooks on the probability to reach the impact level with the input given at this early point of the journey, but it validates the logical model itself so far showing that the customers step by step manage to advance on the results staircase. However, the further the participants progress on the staircase, the more difficult it becomes to judge their progress and ascribe it to specific inputs taking into account that the influence of external factors increases as the staircase is being climbed. The indicators proposed for the more advanced steps of the staircase affirm this.

*Table 13: Farmers' progress on the results staircase (cf. Table 2).*

| Results Staircase Steps | Customers' Progress |
|---:|:---:|
| - | *Farmers nº 2, nº 10, nº 11* |
| **STEP 1**<br>**Farmer has a new water supply system** | *Farmers nº 1, nº 3* |
| **STEP 2**<br>**Farmer uses the installed system in a proper way** | *Farmers nº 4, nº 5, nº 6, nº 9, nº 12* |
| **STEP 3**<br>**Farmer is satisfied with the new water supply technology** | *Farmers nº 7, nº 8* |
| **STEP 4**<br>**Farmer cultivates more efficiently and reliably** | --- |
| **STEP 5**<br>**Farmer expands his/her activities and generates higher income** | --- |
| **STEP 6**<br>**Farmer's socioeconomic situation improves** | --- |
| **STEP 7**<br>**Rural prosperity at community level** | --- |

# CHAPTER 5 – OUTLOOK

This work represents only one step towards a better understanding of Tanzanian's smallholder horticulture market and its penetration by solar water pumps. In order to progress further, the findings presented in this work have to be verified and validated by research with representative participant pools, and more information has to be acquired e.g. on the farmers' financial characteristics. Solutions have to be found on how to successfully approach financial limited and less educated farmers. As this work has shown, the greater share of reached costumers tend to have an in varying degrees financial stability and be privileged to obtain higher education. Moreover, the initiated impact evaluation should be completed in order to verify assumptions on solar water pumps' potentials and enable better understanding of the logical connections presented in the theory of change model and potentially add missing interrelations. Also, the risks of deploying solar water pumps have to be analysed thoroughly.

## 5.1 Future Completion of Impact Evaluation

Within this work, the farmers' experience was only monitored at most until reaching step three of the results staircase – the available time frame for the field research constituting the main limiting reason. A continuation of the impact evaluation would show how solar pumps affect a farmer's development on the long term and validate the focus set on progressing their deployment. Thus, solar water pump suppliers would be able to better address the market having an improved understanding of the value of their service and thereby being able to increasingly attract investments. Moreover, the local and national administrations could set appropriate policies according to the revealed relevance of the technology in order to facilitate its wide-ranging adoption among others by enhancing the public awareness. As displayed in this work, the outreach of local governmental agriculture offices is remarkable.

In order to complete the impact evaluation, it is proposed to conduct at the very least a final survey of the visited farmers in two years' time, if rated feasible preferably after five years. Thus, an as advanced progress on the results staircase as possible can be observed. Additionally, a precedent survey after one or one and a half years would be advisable to assure that the envisaged progress is taking place and that a final survey after five years' time can actually deliver relevant outputs. Moreover, the precedent study itself can already provide useful information, which can be used to improve market strategies, to increase the authorities' interest in promoting solar water pumps, and also to optimize and/or expand the services provided by solar water pump suppliers.

PHINEO's Social Impact Navigator [77] is a recommendable guidance for conducting impact evaluations. The results staircase used in this work was developed following the navigator's instructions. Complemented with the PRA approach for field surveying and the researcher's own experience, the results presented in this work were obtained. It is recommended to follow a similar procedure for conducting the field research for completion of the impact evaluation in order to assure comparability of the respective survey results. This implies that the survey plans presented in subchapter 3.2 can be adapted to serve as guidance for the final or the precedent surveys. As outlined by the changes implemented on the field however, they do not represent optimal survey plans and should therefore be enhanced by discarding abortive activities such as the timeline for water consumption and complementing the survey with missing activities. Among others, the farmers' vicinities and communities should receive an increased attention in order to be able to make observation of the impact on community level (step seven of the results staircase). Generally, it has to be kept in mind that PRA methods can only be used effectively when sufficient time is allocated for the field research. When taking up a significant amount of somebody's time, showing one's appreciation is vital e.g. by supporting the participant with one's knowhow and network. Beyond this, it is advisable to adapt standard methods to the preferences of both the researcher and the participants, by e.g. keeping the schedule flexible and using flipcharts and markers.

As was experienced during this field trials, learning about the farmers' usage of the solar water pump system can turn out to be challenging or even impossible when looking back over an extended period of time. Thus, it is advisable to deploy water meters on the farms in question as early as possible in order to be able to obtain information on the operation details of each system over a relevant time period. The information should include the daily amount of water delivered as well as the daily operating time of the system. During this field trials, basic water meters were installed in four of the visited farms. However, basic water meters can only provide daily values if read daily – a non-realistic demand – and provide no information at all on the system's operating time. If the PV controller tracks and transmits or stores information on the electricity production throughout each day, the data from basic water meters and PV controllers can be combined delivering the desired information on the usage of solar water pumps. Does the PV controller lack the property of tracking and transmitting or storing electricity production data, smart water meters have to be deployed in order to collect the desired information. While smart meters have most probably to be imported to Tanzania due to their limited availability within the country and come at higher costs, the increased cost are acceptable taking into account the total expenses related to field research (cf. Annex A) and the additional value provided by the smart meters. Moreover, it is essential that the personnel conducting the field survey possesses required knowledge and experience in agriculture and field research. Understanding of the local culture and language as well as experience in navigating in rural areas are indispensable. Last but not least, basic knowledge on solar water pumps and related engineering disciplines should be existent. Appointing a local interpreter as done for this field trials is rated an acceptable solution if no local experts in field research and agriculture can be found.

Furthermore, additional sources of information beyond the farmers themselves should be sought, such as the company providing the service, NGO's or local societies that are active in the area in question, and also governmental entities like the local agriculture offices. This way, the information obtained by the participants can be verified and completed gaining a holistic picture of the development achieved and the role of solar water pumps therein.

## 5.2 Further Research

Besides completing the impact evaluation started with this work, further research is necessary to provide a proper understanding of Tanzania's smallholder horticulture market and how to best promote the widespread adoption of solar water pumps. Firstly, the findings presented within this work need verification and validation by research with representative participant pools. Most importantly, the relevance of identified challenges such as the quality of the water source, deficient initial designs of solar water pump systems, and insufficient briefing of customers have to be assessed. Equally, the diverse reasons for not fully exploiting the farmland require a reliable weighting. Regarding the farmers' sources of information, the apparent popularity of governmental agriculture offices and the seemingly irrelevance of media need verification. With that, the relevance of word-of-mouth recommendation should be assessed in detail. In view of the surmise that well-educated farmers are more easily reached, an assessment of the farmers' varying education level and experience along with their farming objective (main/secondary source of income, retirement plan) can potentially facilitate a more target-group-specific customer approach. The target-group-specific approach according to the categories proposed in the Tanzania Market Snapshot, is an alternative that should also be validated.

Furthermore, topics not addressed in this work have to be explored. Above all, the risk of groundwater depletion as encountered in India and Morocco (cf. subchapter 2.3) should be assessed and appropriate measures identified. As solar water pumps are increasingly deployed, a greater exploitation of groundwater is to be expected. Appropriate measures could include for instance usage patterns of solar water pumps, which guarantee a sustainable utilization of groundwater combined with a maximum amount of groundwater pumps in a specific area. To understand a region's groundwater aquifer configuration, which is key to determine sustainable groundwater use, extensive studies are needed that lied beyond the scope of this work. Another open question not addressed regards the costs a solar water pump supplier faces to acquire a new customer. This information would deliver valuable insights and enable an easier access to the market for new market players, which by increasing the competition would progress the adoption of solar water pumps.

# CHAPTER 6 – CONCLUSION

Aiming to promote the struggling spread of solar water pumps for irrigation purposes in Tanzania, this work carries on the research initiated by the Tanzania Market Snapshot from the Efficiency for Access Coalition [8] aiming to validate prior findings and surface new information. In particular, the farmers' needs and their expectations on their water supply system, the relevance of financial factors, potential benefits offered by solar water pumps as well as the barriers for their optimal utilization were assessed. Therefore, field research was conducted surveying 12 smallholder horticulture farmers spread throughout Tanzania and accompanying them during the period of approximately three months on their experience of adopting solar water pumps with two to three time-displaced visits. The field research was conducted applying participatory rural appraisal methodology and implementing the theory of change on the deployment of solar water pumps aiming for rural community prosperity following PHINEO's Social Impact Navigator [77], which delivered a logical model that serves as guidance for impact evaluations.

The participants of the field surveys were all new Simusolar customers and were either farming as main or secondary source of income, or started farming as a retirement plan. Their farming experience and their level of education varied highly from primary school to university. All participants had at least one additional source of income and reached overall a mean income of 23 million TZS per year – corresponding to approximately 10,000 USD [90] – while facing average expenditures of nearly 22 million TZS. The operation costs of the farmers' former water supply system (mostly fuel-powered pumps were used) reached an average of 36% of their total expenditures. On the other hand, the acquisition costs of the solar water pump systems in question amounted to an average of 42% of the farmers' yearly income. Consequently, only two farmers opted to purchase the system with one single payment, while the remaining made use of Simusolar's financial service and chose payment by instalments. All visited farmers acquired solar water pumps due to struggles to properly irrigate their farmland with their former system. Moreover, the visited farmers encountered further significant farming challenges. Besides expectable struggles (pests and wild animals degrading the harvest; extreme weather conditions; generally unreliable climate), the market constituted a major limitation in terms of yielding proper revenue and in terms of acquiring quality agriculture inputs. The farmers identified value-adding processing of their produce (e.g. by milling or packaging) as a possibility to yield higher prices, and reported the need of adequate mobility in order to be able to reach an increased market and hold greater flexibility. Furthermore, it was observed that farmers struggle obtaining information on best practices or new agriculture methods. Interestingly, their preferred source of information were local governmental agriculture offices, while the media was almost irrelevant for the surveyed farmers. Furthermore, only four of the visited farmers knew any additional solar water pump supplier besides Simusolar, which highlights the low awareness of the sector regarding solar water pumps and indicates the relevance of word-of-mouth recommendation. In fact, most of the farmers' neighbours only learned about the possibility of using solar power for water supply due to their neighbours' new systems – and two eventually purchased a solar water pump system for themselves.

In terms of water supply, the farmers' prior water pumping systems limited the irrigated area for almost half of the farmers visited. Moreover, seven farmers struggled to finance operation and maintenance expenditures for their former pump and were thus facing temporary or long-term water shortages. Maintenance of the fuel pumps was named specifically and described as challenging due to the costs involved as well as the need of a technician and concomitant struggles at often remotely located farms. Solar water pumps constitute an attractive alternative to fuel pumps since they implicate no operational expenditures and are characteristically highly reliable. An assessment of a water supply system's characteristics with the visited farmers yielded that what farmers value most is reliability, followed by low operational costs and simplicity of use. Initial costs of a system were ranked last, which contradicts the experiences of high initial costs as barriers to the adoption of solar water pumps. In fact, when looking closer to the purchase drivers using the categorization approach presented in the Tanzania Market Snapshot [8], it became apparent that although there are correlations between relevant system characteristics and purchase drivers, it is important to differentiate between the two since they are not necessarily prioritized equally and purchase drivers go beyond pure system characteristics.

Taking into account the high uptake of Simusolar's financial service, the initial investment required for solar water pump systems is found to constitute a significant obstacle for their spread. Additional early-state challenges impeding the adoption of solar water pumps were observed during this field research. First of all, the vast area of Tanzania and concomitant logistical challenges pose a barrier hindering a fast penetration of Tanzania's horticulture market by decreasing the suppliers' speed of response and thusly lowering the quality of service provided. Assessing the farmers' needs and consequently ensuring an appropriate system design was detected to be particularly challenging. The farmers' own insufficient knowledge of their needs translates to a requirement of adequately qualified staff to assess the customer's needs. Moreover, it might be necessary to provide an appropriate storage possibility since not all farmers have such already in place. Also, the quality of the water source can constitute a hurdle if a minimum water purity is not safeguarded to prevent pump breakdowns. Lastly, briefing the customers properly is found to be crucial in order to prevent mishandling and to ensure customer satisfaction. The relevance of these challenges is reinforced when looking at the level of progress in adopting solar water pumps reached. Of all participants of the field trials, only two managed to complete the first section of the logical model based on the theory of change, which encompasses the three sections output, outcome, and impact. No farmer managed to progress further and experience benefits in farming efficiency and reliability. However, it was observed that given more time the farmers can potentially progress further on the logical model, and thus solar water pumps can yield a remarkable impact on the development of rural communities.

Looking forward, the insights surfaced in this work need verification and validation by studies with representative participant pools, and more information has to be acquired regarding financial characteristics. Moreover, the initiated impact evaluation should be completed in order to verify the expected benefits of solar water pumps, to enable a better understanding of the interrelations developed in the logical model, and to add missing connections. Beyond that, potential risks of deploying solar water pumps – especially the risk of groundwater depletion – should be analysed thoroughly. Consequently, appropriate counter-measures have to be developed.

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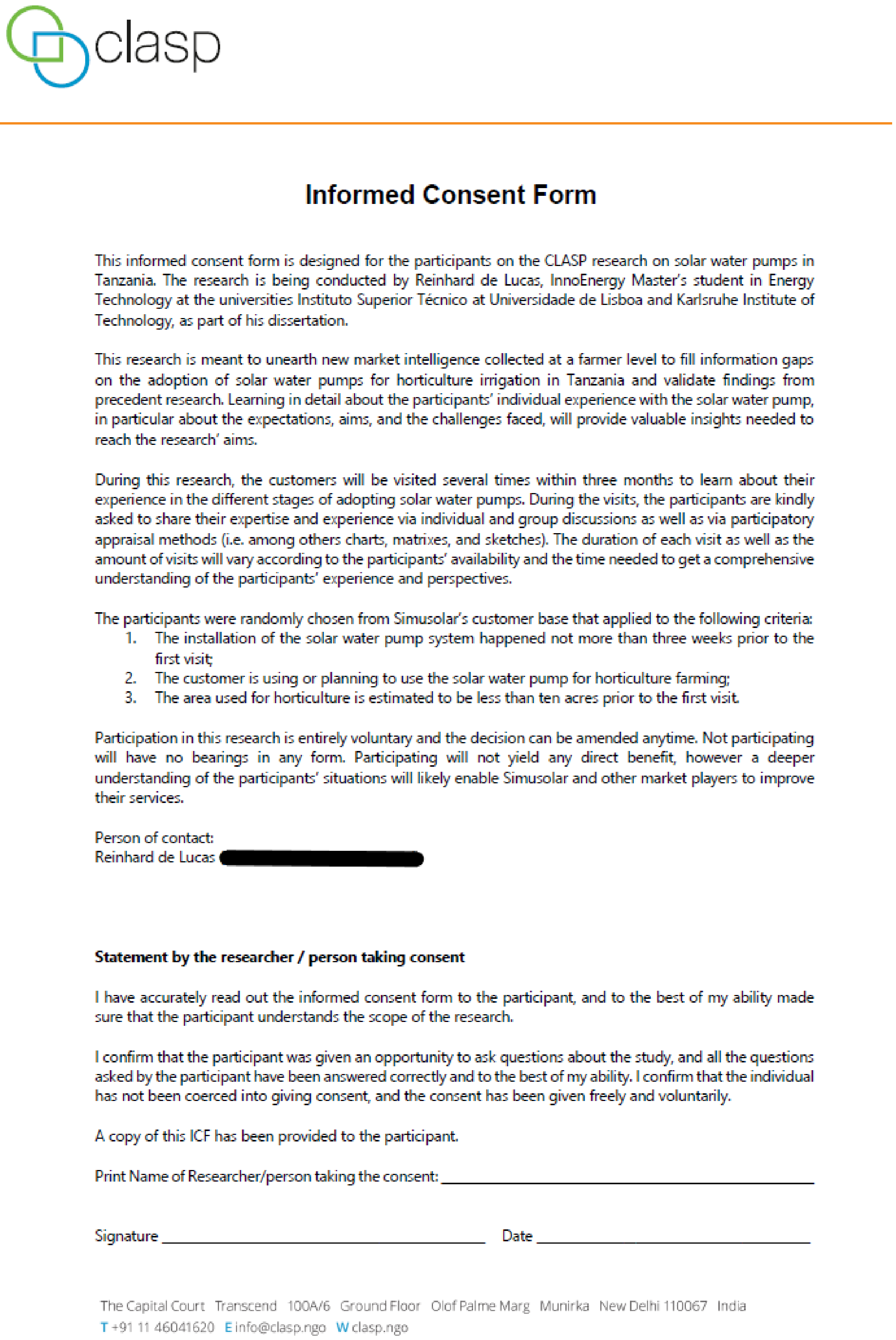
# ANNEX A – INCURRED EXPENDITURES

<u>Field trials March – June 2019:</u>
<u>Total expenditures financed by the Efficiency for Access Coalition through CLASP</u>

| MATTER OF EXPENSE | AMOUNT |
|---|---|
| Transport (for 7 weeks: fuel, car rental, driver wage) | 2,900.58 EUR |
| Interpreter wage (for 7 weeks) | 1,518.27 EUR |
| Accommodation (required for 44 nights) | 542.97 EUR |
| Other (material, permits, fees) | 663.09 EUR |
| ***TOTAL*** | ***5,624.91 EUR*** |

# ANNEX B – BLANK CONSENT FORM



clasp

## Informed Consent Form

This informed consent form is designed for the participants on the CLASP research on solar water pumps in Tanzania. The research is being conducted by Reinhard de Lucas, InnoEnergy Master's student in Energy Technology at the universities Instituto Superior Técnico at Universidade de Lisboa and Karlsruhe Institute of Technology, as part of his dissertation.

This research is meant to unearth new market intelligence collected at a farmer level to fill information gaps on the adoption of solar water pumps for horticulture irrigation in Tanzania and validate findings from precedent research. Learning in detail about the participants' individual experience with the solar water pump, in particular about the expectations, aims, and the challenges faced, will provide valuable insights needed to reach the research' aims.

During this research, the customers will be visited several times within three months to learn about their experience in the different stages of adopting solar water pumps. During the visits, the participants are kindly asked to share their expertise and experience via individual and group discussions as well as via participatory appraisal methods (i.e. among others charts, matrixes, and sketches). The duration of each visit as well as the amount of visits will vary according to the participants' availability and the time needed to get a comprehensive understanding of the participants' experience and perspectives.

The participants were randomly chosen from Simusolar's customer base that applied to the following criteria:

1. The installation of the solar water pump system happened not more than three weeks prior to the first visit;
2. The customer is using or planning to use the solar water pump for horticulture farming;
3. The area used for horticulture is estimated to be less than ten acres prior to the first visit.

Participation in this research is entirely voluntary and the decision can be amended anytime. Not participating will have no bearings in any form. Participating will not yield any direct benefit, however a deeper understanding of the participants' situations will likely enable Simusolar and other market players to improve their services.

Person of contact:
Reinhard de Lucas [redacted]

**Statement by the researcher / person taking consent**

I have accurately read out the informed consent form to the participant, and to the best of my ability made sure that the participant understands the scope of the research.

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

A copy of this ICF has been provided to the participant.

