Master of Advanced Studies in Development and Cooperation

NADEL, 2022–2024, ETH Zurich

The challenges of scaling up solar water pumps for irrigation systems in Cambodia

An analysis of different stakeholder perspectives

Development policy thesis

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Bern, April 24

Summary

In Cambodia, more than one third of the population still works in agriculture. Smallholder farmers are the main producers of rice, which is the staple crop and has one to two cultivation seasons per year. To have enough water for cultivation, diesel pumps are used to pump water from the rivers or irrigation canals onto individual lands. However, these pumps come with disadvantages such as high fuel costs or CO2 emissions. Due to climatic changes, the frequency of droughts is increasing, which consequently increases the demand of water. The more environmentally friendly solar water pumps are an alternative to diesel pumps and have many advantages, such as no greenhouse gas emissions, no fuel costs, and a long lifespan. However, it can be observed that diesel pumps are still predominantly used for agricultural irrigation.

Therefore, the aim of this thesis is to investigate why the technology of solar water pumps is not scaling up wider and faster, and to analyse the challenges that arise specifically in the Cambodian context.

To identify these challenges, a stakeholder analysis is carried out as a first step to create a comprehensive perspective on the topic. As a second step, 13 qualitative stakeholder interviews are conducted with stakeholders on different geographical scales. The interviews are then coded as a third step to extract the main statements about the challenges in the dissemination of solar water pumps.

The results show the complexity of the topic and the many challenges that arise when upscaling the technology. On the one hand, there are challenges on the demand side, such as a lack of financial resources or a lack of knowledge about the technology. On the other hand, there are challenges on the supply side, such as difficulties in finding a suitable location to install the solar water pumps or the lack of liquidity of private companies.

Finally, recommendations for NGOs are provided to implement solar water pumps in Cambodia and thus scale up the technology. In this context, the NGOs mainly take on a supportive role between the different stakeholders and act between the supply and demand sides.

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List of abbreviations

ADB	Asian Development Bank
FAO	Food and Agriculture Organization of the United Nations
FWUCs	Farmer Water User Communities
MAFF	Ministry of Agriculture, Forestry and Fisheries
MFI	Microfinance Institution
MME	Ministry of Mines and Energy
MOE	Ministry of Environment
MOP	Ministry of Planning
MOWRAM	Ministry of Water Resources and Meteorology
MRD	Ministry of Rural Development
NEEP	The National Energy Efficiency Policy 2022-2030
PDAFF	Provincial Department of Agriculture, Forestry and Fisheries
PDP	Power Development Masterplan 2022-2040
PDWRAM	Provincial Department of Water, Resources and Meteorology
SDGs	Sustainable Development Goals
SH	Stakeholder
SWP	Solar water pump
UN	United Nations
UNDP	United Nations Development Programme

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1. Introduction

Most people in Cambodia still make a living from agricultural practices (Overton & Chandler, 2023). Even though the employment in agriculture decreased during the last years, it remains high with 39% of total employment (World