Print Name of Researcher/person taking the consent: ____________________

Signature ____________________ Date ____________________

The Capital Court Transcend 100A/6 Ground Floor Olof Palme Marg Munirka New Delhi 110067 India
T +91 11 46041620 E info@clasp.ngo W clasp.ngo

**Certificate of Consent**

Full Names ________________________________________________

Address __________________________________________________

Email address ______________________________________________

Contact number _____________________________________________

By signing this form, I consent that…

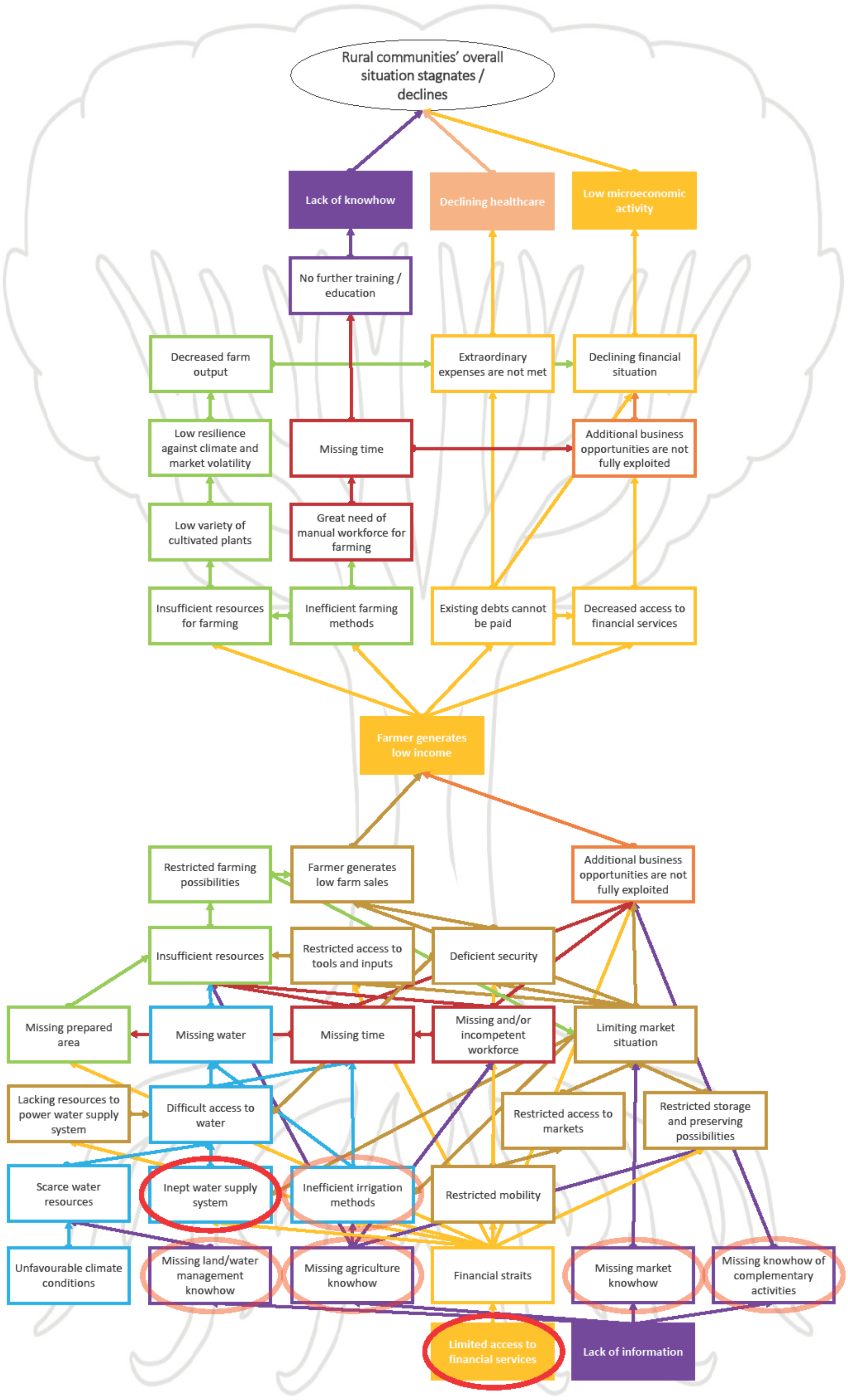
| YES | NO | |
|---|---|---|
| ☐ | ☐ | … all information collected about me (and my children) is used for the purpose of the study and can be published by CLASP and the researcher within his dissertation; |
| ☐ | ☐ | … all information and material about me is used with my identity (if "NO" is selected, I agree to an anonymous use of information and material about me); |
| ☐ | ☐ | … my images and the photo and video material collected can be used within this research as well as for storytelling, marketing and outreach purposes; |
| ☐ | ☐ | … my image may be edited, copied, exhibited, published or distributed in diverse settings within an unrestricted geographic area and to waive the right to inspect or approve the finished product wherein my likeness appears as well as the right to royalties or other compensation arising or related to the use of my image; |
| ☐ | ☐ | … all the information and material can be stored and used in an archive/stimulus set that will be available to other researchers for use in their research studies, including showing the photographs/recordings to participants in other research studies and that there is no time limit on the validity of this release nor is there any geographic limitations where these materials and information may be distributed; |
| ☐ | ☐ | … I had the research and the information on this form satisfactorily explained to me in verbal and / or written form and fully understand the above release and agree to be bound thereby; |
| ☐ | ☐ | … I had the opportunity to ask questions and any questions I asked have been answered to my satisfaction; |
| ☐ | ☐ | … I may withdraw from this study at any time without having to give an explanation. This will not affect my future care or treatment; |

Signatures ______________________________ Date ___________________________

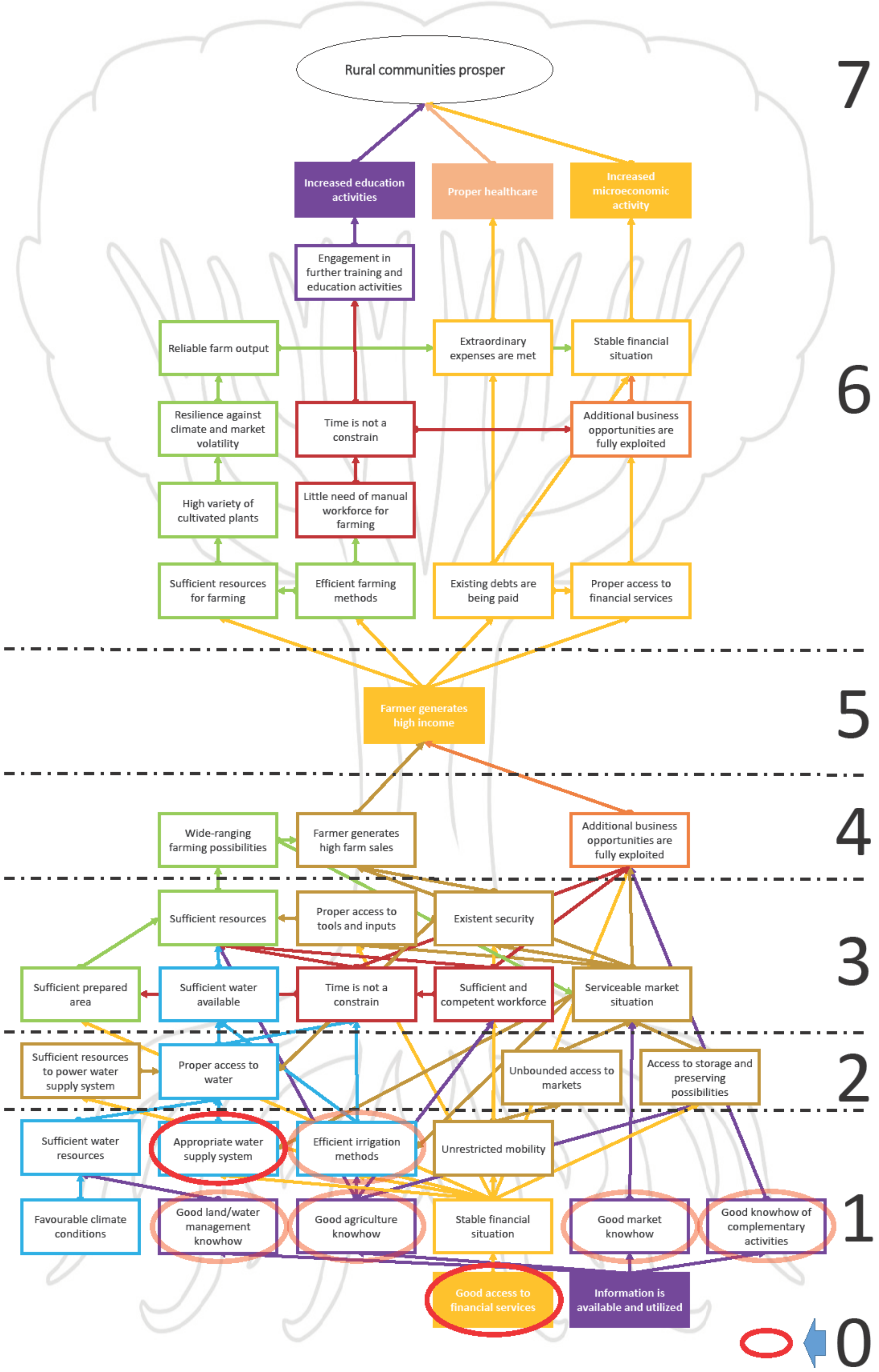
CLASP improves the energy and environmental performance of the appliances & equipment we use every day, accelerating our transition to a more sustainable world.

CLASP conducts research and manages programs that increase the availability and affordability of energy efficient, high-quality appliances. We work with policymakers, consumers, product manufacturers, and governments.

# ANNEX C – PROBLEM AND SOLUTION TREES



THE PROBLEM TREE



# THE SOLUTION TREE

| | | |
|---|---|---|
| ⬭ | ➡ | Input provided by Simusolar |
| ⬭ | ➡ | Potential additional input |
| 0 … 7 | ➡ | Corresponding to $x^{th}$ step of the results staircase |

# ANNEX D – ANALYSIS OF RESEARCH QUESTIONS

| Research Questions | Purchase Factors | SWP Usage | Finances | Benefits of SWP |
|---|---|---|---|---|
| A. What factors do potential customers consider when purchasing an irrigation solution, particularly SWPs? Do these factors correlate with the top six factors uncovered in the study (namely: cost and affordability, availability of the equipment and inputs, water source availability, simplicity of use, awareness about other irrigation technologies and area and reliability/efficiency of the irrigation solution)? | X | | | |
| B. How do consumers value capital expenditure vs. operational and other factors when choosing between diesel/petrol pumps and SWPs? Does this output concur with the study finding and any reasons for differences observed? | X | | | |
| C. How many hours a day/days a year do customers use SWPs? How much would they use if not constrained by cost and capacity? | | X | | |
| D. How much are potential customers willing to pay for SWPs in different use cases / farmer typologies? How much are they willing and able to pay for a deposit and monthly payments? | | | X | |
| E. How much additional income or cost savings can be generated by a smallholder farmer who transitions to a SWP in different use cases/typologies? | | | X | |
| F. What are other socioeconomic/development benefits from SWPs beyond higher incomes and reduced labour for irrigation? (e.g. education, health, safety, women's empowerment, business, access to credit/banking, reduced food waste) | | | | X |
| G. What are the costs incurred by a company to acquire a new customer? | Not considered in the field trials. | | | |

Breaking down the research questions leads to the following required information. Besides the required information regarding the purchase factors (A. + B.), all information should be obtained for the initial situation, in which the farmer hasn't received yet the solar water pump and is using his/her former means for water supply, as well as for the arising situation with the new solar water pump at the end of the field trials.

A. + B. Purchase Factors

In order to be able to answer the research questions A and B, a prioritized list of purchase factors is needed. The prioritization has to be conducted by the farmers. The completeness of the factors included in each list can be assured by taking into account…

… the hoped-for benefits from SWPs;

… the encountered problems with the current water supply system and reason for its use;

… the source(s) of information of SWP and the available SWP suppliers;

… the operation of the water supply system;

… the capital and operational expenditures.

C. SWP Usage

For documenting the usage of SWPs as well as possible constrains, the following information is required:

- The actual usage of the water supply system…
  - … in [liters/hour];
  - … in [hours/day];
  - … in [days/year];
- The hoped-for usage of the SWP…
  - … in [hours/day];
  - … in [days/year];
- The time period out of function of the water supply system…
  - … due to maintenance;
  - … due to malfunction;
  - … due to weather constrains;
  - … due to operation difficulties;
- The type of water source used including…
  - … the availability of the water source throughout the year;
  - … the quality of the water source;
  - … the amount of water used;
  - … the reason for its usage;
- The type of irrigation technology used including…
  - … its water demand;
  - … its labour/time demand;
  - … the frequency of irrigation.

D. + E. Finances

The answer for the financial questions can be obtained by documenting the farmers' experience and their actual expenditures and revenues. Moreover, the farmers' general financial situation can provide additional information on financial scopes. Therefore, the following information should be collected:

- The farmer's savings;
- The paid deposit (CAPEX) for the SWP;
- Former loans;
- Upcoming investments;
- The monthly payments for the SWP;
- The quantity and the types of income sources;
- The yearly income (as detailed as possible);
- The yearly expenditures (as detailed as possible);
- The expenditures for operating (required energy/fuel) and maintaining the former water supply system;
- The seasonality and reliability of income and expenditures;
- Potential business opportunities;

F. Benefits of SWP

In order to assess the benefits provided by SWPs, the theory of change is applied. Thus, an impact evaluation plan is developed and the indicators that have to be measured identified as follows:

- Finances (cf. D. + E.) including access to financial services;
- Water supply and irrigation systems (cf. C);

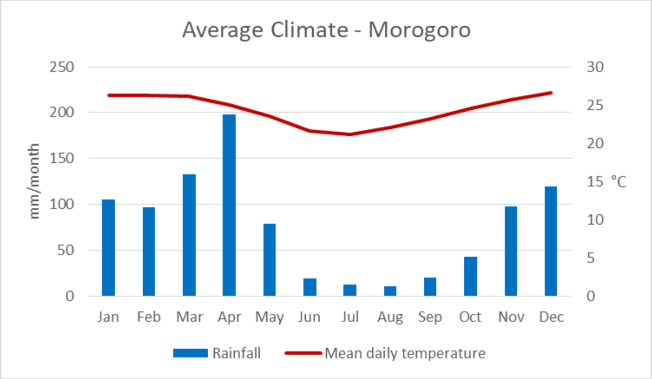
- Further training / education activities pursued by each farm member;
- Employment situation;
- Cultivated area;
- Unexploited area (incl. reasons);
- Variety of cultivated crops;
- Yields per crop;
- Inputs and tools used;
- Time spent on farm work;
- Harvest storage and preserving possibilities;
- Business opportunities;
- Mobility;
- Women empowerment;
- Sustainable use of resources;
- Access to health services;
- Safety situation;
- Waste situation;
- Resilience (vs. climate & market fluctuations);
- Status within the community;
- Neighbours’ perception of SWP;

# ANNEX E – FARMER PROFILES

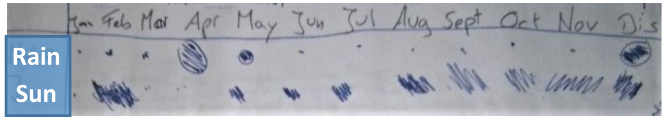
## Farmer № 1 – Morogoro Region

| | |
|---|---|
| Farm size | *2.02 ha* |
| Cultivated area | *1.62 ha* |
| Cultivated crops | - *Tomato*<br>- *Maize*<br>- *Water melon*<br>- *Sweet pepper*<br>- *Hot pepper*<br>- *Bitter tomato*<br>- *Banana* |
| Unexploited area | *0.4 ha (cause: insufficient water for irrigation)* |
| Otherwise used area | *On two extra acres: Poultry house and farmers' domicile* |
| Water sources | *Borehole (70 m depth); well with manual pump (15 m depth) for community use* |
| Water use | *1st irrigation; 2nd domestic; 3rd poultry watering* |
| Irrigation system | *Drip irrigation (still to install in < 0.4 ha, there currently irrigating manually)* |

| | |
|---|---|
| Main farmers | *Wife and husband*<br>*(wife as head farmer)* |
| Workers | *1 (permanent), 5-20 (day-workers)* |
| Living at the farm | *Main farmers only* |
| Other sources of income | - *Rice farm (flooding via canals)*<br>- *Sunflower farm (no irrigation)*<br>- *Husband's bar at the main road*<br>- *Poultry*<br>- *Milling with women's society* |
| Average yearly income (total) | *24 million TZS / 10,420 USD*<br>*(rate: 2,303.39 TZS : 1 USD* [90]*)* |
| Notes | - *5 adult children out of home*<br>- *Owning an unexploited 4th farm* |
| Former water supply system | - *Grid-connected electric pump*<br>- *Water storage of 10,000 litres at 2 m height; 1,000 at 3 m height*<br>- *OPEX: up to 10,000 TZS/day for electricity w/o obtaining sufficient water* |



Date Source: CLIMWAT 2.0 [84]



| | |
|---|---|
| New SWP system<br>Installation on 09/03/19 | - *Submersible pump (Simusolar SP7)*<br>- *3 panels à 230 Wp (+3 installed later)*<br>- *CAPEX: 1.45 million TZS as deposit*<br>- *OPEX: total of 5.2 million TZS in instalment payments to supplier*<br>- Add. panels installed on 28/03/19 |

| | | | |
|---|---|---|---|
| Farming challenges | - *Getting good prices at the market*<br>- *Irrigating crops sufficiently*<br>- *Insects*<br>- *Fungus* | Education and sources of information | *Wife: dropped after primary school*<br>*Husband: univiersity degree in agriculture from Italy*<br>*Children: secondary school - university*<br>*Information sources: NGOs, TAHA, local societies* |
| Farmers' goals | - *Drip irrigation for whole farmland*<br>- *Try out new crops and keep livestock again*<br>- *Purchase greenhouse & tractor*<br>- *Build a new poultry house* | Community involvement | - *Living at the edge of the village, close relationship with neighbours (friendly and supportive)*<br>- *Members of elders' society and women's society (board)*<br>- *One son living in the same village* |

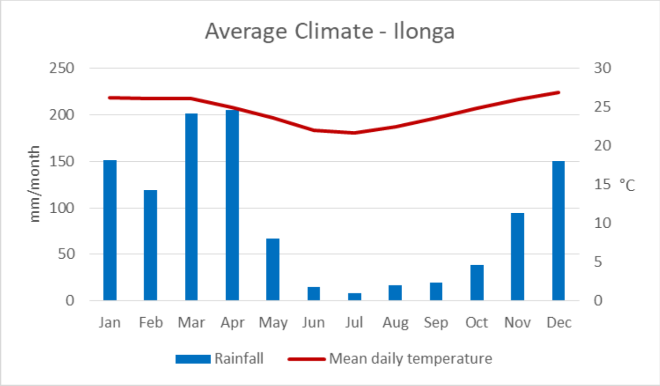
| Matrix of Crops – Farmer № 1 | Total | Tomato | Maize | Water Melon | Sweet Pepper | Hot Pepper | Bitter Tomato | Banana |
|---|---|---|---|---|---|---|---|---|
| Area | *1.62 ha* | *0.81 ha<br>3 times/year* | *1.62 ha* | *1.62 ha* | *0.40 ha* | *0.40 ha* | *0.40 ha* | *20 trees (dispersed)* |
| Total yield/year | | *16,000 kg (max 500,000 kg)* | *5,000 pieces (70,000 - 140,000 pieces)* | *2,000 pieces (max 7,200 pieces)* | *8,400 - 9,600 kg* | *1,200 - 2,000 buckets (5kg-paint bucket)* | *25,600 - 32,000 kg* | *20 bunch* |
| Price at market | | | *Not harvested enough for selling* | | | | | *10,000 – 20,000 TZS / bunch* |
| **Income from farm** | ***12 - 15 million TZS*** | ***< 1 million TZS*** | ***None*** | ***3 million TZS*** | ***500,000 TZS*** | ***300,000 TZS*** | ***50,000 TZS*** | ***200,000 – 400,000 TZS*** |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | *1: max. 111,3* $m^3$*;<br>av. 78.0* $m^3$<br>*2: 60* $m^3$ *required;<br>20* $m^3$ *supplied* | *Max. 49.0* $m^3$ | *Max. 28.4* $m^3$ | *Max. 81.1* $m^3$ | *Max. 13.0* $m^3$ | *Max. 13.0* $m^3$ | *Max. 13.3* $m^3$ | *No irrigation* |
| Expenditures for irrigation | *3.65 million TZS* | | | | | | | |
| Payed workers | *5-20 (10,000 - 50,000 TZS daily)* | | | | | | | |
| Seeds used | *2.68 million TZS* | *0.05-0.1 kg; 300,000 TZS / 0.025 kg* | *40 kg: 280,000 plants; 7,500 TZS / 1 kg* | *0.5 kg; 300,000 TZS / 0,25 kg* | *25 g: 12,000 plants; 250,000 TZS* | *25 g: 12,000 plants; 250,000 TZS* | *0,1 kg: 8,000 - 10,000 plants 20,000 TZS / 25 g* | |
| Fertilizer used | *4 million TZS* | | | | | | | |
| Chemicals used | *3 – 5 million TZS* | | | | | | | |
| **Expenditures for farming** | ***48 million TZS*** | ***9 million TZS*** | ***5 million TZS*** | ***10 million TZS*** | ***2 million TZS*** | ***1 million TZS*** | ***200,000 TZS*** | |

In green: expected

## Farmer N° 2 – Morogoro Region

| | |
|---|---|
| Farm size | *3.24 ha* |
| Cultivated area | *1.21 ha* |
| Cultivated crops | - *Rice*<br>- *Maize*<br>- *Sunflower*<br>- *Spinach, sweet pepper, tomato, bitter tomato*<br>- *Formerly onion* |
| Unexploited area | *2.03 ha (cause: farm just initiated – increasing cultivated area step by step)* |
| Otherwise used area | *None* |
| Water sources | *Building hand-dug well (12 m depth); 2 temporary ponds; borehole (41 m depth, muddy)* |
| Water use | *Irrigation only* |
| Irrigation system | *Intend to use drip irrigation and sprinklers* |

| | |
|---|---|
| Main farmers | *Wife and husband (wife as head farmer)* |
| Workers | *1 (permanent), 0-11 (day-workers)* |
| Living at the farm | *No one* |
| Other sources of income | - *Husband's salary*<br>- *Real estate property* |
| Average yearly income (total) | *34.2 million TZS / 14,850 USD (rate: 2,303.39 TZS : 1 USD* [90]*)* |
| Notes | - *SWP could not be installed due to poor quality water source and was instead used in a temporary pond*<br>- *SWP was stolen but got recovered* |
| Former water supply system | - *None (no irrigation)*<br>- *Used petrol pump 0.5-2 h/day after SWP was stolen*<br>- *No water storage system in place* |



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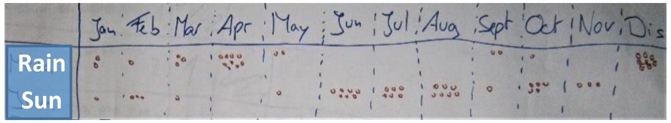


| | |
|---|---|
| New SWP system<br>Installation not realized | - *Submersible pump (Simusolar SP7)*<br>- *3 panels à 230 Wp*<br>- *CAPEX: 1 million TZS as deposit*<br>- *OPEX: total of 6.22 million TZS in instalment payments to supplier* |

| | |
|---|---|
| Farming challenges | - *Price obtained at local markets*<br>- *Quality of water source*<br>- *Security of equipment* |
| Education and sources of information | *Wife: diploma in logistics*<br>*Husband: Master's in economic in the UK*<br>*Children: secondary school, university*<br>*Information sources: Internet, friends and family, trade fairs* |
| Farmers' goals | - *Eliminate unpredictabilities*<br>- *Year-long cultivation*<br>- *Stable source of income*<br>- *Community learning and wellbeing* |
| Community involvement | - *Moved to the region 1 year ago*<br>- *Planning to move to the village next to the farm*<br>- *Aiming to supply water to the village for domestic use incorporating the SWP* |

In green: in the future

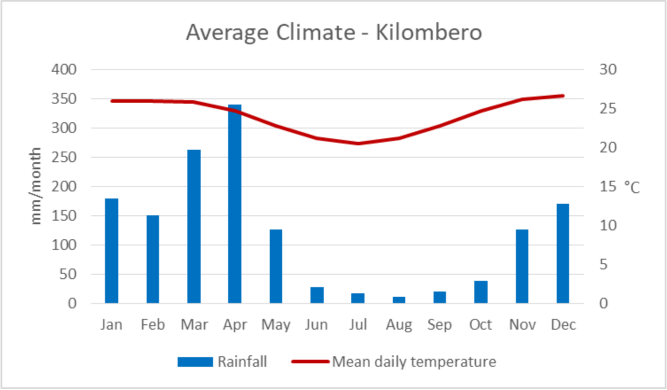
| **Matrix of Crops – Farmer N° 2** | Total | Rice | Maize | Sunflower | Tomato, Sweet Pepper, Spinach, Bitter Tomato | Formerly Onion |
|---|---|---|---|---|---|---|
| Area | *1.21 ha* | *1.12 ha*<br>*2 times/year* | *0.30 ha* | *0.81 ha* | *1.12 ha*<br>*3 times/year* | *0.81 ha* |
| Total yield/year | | *25,000 kg* | *7-15 bags* | *20 bags* | *100 kg / week* | *117 bags*<br>*(à 100 kg / bag)* |
| Price at market | | *80,000 TZS / 100 kg* | *30,000 TZS / bag* | *35,000 TZS / bag* | *25,000 – 30,000 TZS / 100 kg* | *10,000 – 30,000 TZS / bag* |
| **Income from farm** | | | | | | |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | *1: max. 197.3 $m^3$;*<br>*av. 92.0 $m^3$*<br>*2: -* | *Max. 67.7 $m^3$* | *No irrigation (max. 18.3 $m^3$)* | *No irrigation (max. 49.8 $m^3$)* | *Max. 112.1 $m^3$* | *Max. 47.6 $m^3$* |
| Expenditures for irrigation | *2,200 TZS / day* | | | | | |
| Payed workers | *1-10 (permanent worker: 80,000 TZS/month)* | | *0.12 million TZS* | | | |
| Seeds used | | *25 kg* | *2 kg;*<br>*70,000 TZS* | | | |
| Fertilizer used | *None* | *None* | *None* | *None* | *None* | *None* |
| Chemicals used | *None* | *None* | *None* | *None* | *None* | *None* |
| **Expenditures for farming** | | ***1,2 million TZS*** | | | | |

In green: expected

## Farmer N° 3 – Morogoro Region

| | |
|---|---|
| Farm size | *4.05 ha* |
| Cultivated area | *2.02 ha* |
| Cultivated crops | *- Tomato*<br>*- Cucumber*<br>*- Papaya*<br>*- Banana* |
| Unexploited area | *2.03 ha (uncleared area, insufficient irrigation, and partly otherwise used)* |
| Otherwise used area | *Area for poultry house, fish ponds, and housing* |
| Water sources | *River* |
| Water use | *1st irrigation; 2nd poultry and fish farming* |
| Irrigation system | *Flooding (fruit trees individually via piping)* |

| | |
|---|---|
| Main farmers | *Husband and wife (husband as head farmer)* |
| Workers | *2 permanent (after SWP acquisition 4)* |
| Living at the farm | *Main farmers and 1 worker with wife and children* |
| Other sources of income | *- Poultry*<br>*- Used to farm fish; ponds need to be repaired to resume* |
| Average yearly income (total) | *10.8 million TZS / 4,700 USD (rate: 2,303.39 TZS : 1 USD* [90]*)* |
| Notes | *- Tried to set up a SWP system by himself without success but still has 9 PV panels à 100 Wp*<br>*- SWP got flushed away by river in early May during the rainy season*<br>*- Children (3) living with relatives* |
| Former water supply system | *- Petrol pump, used 3 h/day*<br>*- No water storage in place*<br>*- OPEX: 10,000 TZS / 0.4 ha*<br>*- 2x per month out of function and died in early 2019* |



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| | |
|---|---|
| New SWP system<br>Installation on 05/04/19 | *- Submersible pump (Simusolar SP7)*<br>*- 3 panels à 230 Wp (4 expected)*<br>*- CAPEX: 0.9 million TZS as deposit*<br>*- OPEX: total of 6.12 million TZS in instalment payments to supplier*<br>*- New pump installed on 09/06/19* |

| | |
|---|---|
| Farming challenges | *- Reliability of water supply*<br>*- Quality of agricultural inputs*<br>*- Access to information (no governmental agriculture office or NGO nearby)*<br>*- Capital for required investements* |
| Education and sources of information | *Husband and wife: dropped school after primary school*<br>*Children: going to school, oldest finished university*<br>*- Information sources: Other farmers, friends and familiy – learning by doing* |
| Farmers' goals | *- Farming as main source of income*<br>*- Resume fish farming, keep more livestock and increase cultivated area*<br>*- Set up grill restaurant with camping for ecotourists* |
| Community involvement | *- No good relationship with neighbours (arrived 7 years ago, is not accepted; disputes on use of land)*<br>*- Joined a society for lending, which is just starting* |

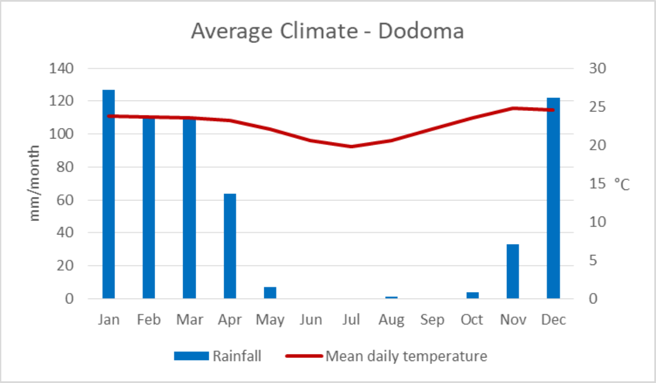
| Matrix of Crops – Farmer N° 3 | Total | Tomato | Cucumber | Papaya | Banana |
|---|---|---|---|---|---|
| Area | *2.02 ha* | *0.40 ha + 0.20 ha + 0.10 ha* | *0.10 ha + 0.30 ha* | *0.47 ha*<br>*(600 trees planted)* | *0.30 ha* |
| Total yield/year | | *75 boxes (harvest of 0.1 ha season entirely lost)* | *10,000 + 30,000 pieces* | *Minimum 25 pieces / tree* | *8,000 bunch* |
| Price at market | | *8,000 TZS / box* | *100 TZS / piece* | *500 – 1,000 TZS / piece* | *10,000 TZS / bunch* |
| **Income from farm** | | ***0,6 million TZS*** | ***4 million TZS*** | | |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | *1: max. 85.0 $m^3$; av. 46.8 $m^3$*<br>*2: -* | *Max. 23.1 $m^3$* | *Max. 23.5 $m^3$* | *Max. 31.2 $m^3$* | *Max. 19.9 $m^3$* |
| Expenditures for irrigation | *10,000 TZS / day* | | | | |
| Payed workers | *2 + 2 new ones (100,000 TZS/month)* | | | | |
| Seeds used | | *47,000 TZS* | *27,000 TZS* | *Leftover seeds -> total of 2,000 trees* | *-* |
| Fertilizer used | | *Manure (no expenses)* | *Manure (no expenses)* | *Manure (no expenses)* | *None* |
| Chemicals used | | *100,000 TZS* | | *36,000 TZS / month* | *None* |
| **Expenditures for farming** | | | | | |

In green: expected

# Farmer N° 4 – Central Region

| | |
|---|---|
| Farm size | *4.05 ha* |
| Cultivated area | *0.81 ha* |
| Cultivated crops | - *Tomato*<br>- *Cucumber*<br>- *Leaf vegetables*<br>- *Water melon*<br>- *Grapes* |
| Unexploited area | *3.24 ha (increasing area in accordance to water supply)* |
| Otherwise used area | *Area for poultry house (planning to use area for keeping livestock)* |
| Water sources | *Borehole (140 m depth)* |
| Water use | *1st irrigation; 2nd poultry and livestock watering* |
| Irrigation system | *Drip irrigation* |
| Farming challenges | - *Supplying sufficient water for irrigation* |
| Farmers' goals | - *Keep livestock and increase cultivated area*<br>- *Set up farming as new main source of income*<br>- *Enter water purifying and bottling business* |

| | |
|---|---|
| Main farmers | *Father and son (father as head farmer)* |
| Workers | *3 (permanent), 0-8 (daily worker)* |
| Living at the farm | *During the week: permanent workers* |
| Other sources of income | - *Timber business (run by mother)*<br>- *Poultry* |
| Average yearly income (total) | *60 million TZS / 26,000 USD (rate: 2,303.39 TZS : 1 USD* [90]*)* |
| Notes | - *Salesman provided SWP system unable to cover the water demand*<br>- *While unused, 10,000 l water tank was blown away by the wind*<br>- *Father's brother is one of the permanent workers* |
| Former water supply system | - *Diesel pump with 3,000 l water tank at 3 m height*<br>- *Performing unsatisfactorily (insufficient water delivered)*<br>- *OPEX: 50,000 TZS / day* |
| Education and sources of information | *Father and mother: completed secondary school*<br>*Children (6): in school/university; oldest finished university*<br>*Information sources: Governmental agriculture office* |
| Community involvement | - *Living in the city far from the farm*<br>- *Sold part of his farmland to neighbours*<br>- *No village nearby, nearby surrounding area unexploited* |



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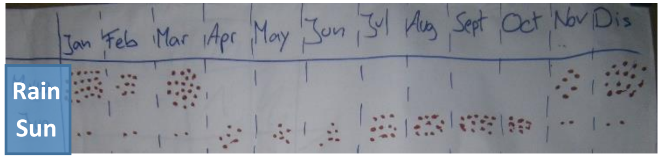


| | |
|---|---|
| New SWP system<br>Installation on 02/03/19 | - *Submersible pump (Simusolar SP8)*<br>- *6 panels à 230 Wp (+5 installed later)*<br>- *CAPEX: 1.65 million TZS as deposit*<br>- *OPEX: total of 8.31 million TZS in instalment payments to supplier*<br>- *Add. Panels installed on 01/06/19* |

In green: expected

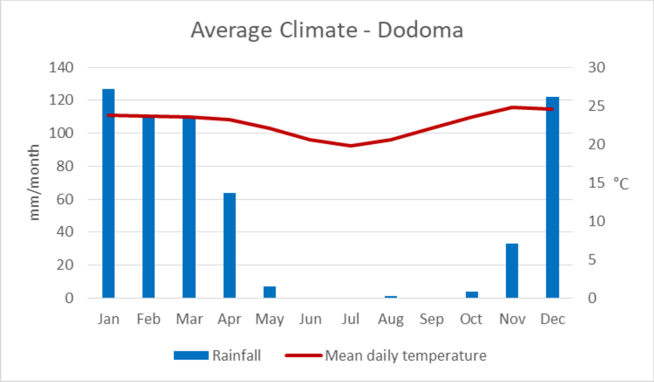
| Matrix of Crops – Farmer N° 4 | Total | Tomato | Cucumber | Leaf Vegetables | Water Melon | Grapes |
|---|---|---|---|---|---|---|
| Area | *0.81 ha* | *0.40 ha<br>2-3 times/year* | *0.20 ha* | *0.10 ha* | *0.40 ha<br>3 times/year* | *1.21 ha* |
| Total yield/year | | *500 box / harvest* | | | *18,000 pieces* | *20 million TZS / 0.4 ha* |
| Price at market | | *15,000 TZS / box* | *3,000 – 5,000 TZS / kg* | *500 TZS / bunch* | *2,000 TZS / piece* | *2,000 TZS / kg* |
| **Income from farm** | | | | | | |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | *1: max. 101.5 m³;<br>av. 70.4 m³<br>2: 60 m³ required;<br>12 m³ supplied* | *Max. 40.0 m³* | *Max. 9.2 m³* | *Max. 5.4 m³* | *Max. 36.3 m³* | *Max. 59.7 m³* |
| Expenditures for irrigation | *50,000 TZS / day* | | | | | |
| Payed workers | *3 + 0-11;<br>3: 60,000 TZS/month<br>0-11: 5,000 TZS/day* | | | | | |
| Seeds used | | *30,000 TZS* | *0.5 kg;<br>15,000 TZS* | *0.25 kg;<br>52,000 TZS* | *0.5 kg;<br>280,000 TZS* | |
| Fertilizer used | *140,000 TZS* | | | | | |
| Chemicals used | *43,000 TZS* | | | | | |
| **Expenditures for farming** | ***24 million TZS*** | | | | | |

In green: expected

# Farmer N° 5 – Central Region

| | |
|---|---|
| Farm size | *20.24 ha* |
| Cultivated area | *2.83 ha* |
| Cultivated crops | - *Tomato*<br>- *Water Melon*<br>- *Sunflower*<br>- *Cucumber*<br>- *Okra* |
| Unexploited area | *17.41 ha (new farm; increasing cultivated farmland step by step)* |
| Otherwise used area | *None* |
| Water sources | *Borehole (120 m depth); pumping test: 11,000 l/h* |
| Water use | *1st irrigation; 2nd selling to neighbours for livestock watering* |
| Irrigation system | *Planning to set up drip irrigation system* |
| Farming challenges | - *Delays in setting up water supply and irrigation infrustructure* |
| Farmers' goals | - *Get farm started and reach profitability*<br>- *Create housing possibilities at the farm*<br>- *Farm meant as retirement plan for father* |

| | |
|---|---|
| Main farmers | *Family: 2 sons, 2 sisters (1 son as head farmer)* |
| Workers | *1 (permanent)* |
| Living at the farm | *No one* |
| Other sources of income | - *Taylor business (run by mother)*<br>- *Salaries from father (government employee), 2 sisters, and 1 brother* |
| Average yearly income (total) | *missing* |
| Notes | - *Only head farmer is regularly at the farm*<br>- *Farming decisions are taken within the whole family* |
| Former water supply system | - *No irrigation*<br>- *Added new 6,000 l water tank at 3 m height* |



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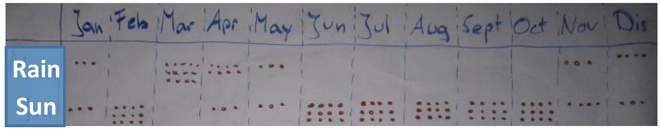


| | |
|---|---|
| New SWP system<br>Installation on 01/06/19 | - *Submersible pump (Simusolar SP8)*<br>- *6 panels à 230 Wp*<br>- *CAPEX: 8.31 million TZS*<br>- *OPEX: none* |
| Education and sources of information | *Parents: missing*<br>*Children: university degrees in marketing, management, and medicine*<br>*Information sources: Governmental agriculture office, other farmers, friends and family* |
| Community involvement | - *Living 2 h away in the city*<br>- *Know neighbourhood due to governmental mango project, where father was involved*<br>- *Employing neighbours (mainly substential farmers) as day-workers as needed*<br>- *Providing livestock watering place for neighbours' livestock against payment for water* |

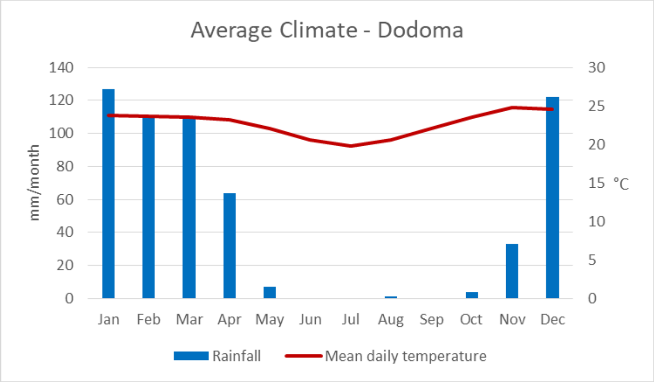
| **Matrix of Crops – Farmer N° 5** | Total | Tomato | Water Melon | Sunflower | Cucumber | Okra |
|---|---|---|---|---|---|---|
| Area | *2.83 ha* | *0.40 ha* | *0.40 ha*<br>*(1.21 ha)* | *2.83 ha* | *0.40 ha* | *0.40 ha* |
| Total yield/year | | *40-60 buckets* | *5,000 – 6,000 pieces / 0.4 ha* | *14-15 bags* | *5,000 – 6,000 pieces* | |
| Price at market | | *14,000 – 20,000 TZS / bucket* | *1,000 – 4,000 TZS / piece* | *60,000 TZS / bag* | *500 TZS / 3 pieces* | *500 TZS / handful* |
| **Income from farm** | | | | | | |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | *1: max. 118.5 $m^3$; av. 45.0 $m^3$*<br>*2: 20 $m^3$ required* | *Max. 24.8 $m^3$* | *Max. 21.6 $m^3$*<br>*(max. 65.2 $m^3$)* | *Max. 118.5 $m^3$* | *Max. 18.7 $m^3$* | *Max. 17.7 $m^3$* |
| Expenditures for irrigation | *No irrigation until now* | | | | | |
| Payed workers | *1 + 2-4;*<br>*1: 100,000 TZS/month*<br>*2-4: 50,000 TZS/ month* | | | | | |
| Seeds used | | | *0.25 kg;*<br>*175,000 TZS* | *350,000 TZS* | *0.2 kg;*<br>*40,000 TZS* | *0.2 kg;*<br>*40,000 TZS* |
| Fertilizer used | *Manure (no expenses)* | | | | | |
| Chemicals used | *25,000 – 50,000 TZS / season* | | | | | |
| **Expenditures for farming** | | | | | | |

In green: expected

# Farmer N° 6 – Central Region

| | |
|---|---|
| Farm size | 8.10 ha |
| Cultivated area | 1.21 ha |
| Cultivated crops | - Onion<br>- Sunflower<br>- Tomato<br>- Water melon<br>- Spinach<br>- Maize |
| Unexploited area | 4.46 ha (new farm, planning to cultivate initially up to 3.24 ha) |
| Otherwise used area | 2.43 ha cultivated by the parents for their own income |
| Water sources | Borehole (100 m depth; drilled in Nov. 2018) |
| Water use | 1st irrigation; 2nd selling to community for domestic use and livestock watering |
| Irrigation system | Planning to set up drip irrigation system |

| | |
|---|---|
| Main farmers | Farming group: 6 family members + 3 villagers (all from the same village) |
| Workers | Only members of the farming group |
| Living at the farm | No one |
| Other sources of income | - Each member's income (farmers, teachers, nurses, doctors) |
| Average yearly income (total) | Missing (took a bank group credit to set up water supply and irrigation system) |
| Notes | - Farmland belongs to parents of the family<br>- 3.24 ha fenced to protect from neighbours' livestock<br>- Neighbour acquired SWP (word-of-mouth) |
| Former water supply system | - No irrigation<br>- 10,000 l water tank at 3 m height in place |



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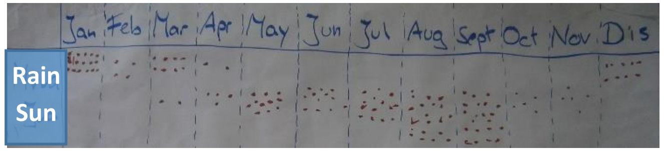


| | |
|---|---|
| New SWP system<br>Installation on 09/04/19 | - Submersible pump (Simusolar SP8)<br>- 6 panels à 230 Wp<br>- CAPEX / OPEX missing<br>- Temporarily using SP7 until SP8 is available |

| | |
|---|---|
| Farming challenges | - Initially installed pump (SP8) not working, had to be replaced by smaller pump (SP7) until new SP8 pumps are delivered |
| Farmers' goals | - Obtain a productive farm<br>- Farm as reliable source of income |

| | |
|---|---|
| Education and sources of information | Secondary school to university degree<br>Information sources: Governmental agriculture office, NGOs, internet, other farmers |
| Community involvement | - 5 members of the farming group living in nearby village<br>- Planning to provide community with water for domestic use and livestock watering against a small fee |

In green: expected

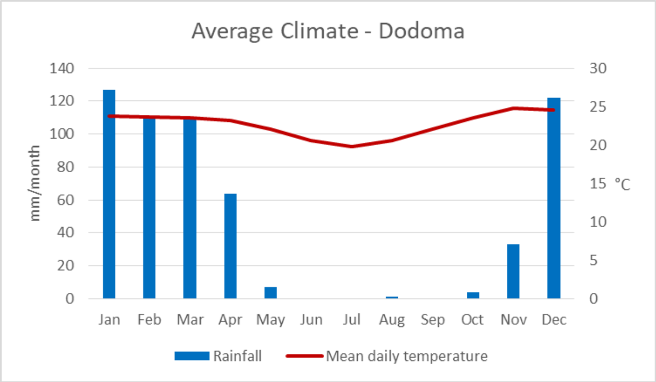
| Matrix of Crops – Farmer N° 6 | Total | Onion | Sunflower | Tomato | Water Melon | Spinach | Maize |
|---|---|---|---|---|---|---|---|
| Area | *1.21 ha*<br>*(3.24 ha)* | *0.40*<br>*3 times/year* | *0.81 ha* | *0.40 ha* | *0.40 ha* | *0.20 ha* | *0.81 ha* |
| Total yield/year | | *10 bags*<br>*+ 40 bags* | *6 bags* | | | | |
| Price at market | | *50,000 – 130,000 TZS / bag* | *60,000 TZS / bag* | *20,000 TZS / bucket* | *2,000 – 5,000 TZS / piece* | *500 TZS / bunch* | *300 – 500 TZS / piece* |
| **Income from farm** | | | | | | | |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | *1: max. 136.1 $m^3$; av. 58.9 $m^3$*<br>*2: 10 $m^3$ required* | *Max. 66.5 $m^3$* | *Max. 43.1 $m^3$* | *Max. 23.4 $m^3$* | *Max. 20.7 $m^3$* | *Max. 8.2 $m^3$* | *Max. 45.7 $m^3$* |
| Expenditures for irrigation | *No irrigation until now* | | | | | | |
| Payed workers | *None (all work done by farm group members)* | | | | | | |
| Seeds used | | *150,000 TZS* | | *21,000 TZS* | *100,000 TZS* | *12,000 TZS* | *60,000 TZS* |
| Fertilizer used | *100,000 TZS* | | | | | | |
| Chemicals used | *600,000 TZS* | | | | | | |
| **Expenditures for farming** | | | | | | | |

In green: expected

# Farmer N° 7 – Central Region

| | |
|---|---|
| Farm size | *20.24 ha* |
| Cultivated area | *8.10 ha* |
| Cultivated crops | - *Onion*<br>- *Maize*<br>- *Sunflower*<br>- *Sunflower hybrid*<br>- *Groundnuts*<br>- *Sweet potato*<br>- *Papaya*<br>*Own use: cassava, orange* |
| Unexploited area | *12.14 ha (area needs to be prepared for cultivation)* |
| Otherwise used area | *Area for school and housing* |

| | |
|---|---|
| Main farmers | *School management (11 persons)* |
| Workers | *0-20 (day-workers)* |
| Living at the farm | *School management* |
| Other sources of income | - *Affiliated institutions* |
| Average yearly income (total) | *missing* |
| Notes | - *Nursery and primary schools (12 teachers, 183 students)*<br>- *Children and teachers contribute 1 day/week to farm work; each child owns a papaya and a cassava tree*<br>- *Planning to increase water supply with additional panels to facilitate irrigation of farmland* |



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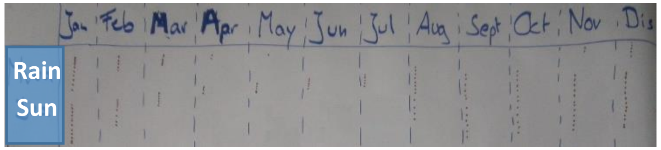


| | |
|---|---|
| Water sources | *Borehole (80 m depth)* |
| Water use | *1st domestic; 2nd irrigation* |
| Irrigation system | *None, irrigating only seedlings (manually)* |

| | |
|---|---|
| Former water supply system | - *Diesel pump with two water tanks at 3 m height (5,000 l & 3,000 l) and an underground tank (5,000 l)*<br>- *OPEX: 200,000 TZS / month* |

| | |
|---|---|
| New SWP system<br><br>Installation on 23/03/19 | - *Submersible pump (Simusolar SP7)*<br>- *3 panels à 230 Wp*<br>- *CAPEX: 1.45 million TZS as deposit*<br>- *OPEX: total of 6.67 million TZS in instalment payments to supplier*<br>- *Planning to increase number of panels* |

| | |
|---|---|
| Farming challenges | - *Obtaining good prices at the market*<br>- *Climate dependency (so far only rainfed farming)* |
| Education and sources of information | *Head farmers: university degree in agriculture (3 persons)*<br>*Information sources: Governmental agriculture office, internet, other farmers* |
| Farmers' goals | - *Set up irrigation system for farmland*<br>- *Reach production / cultivation throughout the year* |
| Community involvement | - *Good relationship with neighbours (mutual support)*<br>- *Only school in the region increasing school attendance due to reduced distance to school for local children (thusly valued and respected by the community)* |

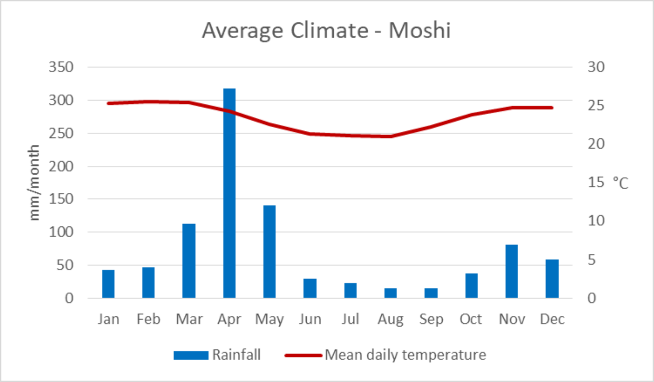
| Matrix of Crops – Farmer N° 7 | Total | Onion | Maize | Sunflower | Sunflower Hybrid | Groundnuts | Sweet potato | Papaya |
|---|---|---|---|---|---|---|---|---|
| Area | *8.10 ha* | *1.21 ha*<br>*2 times/year* | *0.81 ha* | *1.21 ha* | *4.05 ha* | *0.20 ha* | *Pilot*<br>*(15 $m^2$)* | *(50 trees)*<br>*(100 trees)* |
| Total yield/year | | *9 bags* | *14 bags* | *4-15 bags / 0.4 ha* | *50-55 bags* | *1-5 bags* | | *40-50 pieces / tree* |
| Price at market | | *35,000 – 120,000 TZS / bag* | *30,000 TZS / bag* | *50,000 – 200,000 TZS / bag* | *90,000 TZS / bag* | *Own consumption* | | *500 - 1,000 TZS / piece* |
| Income from farm | | | | | | | | |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | *1: max. 367.0 $m^3$; av. 141.1 $m^3$*<br>*2: 7 $m^3$ required for the seedling* | *Max. 102.1 $m^3$* | *Max. 35.9 $m^3$* | *Max. 75.0 $m^3$* | *Max. 241.4 $m^3$* | *Max. 11.3 $m^3$* | *Not considered* | *Max. 13.3 $m^3$* |
| Expenditures for irrigation | *200,000 TZS / month* | | | | | | | |
| Payed workers | | | *60,000 TZS* | *40,000 TZS* | *20,000 TZS* | *10,000 TZS* | | |
| Seeds used | | *100,000 TZS* | *56,000 TZS* | *70,000 TZS* | *135,000 TZS* | *10,000 TZS* | - | - |
| Fertilizer used | | *150,000 TZS* | *225,000 TZS* | *150,000 TZS* | *None* | *None* | *None* | *50,000 TZS* |
| Chemicals used | | *55,000 TZS* | *20,000 TZS* | *None* | *100,000 TZS* | *None* | *None* | *None* |
| **Expenditures for farming** | | ***0.6 million TZS*** | | | ***0.8 million TZS*** | ***0.03 million TZS*** | ***0.02 million TZS*** | |

In green: expected

## Farmer N° 8 – Northern Highlands

| | |
|---|---|
| Farm size | *1.21 ha* |
| Cultivated area | *0.81 ha* |
| Cultivated crops | - *Hot pepper*<br>- *Papaya*<br>- *Cucumber* |
| Unexploited area | *0.4 ha (steadily increasing cultivated area)* |
| Otherwise used area | *Area for housing* |

| | |
|---|---|
| Main farmers | *Husband (wife helps when needed)* |
| Workers | *1 (permanent), 0-3 (day-workers)* |
| Living at the farm | *Permanent worker* |
| Other sources of income | - *Husband's salary from main job*<br>- *Wife's shop for animal feed* |
| Average yearly income (total) | *9 million TZS / 3,900 USD (rate: 2,303.39 TZS : 1 USD* [90]*)* |
| Notes | - *Started farming in 2018* |



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| | |
|---|---|
| Water sources | *Hand-dug well (8 m depth)* |
| Water use | *Irrigation only as of now* |
| Irrigation system | *Drip irrigation* |

| | |
|---|---|
| New SWP system<br>Installation on 21/03/19 | - *Submersible pump (Simusolar SP7)*<br>- *5 panels à 230 Wp (initially only 3 panels planned)*<br>- *CAPEX: 1.45 million TZS as deposit*<br>- *OPEX: total of 6.67 million TZS in instalment payments to supplier* |
| Former water supply system | - *Petrol pump with two water tanks at 3 meter height à 5,000 l*<br>- *OPEX: 5,000 TZS / day* |

| | |
|---|---|
| Farming challenges | - *Maintaining petrol pump (technician from town needed)*<br>- *Reliability of workers*<br>- *Locally high soil salinization*<br>- *Fungus* |
| Farmers' goals | - *Reach profitable farming*<br>- *Keep livestock and poultry, fish farming*<br>- *Farming as retirement plan* |

| | |
|---|---|
| Education and sources of information | *Husband: university degree in accounting, currently pursuing MBA studies*<br>*Wife: completed secondary school*<br>*Children: going to school or university*<br>*Information sources: Governmental agriculture office, friends and family* |
| Community involvement | - *Living in the city, visiting farm every second day if possible*<br>- *Occasionally employing one neighbour*<br>- *Loose, friendly contact with other neighbours* |

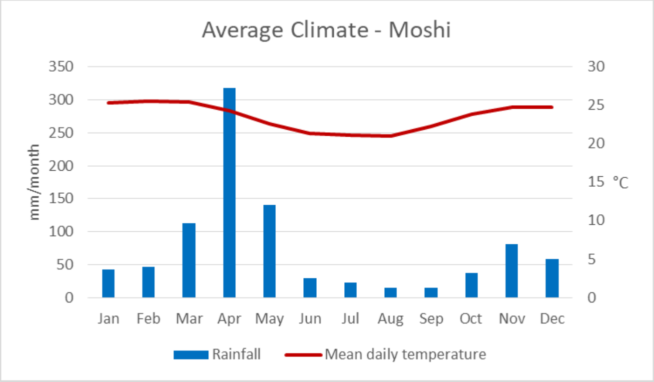
| Matrix of Crops – Farmer N° 8 | Total | Hot Pepper | Papaya | Cucumber |
|---|---|---|---|---|
| Area | *0.81 ha* | *0.81 ha* | *0.40 ha* | *0.20 ha* |
| Total yield/year | | *360,000 TZS / week* | *80 pieces / tree* | *300 buckets* |
| Price at market | | *1,700 – 5,000 TZS / kg* | *1,500 – 3,000 TZS / piece* | *9,000 TZS / bucket* |
| **Income from farm** | | | | |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | *1: max. 61.8 m³;<br>av. 92.0 m³<br>2: 20 m³ required;<br>10 m³ supplied* | *Max. 30.5 m³* | *Max. 25.3 m³* | *Max. 9.0 m³* |
| Expenditures for irrigation | *150,000 TZS / month* | | | |
| Payed workers | *1 + 0-3;<br>1: 80,000 TZS/month<br>0-3: 10,000 TZS / 1-3 days* | | | |
| Seeds used | | *400,000 TZS* | *900 seedlings;<br>2,500 TZS / seedling* | *100,000 TZS* |
| Fertilizer used | *300,000 TZS* | | | |
| Chemicals used | *500,000 TZS* | | | |
| **Expenditures for farming** | ***0.4 million TZS / month*** | | | |

In green: expected

# Farmer N° 9 – Northern Highlands

| | |
|---|---|
| Farm size | *8.10 ha* |
| Cultivated area | *1.62 ha* |
| Cultivated crops | - *Maize*<br>- *Onion*<br>- *Sweet pepper*<br>- *Papaya*<br>- *Beans*<br>- *Sweet potato* |
| Unexploited area | *6.48 ha (insufficient irrigation; half of the area is covered by forest)* |
| Otherwise used area | *- Area for housing, livestock housing, and fish ponds* |
| Water sources | *Hand-dug well (11 m depth)* |
| Water use | *1st irrigation, 2nd livestock watering, 3rd domestic* |
| Irrigation system | *Flooding* |

| | |
|---|---|
| Main farmers | *Farm manager and farm owner* |
| Workers | *1 (permanent), 0-10 (day-workers)* |
| Living at the farm | *Farm manager* |
| Other sources of income | - *Farm manager: farm, wife's clothing store*<br>- *Farm owner: pension, textile printing business* |
| Average yearly income (total) | *Farm owner: 8.4 million TZS / 3,650 USD*<br>*(rate: 2,303.39 TZS : 1 USD* [90]*)* |
| Notes | - *Additionally cultivating farmland from neighbour*<br>- *Poor communication with SWP supplier (farmers didn't know how much space the PV panels needed)*<br>- *Planning to set up water storage for farm use* |
| Former water supply system | - *Petrol and diesel pumps, no water storage (10,000 l water tank at 3 m height for domestic use only)*<br>- *OPEX: 10,000 TZS / day* |



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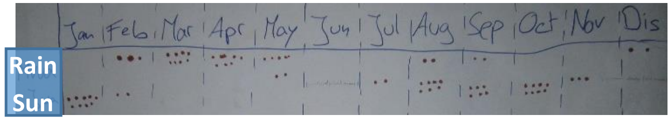


| | |
|---|---|
| New SWP system<br>Installation on 26/03/19 | - *Submersible pump (Simusolar SP6)*<br>- *6 panels à 230 Wp*<br>- *CAPEX 1.2 million TZS as deposit*<br>- *OPEX: total of 6.42 million TZS in instalment payments to supplier*<br>- *Installation finisehd on 05/04/19* |

| | |
|---|---|
| Farming challenges | - *Supplying sufficient water for irrigation (fuel pumps: too high costs;SWP: insufficient power)*<br>- *Quality of agriculture imputs*<br>- *Access to information* |
| Education and sources of information | *Farm manager: diploma in agriculture*<br>*Farm owner: missing (used to work at governmental office)*<br>*Information sources: Company exhibitions, other farmers* |
| Farmers' goals | - *Planning to set up efficient irrigation system*<br>- *Independency from seasons*<br>- *Resume fish farming*<br>- *Profitable farming* |
| Community involvement | - *Loose, inpersonal contact to most neighbours*<br>- *Setting up a local farmer society for mutual support and exchange of experience and knowhow* |

In green: expected

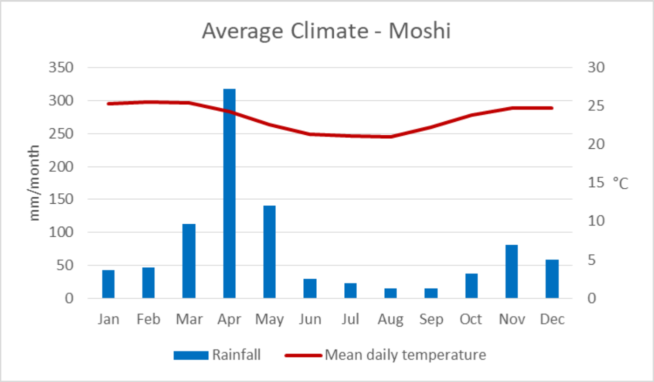
| Matrix of Crops – Farmer N° 9 | Total | Maize | Onion | Sweet Pepper | Papaya | Beans | Sweet Potato |
|---|---|---|---|---|---|---|---|
| Area | *1.62 ha* | *1.21 ha* | *1.21 ha + 0.30 ha + 1.21 ha* | *0.40 ha* | *0.40 ha* | *0.40 ha* | *0.40 ha* |
| Total yield/year | | *36-79 bags* | *180-200 bags* | *10 bags / week* | *None (insufficient irrigation)* | | |
| Price at market | | *45,000 – 60,000 TZS / bag* | *60,000 – 120,000 TZS / bag* | *70,000 – 120,000 TZS / bag* | | | |
| **Income from farm** | | | ***11 million TZS*** | ***16 million TZS*** | | | |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | *1: max. 145.6 $m^3$; av. 107.5 $m^3$ 2: -* | *Max. 42.5 $m^3$* | *Max. 89.2 $m^3$* | *Max. 21.7 $m^3$* | *Max. 26.8 $m^3$* | *Max. 18.8 $m^3$* | *Max. 27.2 $m^3$* |
| Expenditures for irrigation | *10,000 TZS / day* | | | | | | |
| Payed workers | *1 + 0-11* | | | | | | |
| Seeds used | | - | *400,000 TZS* | *60,000 TZS* | | | *40,000 TZS* |
| Fertilizer used | | *Manure (no expenses)* | *100,000 TZS* | *150,000 TZS* | | | |
| Chemicals used | | *230,000 TZS* | *180,000 TZS* | *210,000 TZS* | | | |
| **Expenditures for farming** | ***0.8 million / month*** | | | | | | |

In green: expected

# Farmer N° 10 – Northern Highlands

| | |
|---|---|
| Farm size | *1.62 ha* |
| Cultivated area | - |
| Cultivated crops | - *Tomato*<br>- *Onion*<br>- *Beans*<br>- *Maize*<br>- *Sweet pepper* |
| Unexploited area | *1.62 (unable to irrigate)* |
| Otherwise used area | *None* |
| Water sources | *River* |
| Water use | *Irrigation* |
| Irrigation system | *Flooding* |
| Farming challenges | - *Unable to afford sufficient fuel for appropriate irrigation*<br>- *Maintenance of petrol pump (technician from town required)*<br>- *Obtained prices at market* |
| Farmers' goals | - *Get rid of middlemen and sell directly at the market*<br>- *Reliable water supply and irrigation system*<br>- *Profitable farming*<br>- *Buy a tractor and rent it to neighbours* |

| | |
|---|---|
| Main farmers | *3 brothers* |
| Workers | *2 (permanent), 0-20 (day-worker)* |
| Living at the farm | *No one* |
| Other sources of income | - *2nd farm*<br>- *Keeping livestock*<br>- *Each wife's job* |
| Average yearly income (total) | *Missing* |
| Notes | - *Deposit paid by TAHA (delay in payment), farmer unaware about reason for delayed installation*<br>- *Flooding of whole area around the farm once a year for several weeks* |
| Former water supply system | - *Petrol pump, no water storage in place*<br>- *OPEX: 13,000 TZS / day*<br>- *Repeatedly out of function up to a month* |



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| | |
|---|---|
| New SWP system<br>Installation not realized | - *Submersible pump (Simusolar SP6)*<br>- *6 panels à 230 Wp*<br>- *CAPEX / OPEX: missing*<br>- *Contact to supplier through TAHA* |
| Education and sources of information | *Between dropping after primary school and completing secondary school*<br>*Information sources: Radio, TV, TAHA, NGOs, local societies* |
| Community involvement | - *Living in nearby village, part of local community*<br>- *Family farm taken over from parents* |

In green: expected

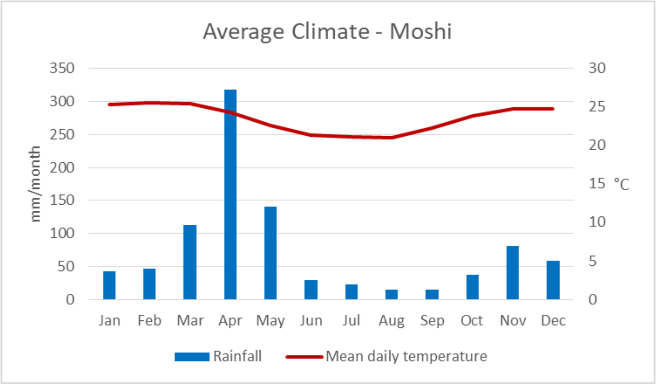
| Matrix of Crops – Farmer N° 10 | Total | Tomato | Onion | Beans | Maize | Sweet Pepper |
|---|---|---|---|---|---|---|
| Area | - | 0.40 ha<br>2 times/year | 0.81 ha | 0.81 ha | 1.42 ha<br>3 times/year | 0.81 ha |
| Total yield/year | | 600-800 boxes | 160 bags | 8 bags | 7,000 pieces<br>& 21-25 bags | 180-240 bags |
| Price at market | | 2,000 – 45,000 TZS / box | 25,000 – 200,000 TZS / bag | 150,000 – 180,000 TZS / bag | 300 TZS / piece<br>& 30,000 – 60,000 TZS / bag | 50,000 – 120,000 TZS / bag |
| **Income from farm** | ***17 million TZS*** | | | | | |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | 1: max. 203.0 $m^3$; av. 136.4 $m^3$<br>2: - | Max. 40.4 $m^3$ | Max. 43.7 $m^3$ | Max. 12.5 $m^3$ | Max. 101.6 $m^3$ | Max. 46.0 $m^3$ |
| Expenditures for irrigation | 13,000 TZS / (day & 0.4 ha) | | | | | |
| Payed workers | 2 + 0-20 (8,000 TZS / day) | 4-20 | 20 | 4-20 | 4-20 | 4-20 |
| Seeds used | | 0.04 kg;<br>550,000 TZS | 12 kg;<br>360,000 TZS | 100 kg;<br>100,000 TZS | 105 kg;<br>630,000 TZS | 0.8 kg;<br>480,000 TZS |
| Fertilizer used | | - | - | - | - | 610,000 TZS |
| Chemicals used | 350,000 TZS / (0.4 ha & season) | Normal | A lot | Normal | Normal | Normal |
| **Expenditures for farming** | ***12 million TZS*** | | | | | |

In green: expected

# Farmer N° 11 – Northern Highlands

| | |
|---|---|
| Farm size | *8.70 ha* |
| Cultivated area | *8.10 ha* |
| Cultivated crops | - *Maize*<br>- *Tomato*<br>- *Sweet Pepper*<br>- *Eggplant*<br>- *Okra*<br>- *Onion* |
| Unexploited area | *0.6 ha (occupied by road check point)* |
| Otherwise used area | *None (housing on additional land)* |
| Water sources | *River* |

| | |
|---|---|
| Main farmers | *Husband* |
| Workers | *1 (permanent), 0-14 (day-worker)* |
| Living at the farm | *Family and permanent worker* |
| Other sources of income | - *Wife's maize milling business*<br>- *Renting tractor* |
| Average yearly income (total) | *missing* |
| Notes | - *Deposit paid by TAHA (delay in payment), farmer unaware about reason for delayed installation*<br>- *Poor communication, farmer ignorant of required preparatory work and SWP specifications* |



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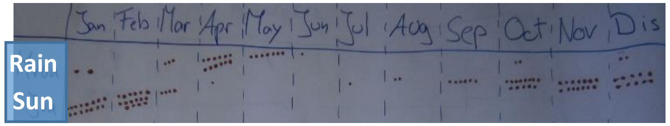


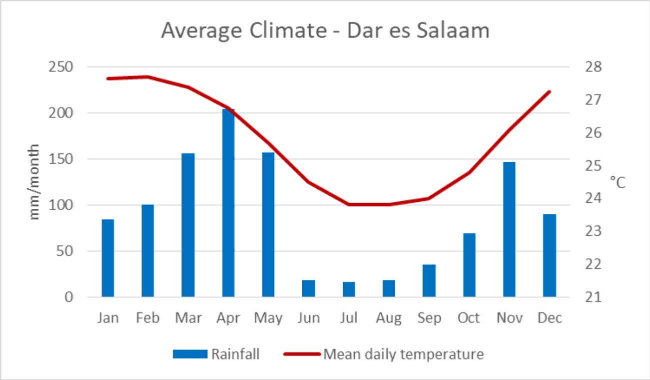
| | |
|---|---|
| Water use | *Irrigation* |
| Irrigation system | *Flooding; planning to set up drip irrigation system* |
| Former water supply system | - *Diesel pump, no water storage in place*<br>- *OPEX: 20,000 TZS / day* |
| New SWP system<br>Installation not realized | - *Submersible pump (Simusolar SP6)*<br>- *6 panels à 230 Wp*<br>- *CAPEX / OPEX missing*<br>- *Contact to supplier through TAHA* |
| Farming challenges | - *Irrigated area limited by available budget for fuel*<br>- *High and costly maintenance needs of diesel pump* |
| Education and sources of information | *Husband: completed secondary school*<br>*Wife: missing*<br>*Children: going to school*<br>*Information sources: TAHA, NGOs, friends and family* |
| Farmers' goals | - *Increase reliability and efficiency of farming*<br>- *Reach financial stability* |
| Community involvement | - *Little contact to nearby village*<br>- *Neighbours are his two brothers (divided inherited farmland between siblings)*<br>- *Member of lending society* |

| Matrix of Crops – Farmer N° 11 | Total | Maize | Tomato | Sweet Pepper | Eggplant | Okra | Onion |
|---|---|---|---|---|---|---|---|
| Area | *8.10 ha* | *4.45 ha* | *1.62 ha*<br>*4 times/year* | *1.21 ha* | *0.40 ha* | *0.40 ha* | *0.40 ha* |
| Total yield/year | | *800 pieces* | *2,400 boxes* | *90 bags* | *200-300 buckets* | *120-160 buckets* | *50 bags* |
| Price at market | | *1,000 TZS / piece* | *10,000 TZS / box* | *50,000 TZS / bag* | *15,000 – 30,000 TZS / bucket* | *6,000 – 15,000 TZS / bucket* | *60,000 TZS / bag* |
| **Income from farm** | ***15-47 million TZS*** | | | | | | |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | *1: max. 596.6 m³;*<br>*av. 227.3m³*<br>*2: -* | *Max. 277.7 m³* | *Max. 269.5 m³* | *Max. 66.7 m³* | *Max. 23.9 m³* | *Max. 21.1 m³* | *Max. 25.1 m³* |
| Expenditures for irrigation | *20,000 TZS / day* | | | | | | |
| Payed workers | *1 + 0-14;*<br>*1: 200,000 TZS / month*<br>*0-14: 7,000 TZS / day* | | | | | | |
| Seeds used | | *250,000 TZS* | *560,000 TZS* | *180,000 TZS* | | | |
| Fertilizer used | *1.6 million TZS* | | | | | | |
| Chemicals used | *2 million TZS* | | | | | | |
| **Expenditures for farming** | ***2-3 million TZS / month*** | | | | ***0.2-0.3 million TZS*** | ***0.2-0.3 million TZS*** | ***2 million TZS*** |

# Farmer N° 12 – Pwani Region

| | |
|---|---|
| Farm size | *4.05 ha* |
| Cultivated area | *0.81 ha* |
| Cultivated crops | - *Tomato*<br>- *Water melon*<br>- *Papaya*<br>- *Sugar cane*<br>- *Leaf vegetables* |
| Unexploited area | *3.24 ha (farmland needs to rest)* |
| Otherwise used area | *Area for housing* |
| Water sources | *Borehole (75 m depth), river (not year-long available)* |
| Water use | *Irrigation* |
| Irrigation system | *Drip irrigation* |

| | |
|---|---|
| Main farmers | *Father (on the farm in the weekends)* |
| Workers | *4 (permanent), 0-10 (day-worker)* |
| Living at the farm | *Permanent workers* |
| Other sources of income | - *Father's and mother's salaries*<br>- *Barber shop* |
| Average yearly income (total) | *15 million TZS / 6,500 USD (rate: 2,303.39 TZS : 1 USD* [90]*)* |
| Notes | - *Father's younger brother helping out in farm after finishing diploma in agriculture*<br>- *Still using former system to pump water from the pond to the field*<br>- *Neighbour acquired SWP (word-of-mouth)* |
| Former water supply system | - *Diesel pump, approx. 80,000 l pond for water storage*<br>- *OPEX: 12,000 TZS / day*<br>- *Had to replace diesel pump twice within one year* |



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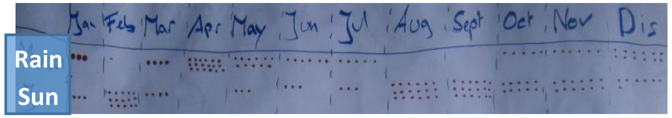


| | |
|---|---|
| New SWP system<br>Installation on 29/03/19 | - *Submersible pump (Simusolar SP7)*<br>- *6 panels à 230 Wp*<br>- *CAPEX: 1.2 million TZS as deposit*<br>- *OPEX: total of 6.42 million TZS in instalment payments to supplier* |

| | |
|---|---|
| Farming challenges | - *Low quality of soil*<br>- *Strong sun*<br>- *Setting up appropiate water storage* |
| Farmers' goals | - *Get the farm working*<br>- *Cultivate papaya and sugar cane*<br>- *Keep livestock* |
| Education and sources of information | *Father and mother: university degree in accounting*<br>*Children: going to school*<br>*Information sources: Governmental agriculture office, internet, friends and family, learning by doing* |
| Community involvement | - *Living in the city 1-2 hours away depending on traffic*<br>- *New in the area, has a community well on his farmland*<br>- *Occasionally employing neighbours* |

In green: expected

| Matrix of Crops – Farmer N° 12 | Total | Tomato | Water Melon | Papaya | Sugarcane | Leaf Vegetables |
|---|---|---|---|---|---|---|
| Area | *0.81 ha* | *0.61 ha*<br>*4 times/year* | *1.21 ha*<br>*(0.61 ha)* | *0.61 ha* | *0.40 ha* | *0.20 ha* |
| Total yield/year | | *1,300 boxes*<br>*(4,000 boxes)* | *6,000 – 9,000 pieces* | | | |
| Price at market | | *15,000 – 45,000 TZS / box* | *3,000 TZS / piece* | | | |
| **Income from farm** | | | | | | |
| Daily water demand (1:FAO calculation; 2: Farmer estimate) | *1: max. 148.3 $m^3$; av. 103.9 $m^3$*<br>*2: 60 $m^3$ required & supplied* | *Max. 58.4 $m^3$* | *Max. 67.8 $m^3$*<br>*(max. 34.2 $m^3$)* | *Max. 42.9 $m^3$* | *Max. 29.4 $m^3$* | *Max. 9.7 $m^3$* |
| Expenditures for irrigation | *12,000 TZS / day* | *Petrol pump still required* | *Only SWP* | *Petrol pump still required* | *Petrol pump still required* | *Petrol pump still required* |
| Payed workers | *4 + 0-10;*<br>*4: 80,000 TZS/month*<br>*0-10: 7,000 TZS/day* | | | | | |
| Seeds used | | *0.06 kg;*<br>*420,000 TZS* | *1.25 kg (0.75 kg)*<br>*575,000 TZS*<br>*(345,000 TZS)* | | | |
| Fertilizer used | *1.14 million TZS* | | | | | |
| Chemicals used | *0.75 million TZS* | | | | | |
| **Expenditures for farming** | ***14 million TZS*** | | | | | |

In green: expected

# ANNEX F – PAIR-RANKING MATRICES

Farm nº 1

| | *Low Operational Costs - **1*** | *Low Initial Investment - **2*** | *Possibility to Cultivate Additional Types of Plants - **3*** | *Saving Time - **4*** | *Simplicity of Use - **5*** | *Reliability of System - **6*** | *Independency from Electricity (TANESCO) - **7*** | *Independency from Money for Irrigation - **8*** | *Low Maintenance - **9*** | *Paying only once for Irrigation - **10*** | *SCORE -* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Low Operational Costs - **1*** | | | | | | | | | | | 4 |
| *Low Initial Investment - **2*** | 1 | | | | | | | | | | 6 |
| *Possibility to Cultivate Additional Types of Plants - **3*** | 1 | 3 | | | | | | | | | 3 |
| *Saving Time - **4*** | 1 | 2 | 3 | | | | | | | | 0 |
| *Simplicity of Use - **5*** | 1 | 2 | 5 | 5 | | | | | | | 4 |
| *Reliability of System - **6*** | 6 | 6 | 6 | 6 | 5 | | | | | | 4 |
| *Independency from Electricity (TANESCO) - **7*** | 7 | 2 | 7 | 7 | 7 | 7 | | | | | 5 |
| *Independency from Money for Irrigation - **8*** | 8 | 2 | 8 | 8 | 5 | 8 | 8 | | | | 5 |
| *Low Maintenance - **9*** | 9 | 2 | 3 | 9 | 9 | 9 | 9 | 9 | | | 6 |
| *Paying only once for Irrigation - **10*** | 10 | 2 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | 8 |

| *NORMALISED SCORE -* | | *RANKING -* |
|---|---|---|
| 0.89 | **Paying only once for Irrigation** | **1** |
| 0.67 | **Low Initial Investment** | **2** |
| 0.67 | **Low Maintenance** | **2** |
| 0.56 | Independency from Electricity (TANESCO) | 4 |
| 0.56 | Independency from Money for Irrigation | 4 |
| 0.44 | Low Operational Costs | 6 |
| 0.44 | Simplicity of Use | 6 |
| 0.44 | Reliability of System | 6 |
| 0.33 | Possibility to Cultivate Additional Types of Plants | 9 |
| 0.00 | Saving Time | 10 |

Farm nº 2

| | *Low Operational Costs -* ***1*** | *Low Initial Investment -* ***2*** | *Possibility to Cultivate Additional Types of Plants -* ***3*** | *Saving Time -* ***4*** | *Simplicity of Use -* ***5*** | *Reliability of System -* ***6*** | *Independency from Seasons -* ***11*** | *SCORE* |
|---|---|---|---|---|---|---|---|---|
| *Low Operational Costs -* ***1*** | | | | | | | | 2 |
| *Low Initial Investment -* ***2*** | 1 | | | | | | | 0 |
| *Possibility to Cultivate Additional Types of Plants -* ***3*** | 3 | 3 | | | | | | 2 |
| *Saving Time -* ***4*** | 4 | 4 | 4 | | | | | 3 |
| *Simplicity of Use -* ***5*** | 1 | 5 | 5 | 5 | | | | 3 |
| *Reliability of System -* ***6*** | 6 | 6 | 6 | 6 | 6 | | | 5 |
| *Independency from Seasons -* ***11*** | 11 | 11 | 11 | 11 | 11 | 11 | | 6 |

| *NORMALISED SCORE* | | *RANKING* |
|---|---|---|
| 1.00 | **Independency from Seasons** | **1** |
| 0.83 | **Reliability of System** | **2** |
| 0.50 | **Saving Time** | **3** |
| 0.50 | **Simplicity of Use** | **3** |
| 0.33 | Low Operational Costs | 5 |
| 0.33 | Possibility to Cultivate Additional Types of Plants | 5 |
| 0.00 | Low Initial Investment | 7 |

Farm nº 3

| | *Low Operational Costs - **1*** | *Low Initial Investment - **2*** | *Possibility to Cultivate Additional Types of Plants - **3*** | *Saving Time - **4*** | *Simplicity of Use - **5*** | *Reliability of System - **6*** | *Supplying Sufficient Water - **12*** | *SCORE* |
|---|---|---|---|---|---|---|---|---|
| *Low Operational Costs - **1*** | | | | | | | | 3 |
| *Low Initial Investment - **2*** | 1 | | | | | | | 1 |
| *Possibility to Cultivate Additional Types of Plants - **3*** | 1 | 3 | | | | | | 3 |
| *Saving Time - **4*** | 1 | 2 | 3 | | | | | 0 |
| *Simplicity of Use - **5*** | 5 | 5 | 3 | 5 | | | | 3 |
| *Reliability of System - **6*** | 6 | 6 | 6 | 6 | 6 | | | 5 |
| *Supplying Sufficient Water - **12*** | 12 | 12 | 12 | 12 | 12 | 12 | | 6 |

| *NORMALISED SCORE* | | *RANKING* |
|---|---|---|
| 1.00 | **Supplying Sufficient Water** | **1** |
| 0.83 | **Reliability of System** | **2** |
| 0.50 | **Low Operational Costs** | **3** |
| 0.50 | **Possibility to Cultivate Additional Types of Plants** | **3** |
| 0.50 | **Simplicity of Use** | **3** |
| 0.17 | Low Initial Investment | 6 |
| 0.00 | Saving Time | 7 |

Farm nº 4.1

| | *Low Operational Costs - **1*** | *Low Initial Investment - **2*** | *Possibility to Cultivate Additional Types of Plants - **3*** | *Saving Time - **4*** | *Simplicity of Use - **5*** | *Reliability of System - **6*** | *SCORE* |
|---|---|---|---|---|---|---|---|
| *Low Operational Costs - **1*** | | | | | | | 2 |
| *Low Initial Investment - **2*** | 1 | | | | | | 1 |
| *Possibility to Cultivate Additional Types of Plants - **3*** | 1 | 3 | | | | | 1 |
| *Saving Time - **4*** | 4 | 2 | 4 | | | | 4 |
| *Simplicity of Use - **5*** | 5 | 5 | 5 | 4 | | | 3 |
| *Reliability of System - **6*** | 6 | 6 | 6 | 4 | 6 | | 4 |

| *NORMALISED SCORE* | | *RANKING* |
|---|---|---|
| 0.80 | **Saving Time** | **1** |
| 0.80 | **Reliability of System** | **1** |
| 0.60 | **Simplicity of Use** | **3** |
| 0.40 | Low Operational Costs | 4 |
| 0.20 | Low Initial Investment | 5 |
| 0.20 | Possibility to Cultivate Additional Types of Plants | 5 |

Farm nº 4.2

| | *Low Operational Costs - **1*** | *Low Initial Investment - **2*** | *Possibility to Cultivate Additional Types of Plants - **3*** | *Saving Time - **4*** | *Simplicity of Use - **5*** | *Reliability of System - **6*** | *SCORE* |
|---|---|---|---|---|---|---|---|
| *Low Operational Costs - **1*** | | | | | | | 2 |
| *Low Initial Investment - **2*** | 1 | | | | | | 3 |
| *Possibility to Cultivate Additional Types of Plants - **3*** | 1 | 2 | | | | | 0 |
| *Saving Time - **4*** | 4 | 2 | 4 | | | | 4 |
| *Simplicity of Use - **5*** | 5 | 2 | 5 | 4 | | | 2 |
| *Reliability of System - **6*** | 6 | 6 | 6 | 4 | 6 | | 4 |

| *NORMALISED SCORE* | | *RANKING* |
|---|---|---|
| 0.80 | **Saving Time** | **1** |
| 0.80 | **Reliability of System** | **1** |
| 0.60 | **Low Initial Investment** | **3** |
| 0.40 | Low Operational Costs | 4 |
| 0.40 | Simplicity of Use | 4 |
| 0.00 | Possibility to Cultivate Additional Types of Plants | 6 |

Farm nº 5

| | *Low Operational Costs - **1*** | *Low Initial Investment - **2*** | *Possibility to Cultivate Additional Types of Plants - **3*** | *Saving Time - **4*** | *Simplicity of Use - **5*** | *Reliability of System - **6*** | *SCORE* |
|---|---|---|---|---|---|---|---|
| *Low Operational Costs - **1*** | | | | | | | 3 |
| *Low Initial Investment - **2*** | 1 | | | | | | 1 |
| *Possibility to Cultivate Additional Types of Plants - **3*** | 1 | 3 | | | | | 0 |
| *Saving Time - **4*** | 4 | 2 | 3 | | | | 2 |
| *Simplicity of Use - **5*** | 1 | 5 | 3 | 4 | | | 1 |
| *Reliability of System - **6*** | 6 | 6 | 6 | 6 | 6 | | 5 |

| *NORMALISED SCORE* | | *RANKING* |
|---|---|---|
| 1.00 | **Reliability of System** | **1** |
| 0.60 | **Low Operational Costs** | **2** |
| 0.40 | **Saving Time** | **3** |
| 0.20 | Low Initial Investment | 4 |
| 0.20 | Simplicity of Use | 4 |
| 0.00 | Possibility to Cultivate Additional Types of Plants | 6 |

Farm nº 6.1

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Low Operational Costs -* ***1*** | | | | | | | | 1 |
| *Low Initial Investment -* ***2*** | 1 | | | | | | | 1 |
| *Possibility to Cultivate Additional Types of Plants -* ***3*** | 3 | 3 | | | | | | 5 |
| *Saving Time -* ***4*** | 4 | 2 | 3 | | | | | 2 |
| *Simplicity of Use -* ***5*** | 5 | 5 | 3 | 4 | | | | 3 |
| *Reliability of System -* ***6*** | 6 | 6 | 6 | 6 | 5 | | | 5 |
| *Supplying Sufficient Water -* ***12*** | 12 | 12 | 3 | 12 | 12 | 6 | | 4 |
| | *Low Operational Costs -* ***1*** | *Low Initial Investment -* ***2*** | *Possibility to Cultivate Additional Types of Plants -* ***3*** | *Saving Time -* ***4*** | *Simplicity of Use -* ***5*** | *Reliability of System -* ***6*** | *Supplying Sufficient Water -* ***12*** | *SCORE* |

| | | |
|---|---|---|
| 0.83 | **Possibility to Cultivate Additional Types of Plants** | **1** |
| 0.83 | **Reliability of System** | **1** |
| 0.67 | **Supplying Sufficient Water** | **3** |
| 0.50 | Simplicity of Use | 4 |
| 0.33 | Saving Time | 5 |
| 0.17 | Low Operational Costs | 6 |
| 0.17 | Low Initial Investment | 6 |
| *NORMALISED SCORE* | | *RANKING* |

Farm nº 6.2

| | *Low Operational Costs -* ***1*** | *Low Initial Investment -* ***2*** | *Possibility to Cultivate Additional Types of Plants -* ***3*** | *Saving Time -* ***4*** | *Simplicity of Use -* ***5*** | *Reliability of System -* ***6*** | *Independency from Seasons -* ***11*** | *Increase Production -* ***13*** | *SCORE* |
|---|---|---|---|---|---|---|---|---|---|
| *Low Operational Costs -* ***1*** | | | | | | | | | 3 |
| *Low Initial Investment -* ***2*** | 1 | | | | | | | | 1 |
| *Possibility to Cultivate Additional Types of Plants -* ***3*** | 3 | 3 | | | | | | | 3 |
| *Saving Time -* ***4*** | 1 | 2 | 3 | | | | | | 0 |
| *Simplicity of Use -* ***5*** | 1 | 5 | 5 | 5 | | | | | 3 |
| *Reliability of System -* ***6*** | 6 | 6 | 6 | 6 | 6 | | | | 7 |
| *Independency from Seasons -* ***11*** | 11 | 11 | 11 | 11 | 11 | 6 | | | 6 |
| *Increase Production -* ***13*** | 13 | 13 | 13 | 13 | 13 | 6 | 11 | | 5 |

| *NORMALISED SCORE* | | *RANKING* |
|---|---|---|
| 1.00 | **Reliability of System** | **1** |
| 0.86 | **Independency from Seasons** | **2** |
| 0.71 | **Increase Production** | **3** |
| 0.43 | Low Operational Costs | 4 |
| 0.43 | Possibility to Cultivate Additional Types of Plants | 4 |
| 0.43 | Simplicity of Use | 4 |
| 0.43 | Low Initial Investment | 6 |
| 0.14 | Saving Time | 7 |

Farm nº 7

| | *Low Operational Costs - **1*** | *Low Initial Investment - **2*** | *Possibility to Cultivate Additional Types of Plants - **3*** | *Saving Time - **4*** | *Simplicity of Use - **5*** | *Reliability of System - **6*** | *SCORE* |
|---|---|---|---|---|---|---|---|
| *Low Operational Costs - **1*** | | | | | | | 4 |
| *Low Initial Investment - **2*** | 1 | | | | | | 0 |
| *Possibility to Cultivate Additional Types of Plants - **3*** | 1 | 3 | | | | | 3 |
| *Saving Time - **4*** | 1 | 4 | 3 | | | | 1 |
| *Simplicity of Use - **5*** | 1 | 5 | 3 | 5 | | | 2 |
| *Reliability of System - **6*** | 6 | 6 | 6 | 6 | 6 | | 5 |

| *NORMALISED SCORE* | | *RANKING* |
|---|---|---|
| 1.00 | **Reliability of System** | **1** |
| 0.80 | **Low Operational Costs** | **2** |
| 0.60 | **Possibility to Cultivate Additional Types of Plants** | **3** |
| 0.40 | Simplicity of Use | 4 |
| 0.20 | Saving Time | 5 |
| 0.00 | Low Initial Investment | 6 |

Farm nº 8

| | *Low Operational Costs - **1*** | *Low Initial Investment - **2*** | *Possibility to Cultivate Additional Types of Plants - **3*** | *Saving Time - **4*** | *Simplicity of Use - **5*** | *Reliability of System - **6*** | *Increase Production - **13*** | *SCORE* |
|---|---|---|---|---|---|---|---|---|
| *Low Operational Costs - **1*** | | | | | | | | 2 |
| *Low Initial Investment - **2*** | 1 | | | | | | | 1 |
| *Possibility to Cultivate Additional Types of Plants - **3*** | 1 | 2 | | | | | | 1 |
| *Saving Time - **4*** | 4 | 4 | 3 | | | | | 2 |
| *Simplicity of Use - **5*** | 5 | 5 | 5 | 5 | | | | 4 |
| *Reliability of System - **6*** | 6 | 6 | 6 | 6 | 6 | | | 5 |
| *Increase Production - **13*** | 13 | 13 | 13 | 13 | 13 | 13 | | 6 |

| *NORMALISED SCORE* | | *RANKING* |
|---|---|---|
| 1.00 | **Increase Production** | **1** |
| 0.83 | **Reliability of System** | **2** |
| 0.67 | **Simplicity of Use** | **3** |
| 0.33 | Low Operational Costs | 4 |
| 0.33 | Saving Time | 4 |
| 0.17 | Low Initial Investment | 6 |
| 0.17 | Possibility to Cultivate Additional Types of Plants | 6 |

Farm nº 9

| | *Low Operational Costs - **1*** | *Low Initial Investment - **2*** | *Possibility to Cultivate Additional Types of Plants - **3*** | *Saving Time - **4*** | *Simplicity of Use - **5*** | *Reliability of System - **6*** | *SCORE* |
|---|---|---|---|---|---|---|---|
| *Low Operational Costs -* ***1*** | | | | | | | 3 |
| *Low Initial Investment -* ***2*** | 1 | | | | | | 0 |
| *Possibility to Cultivate Additional Types of Plants -* ***3*** | 1 | 3 | | | | | 3 |
| *Saving Time -* ***4*** | 1 | 4 | 3 | | | | 1 |
| *Simplicity of Use -* ***5*** | 5 | 5 | 3 | 5 | | | 3 |
| *Reliability of System -* ***6*** | 6 | 6 | 6 | 6 | 6 | | 5 |

| *NORMALISED SCORE* | | *RANKING* |
|---|---|---|
| 1.00 | **Reliability of System** | **1** |
| 0.60 | **Low Operational Costs** | **2** |
| 0.60 | **Possibility to Cultivate Additional Types of Plants** | **2** |
| 0.60 | **Simplicity of Use** | **2** |
| 0.20 | Saving Time | 5 |
| 0.00 | Low Initial Investment | 6 |

Farm nº 10

| | *Low Operational Costs - **1*** | *Low Initial Investment - **2*** | *Possibility to Cultivate Additional Types of Plants - **3*** | *Saving Time - **4*** | *Simplicity of Use - **5*** | *Reliability of System - **6*** | *Less Workers Needed - **14*** | SCORE |
|---|---|---|---|---|---|---|---|---|
| *Low Operational Costs - **1*** | | | | | | | | 1 |
| *Low Initial Investment - **2*** | 2 | | | | | | | 5 |
| *Possibility to Cultivate Additional Types of Plants - **3*** | 3 | 2 | | | | | | 4 |
| *Saving Time - **4*** | 4 | 2 | 3 | | | | | 3 |
| *Simplicity of Use - **5*** | 5 | 2 | 3 | 4 | | | | 2 |
| *Reliability of System - **6*** | 6 | 6 | 6 | 6 | 6 | | | 6 |
| *Less Workers Needed - **14*** | 1 | 2 | 3 | 4 | 5 | 6 | | 0 |

| NORMALISED SCORE | | RANKING |
|---|---|---|
| 1.00 | **Reliability of System** | **1** |
| 0.83 | **Low Initial Investment** | **2** |
| 0.67 | **Possibility to Cultivate Additional Types of Plants** | **3** |
| 0.50 | Saving Time | 4 |
| 0.33 | Simplicity of Use | 5 |
| 0.17 | Low Operational Costs | 6 |
| 0.00 | Less Workers Needed | 7 |

Farm nº 11

| | *Low Operational Costs -* ***1*** | *Low Initial Investment -* ***2*** | *Possibility to Cultivate Additional Types of Plants -* ***3*** | *Saving Time -* ***4*** | *Simplicity of Use -* ***5*** | *Reliability of System -* ***6*** | *SCORE* |
|---|---|---|---|---|---|---|---|
| *Low Operational Costs -* ***1*** | | | | | | | 2 |
| *Low Initial Investment -* ***2*** | 1 | | | | | | 1 |
| *Possibility to Cultivate Additional Types of Plants -* ***3*** | 1 | 2 | | | | | 0 |
| *Saving Time -* ***4*** | 4 | 4 | 4 | | | | 4 |
| *Simplicity of Use -* ***5*** | 5 | 5 | 5 | 4 | | | 4 |
| *Reliability of System -* ***6*** | 6 | 6 | 6 | 6 | 5 | | 4 |

| *NORMALISED SCORE* | | *RANKING* |
|---|---|---|
| 0.80 | **Saving Time** | **1** |
| 0.80 | **Simplicity of Use** | **1** |
| 0.80 | **Reliability of System** | **1** |
| 0.40 | Low Operational Costs | 4 |
| 0.20 | Low Initial Investment | 5 |
| 0.00 | Possibility to Cultivate Additional Types of Plants | 6 |

Farm nº 12

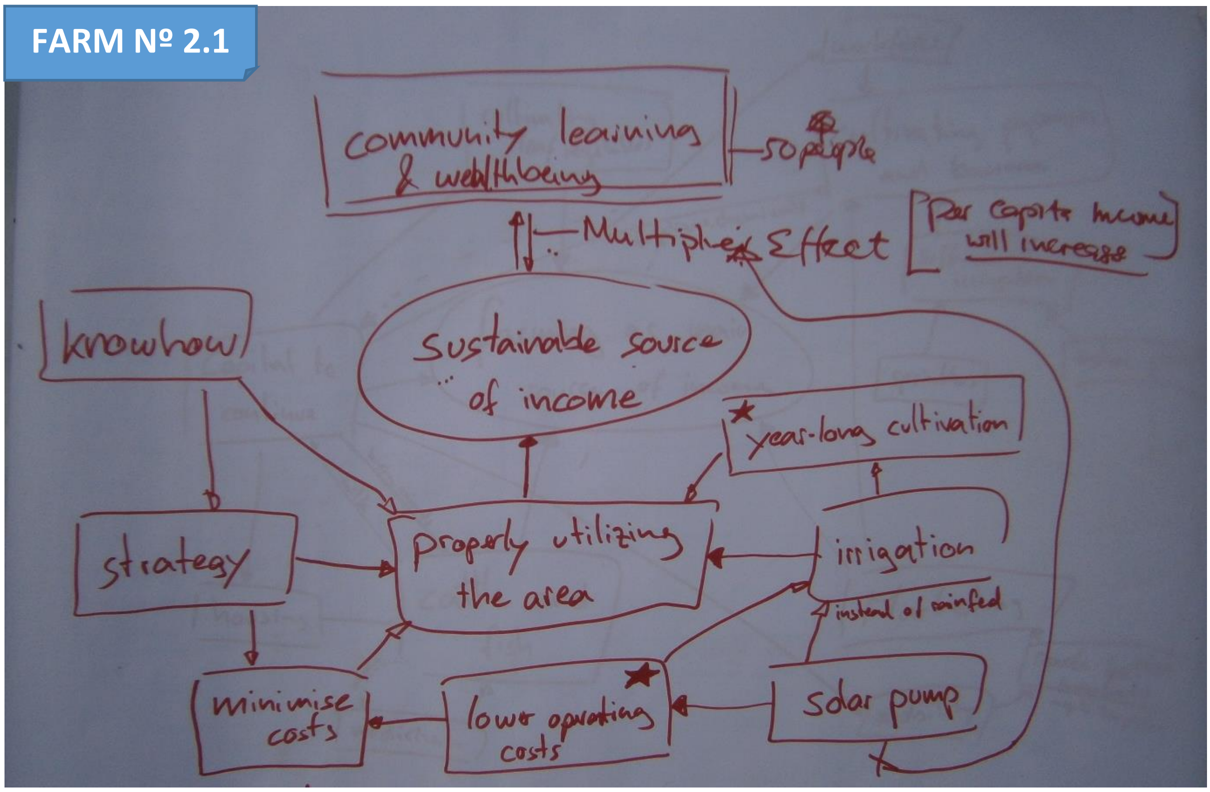
| | *Low Operational Costs - **1*** | *Low Initial Investment - **2*** | *Possibility to Cultivate Additional Types of Plants - **3*** | *Saving Time - **4*** | *Simplicity of Use - **5*** | *Reliability of System - **6*** | *SCORE* |
|---|---|---|---|---|---|---|---|
| *Low Operational Costs - **1*** | | | | | | | 5 |
| *Low Initial Investment - **2*** | 1 | | | | | | 3 |
| *Possibility to Cultivate Additional Types of Plants - **3*** | 1 | 3 | | | | | 4 |
| *Saving Time - **4*** | 1 | 2 | 3 | | | | 0 |
| *Simplicity of Use - **5*** | 1 | 2 | 3 | 5 | | | 1 |
| *Reliability of System - **6*** | 1 | 2 | 3 | 6 | 6 | | 2 |

| *NORMALISED SCORE* | | *RANKING* |
|---|---|---|
| 1.00 | **Low Operational Costs** | **1** |
| 0.80 | **Possibility to Cultivate Additional Types of Plants** | **2** |
| 0.60 | **Low Initial Investment** | **3** |
| 0.40 | Reliability of System | 4 |
| 0.20 | Simplicity of Use | 5 |
| 0.00 | Saving Time | 6 |

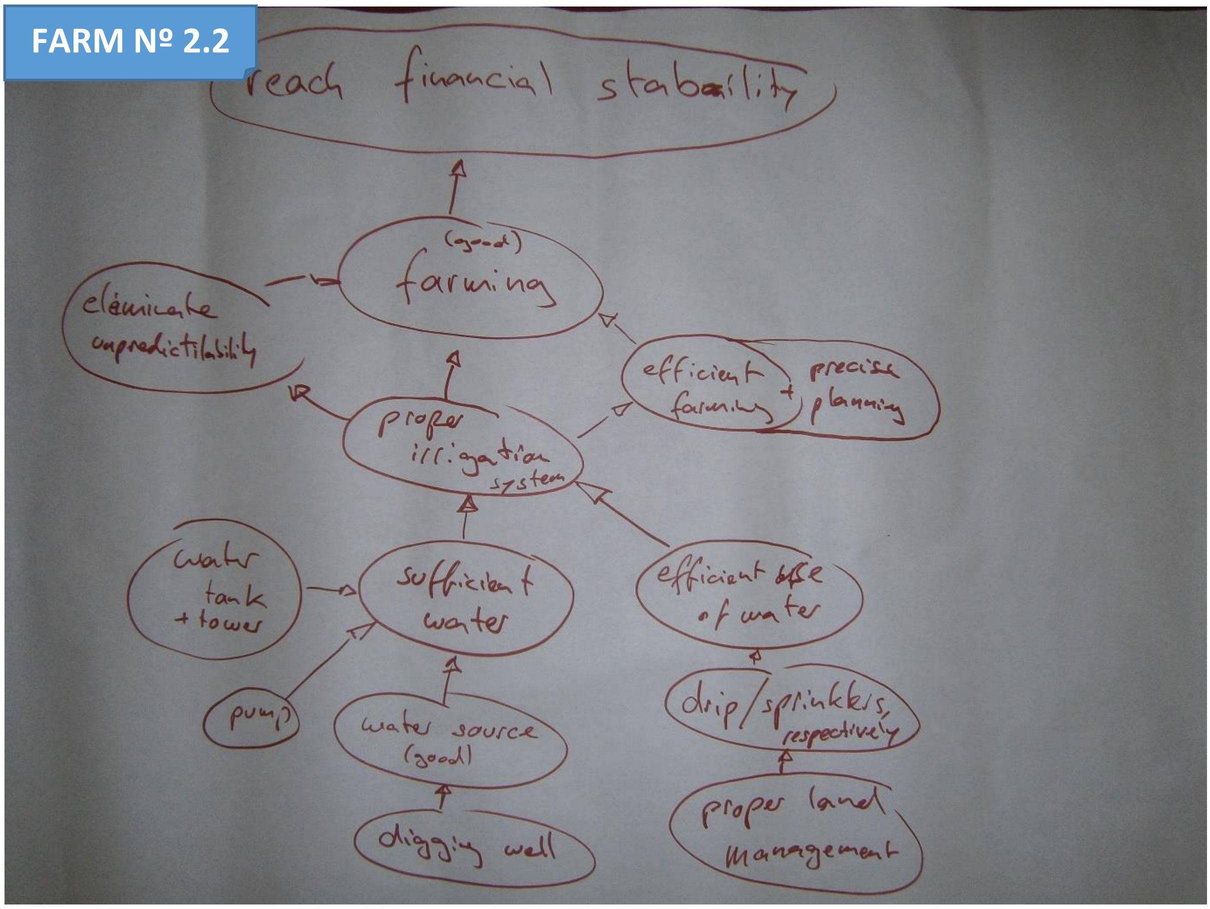
# ANNEX G – FLOWCHARTS

## FARM Nº 1

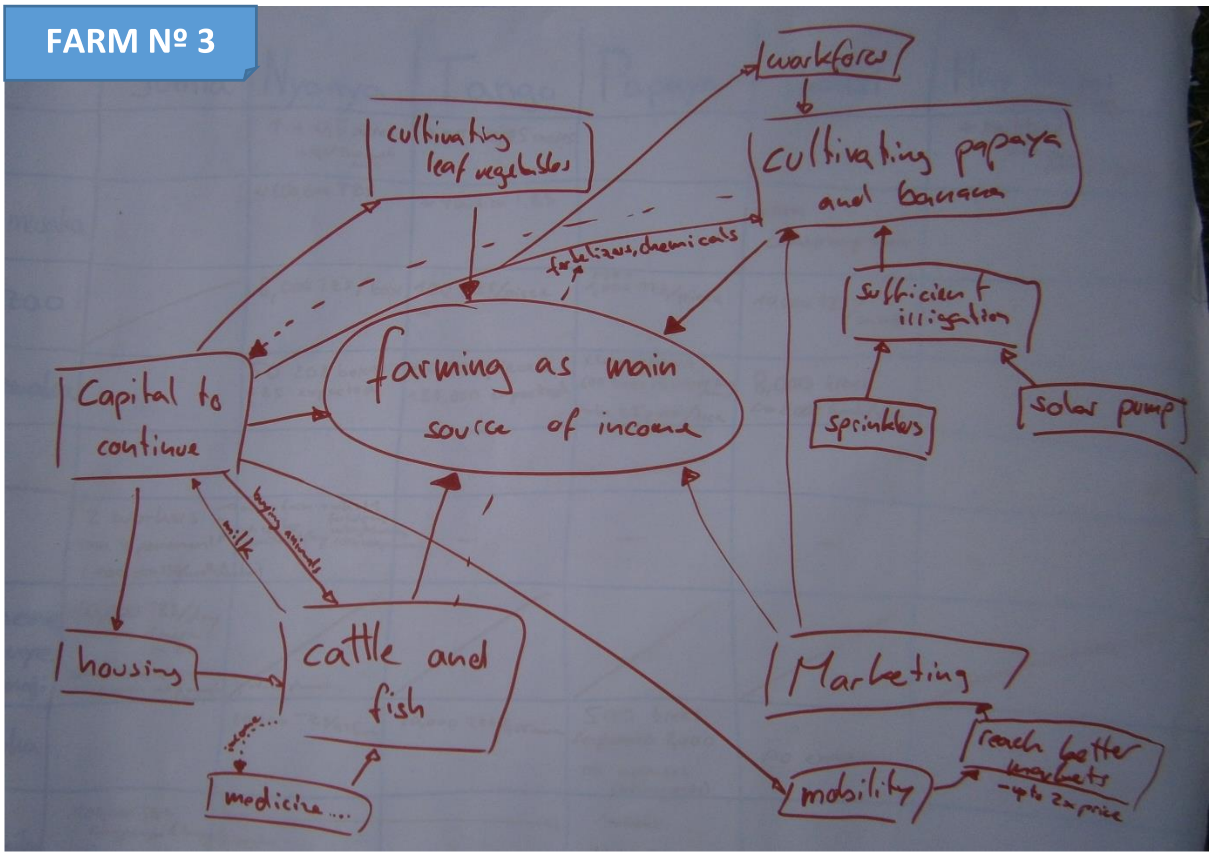
## FARM № 2.1



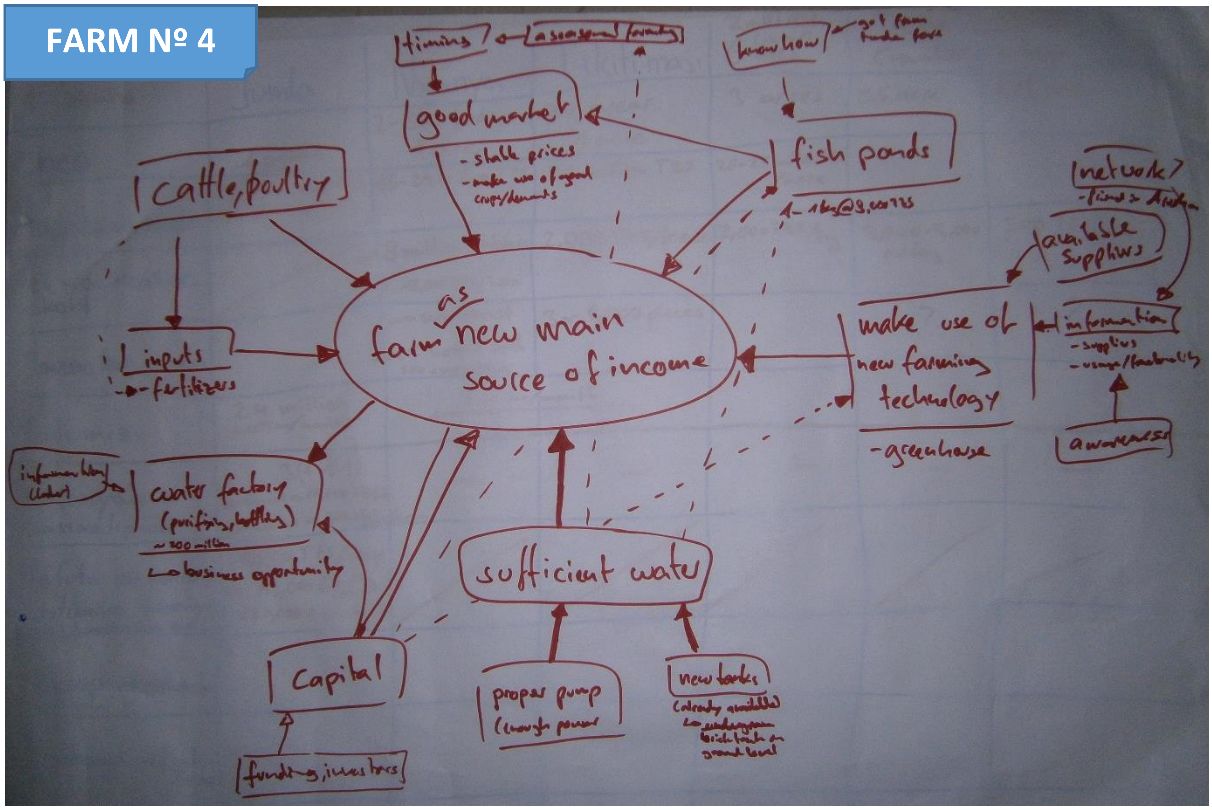
## FARM № 2.2



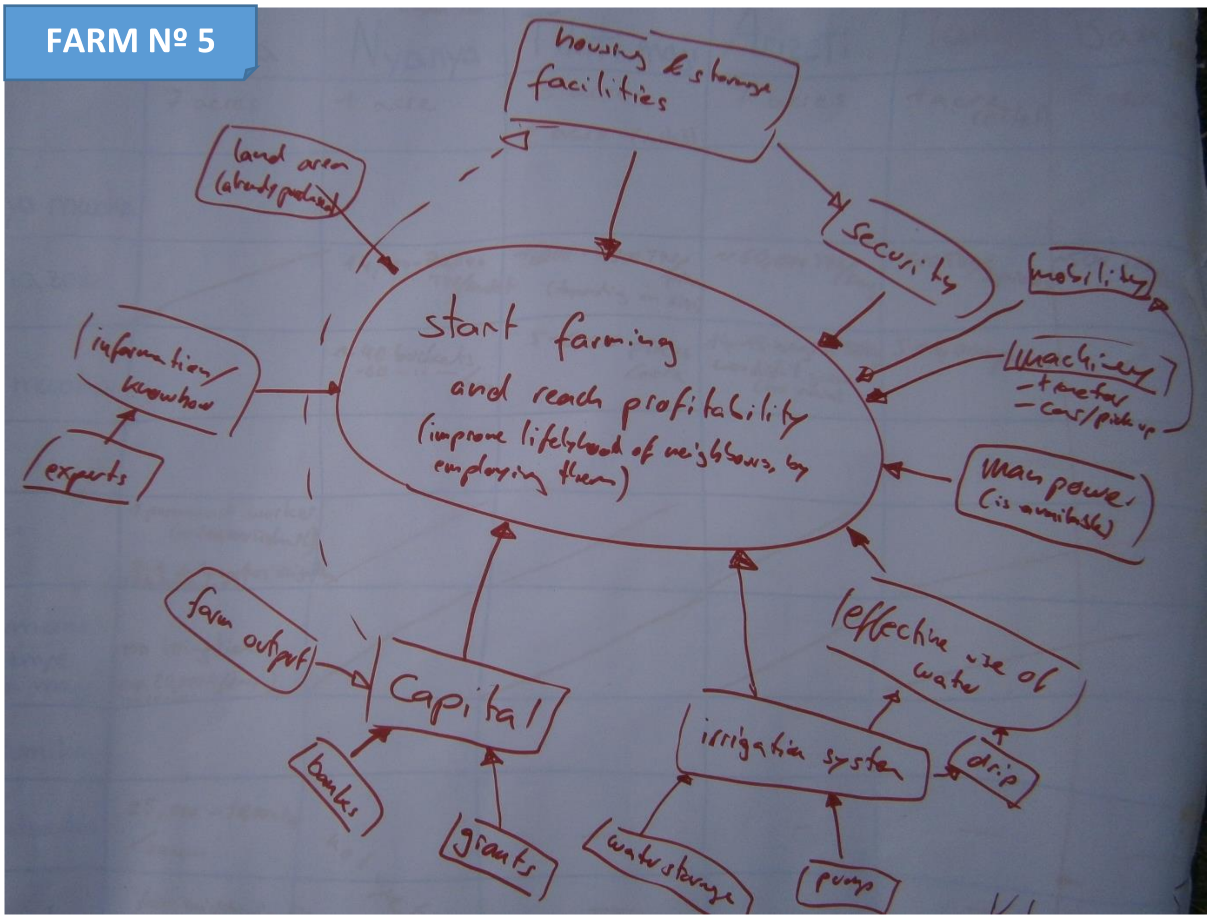
**FARM Nº 3**



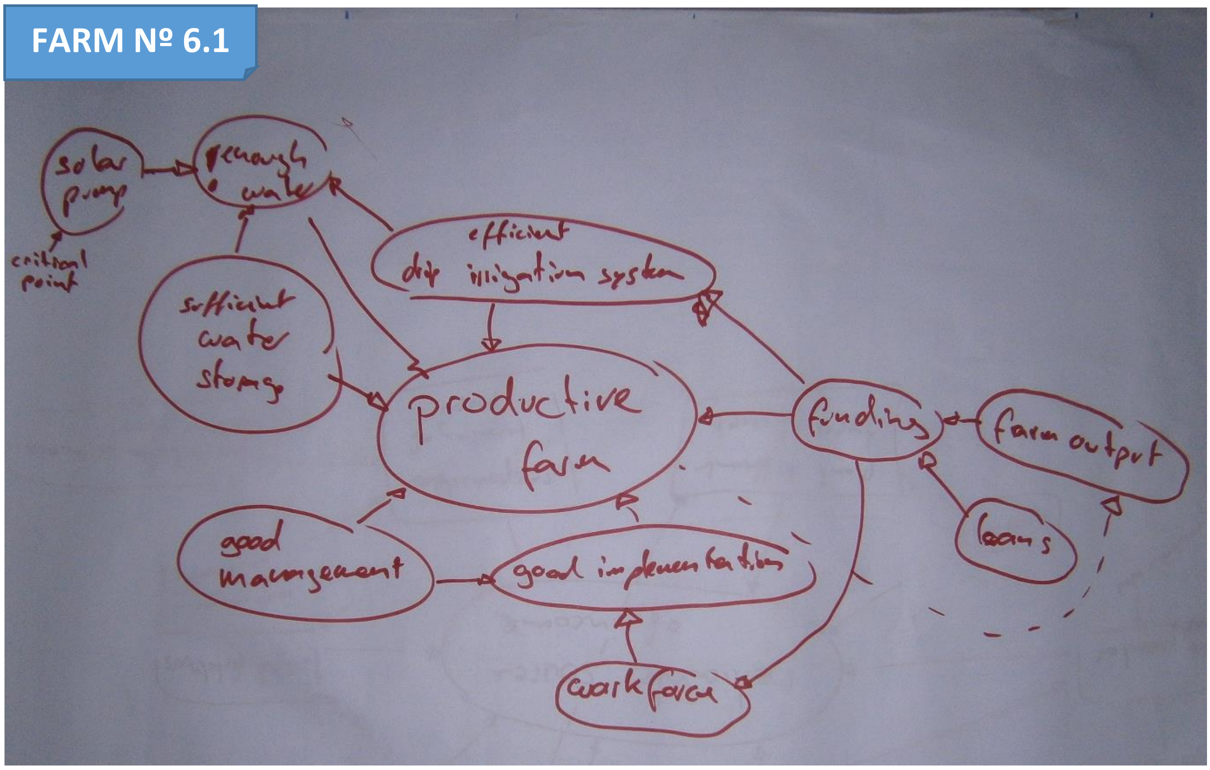
**FARM Nº 4**



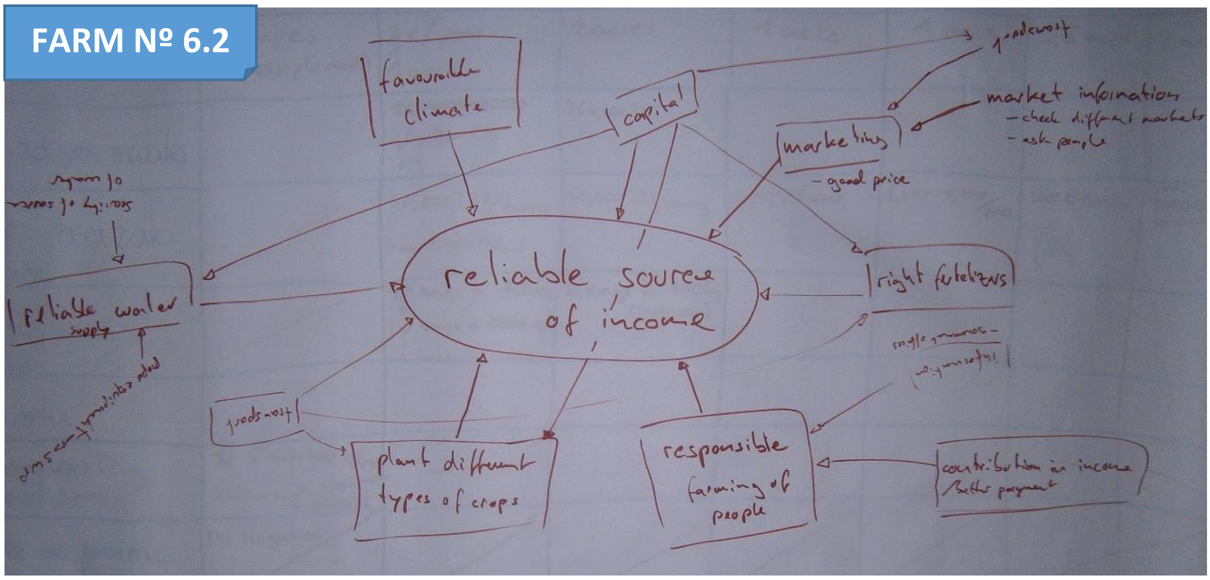
**FARM Nº 5**



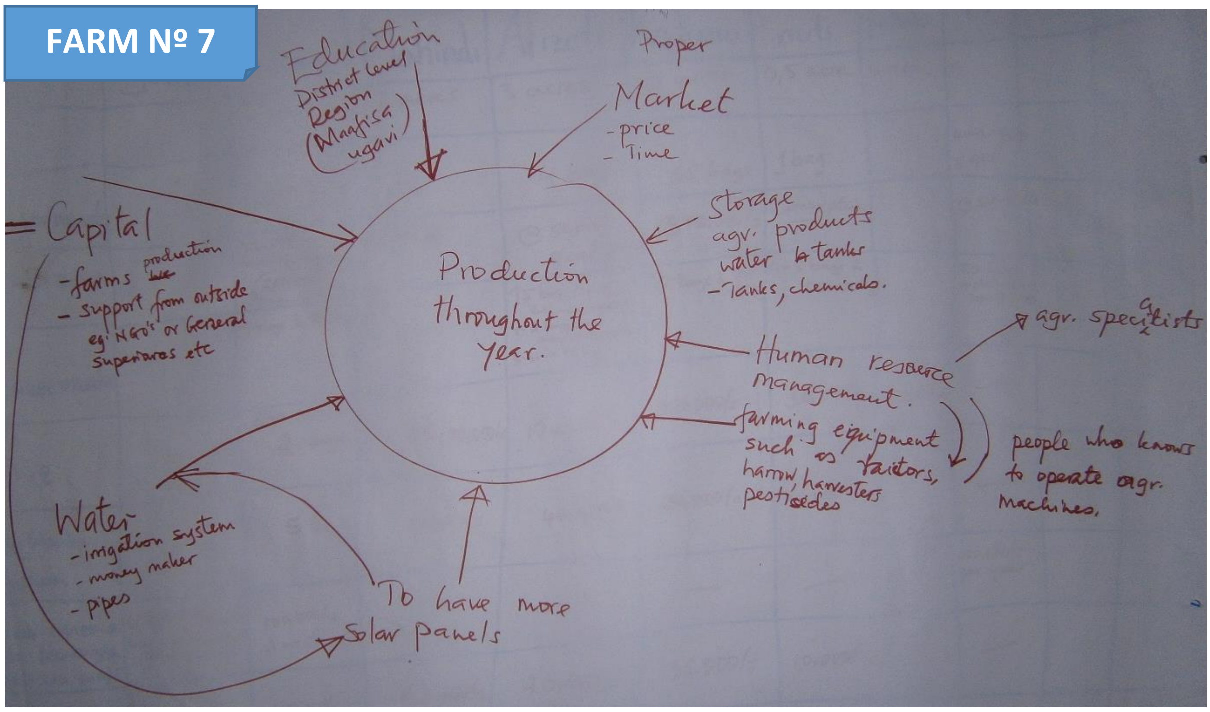
**FARM Nº 6.1**



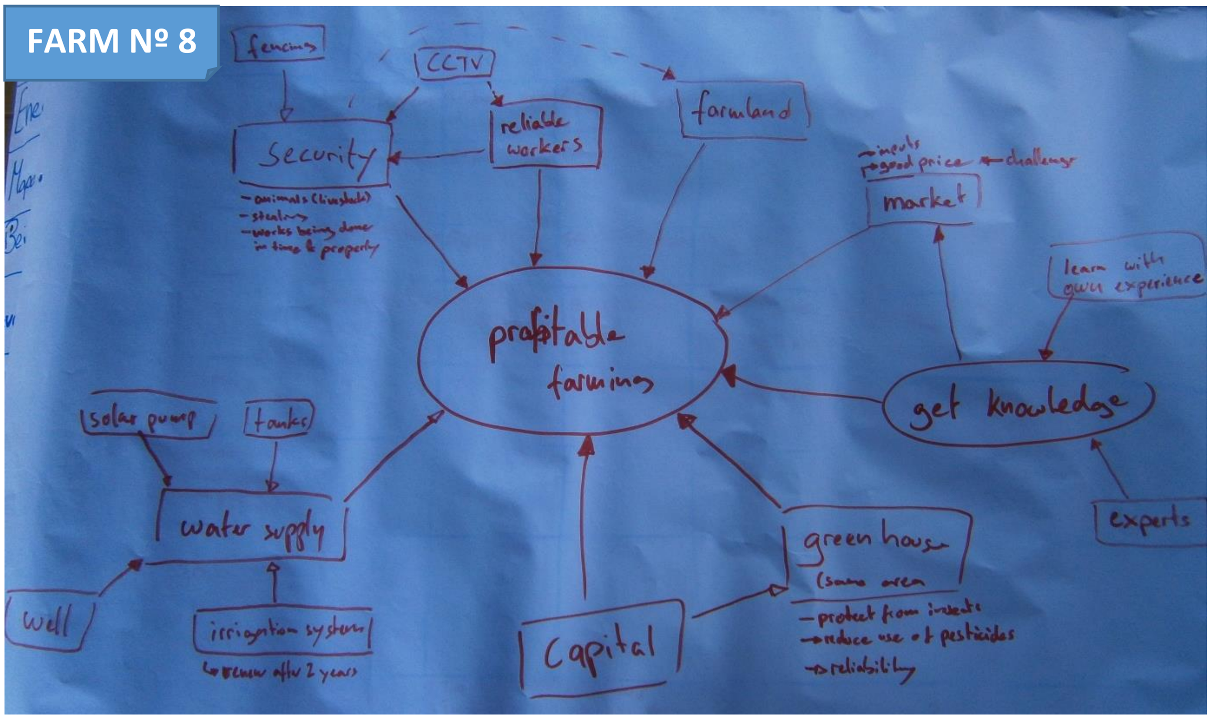
**FARM Nº 6.2**



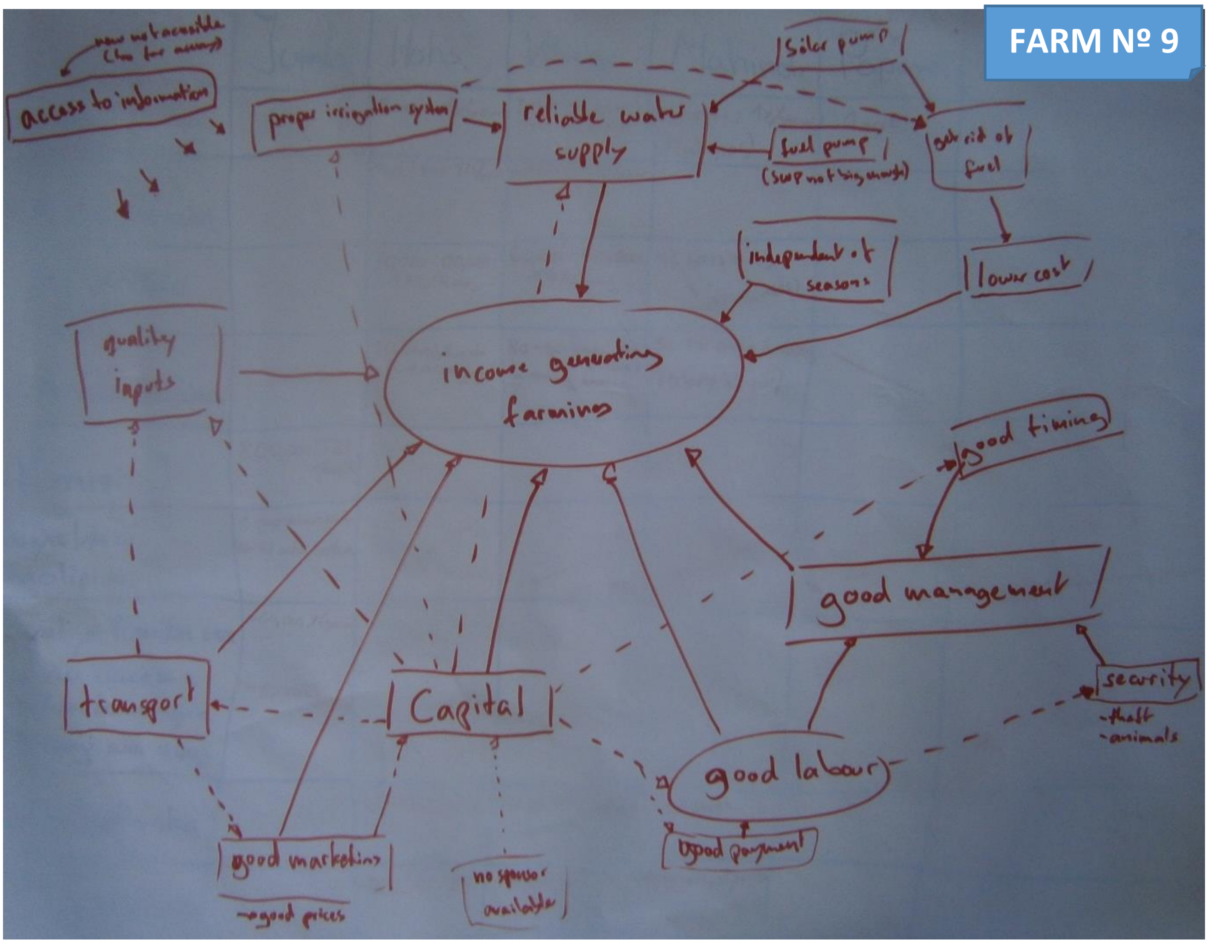
**FARM Nº 7**



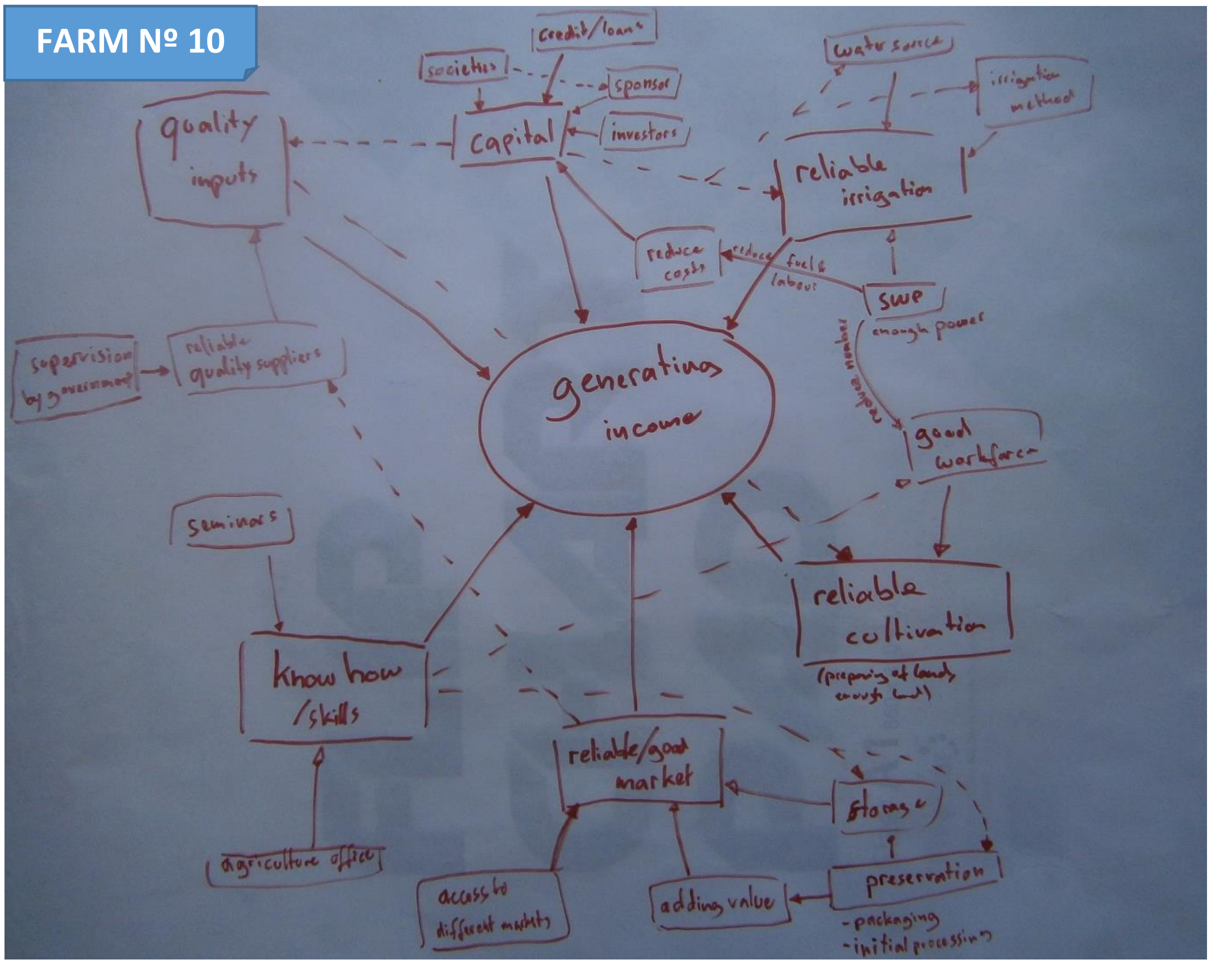
FARM Nº 8



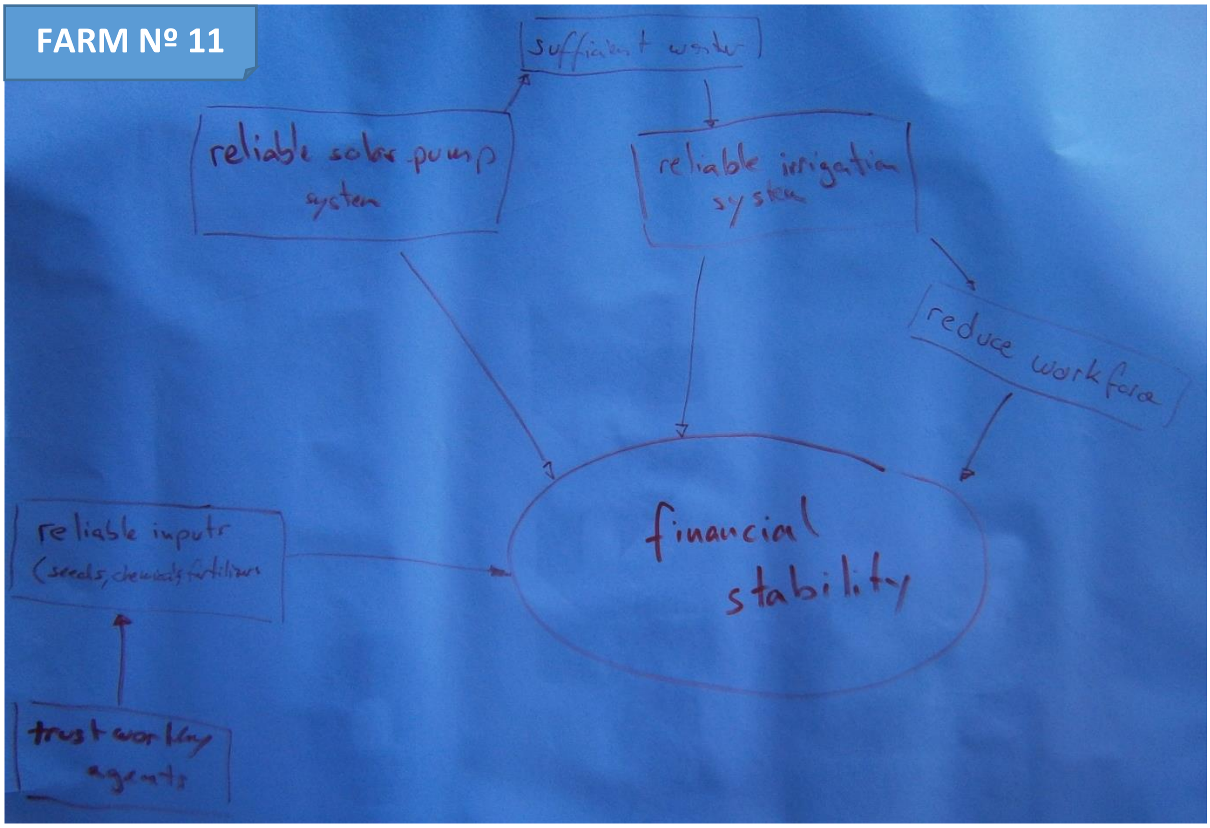
FARM Nº 9



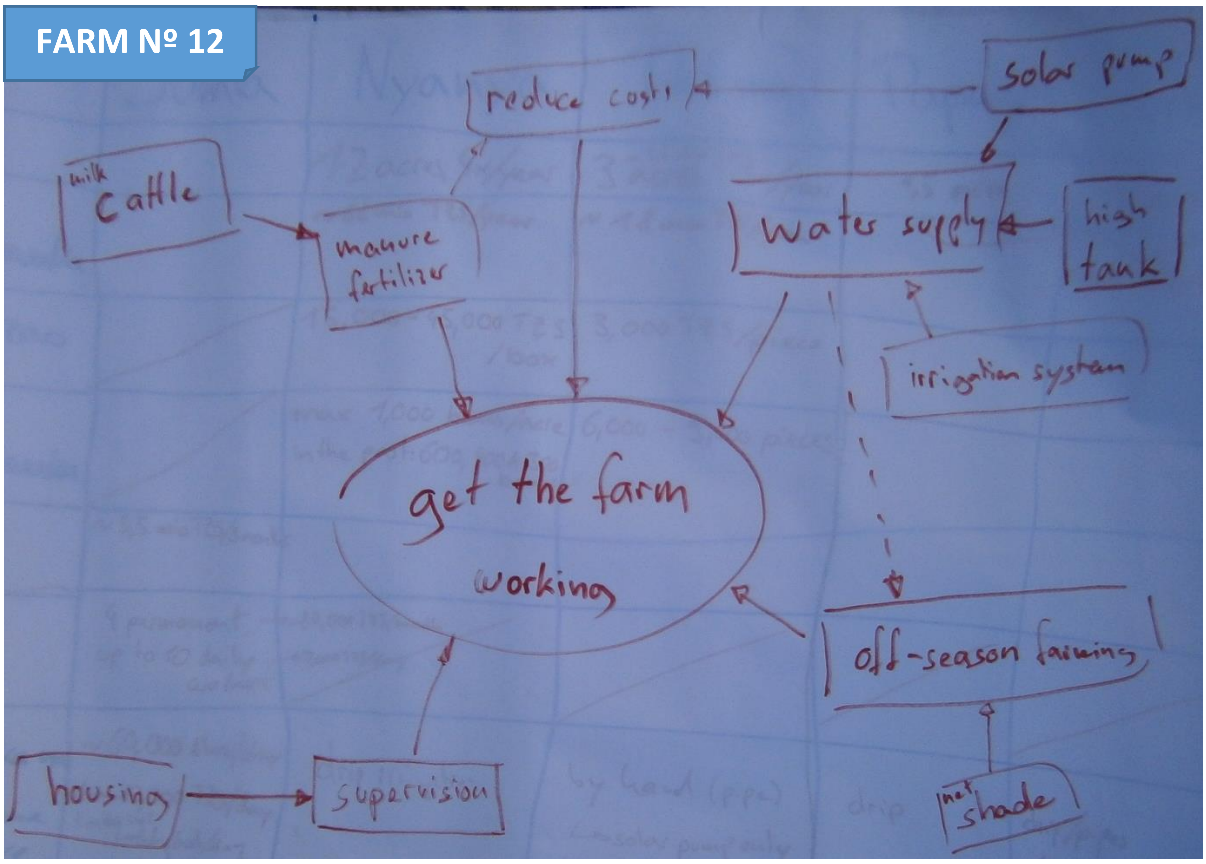
**FARM № 10**



**FARM № 11**



## FARM Nº 12


reduce costs
solar pump
milk cattle
manure fertilizer
water supply
high tank
irrigation system
get the farm working
off-season farming
housing
supervision
net shade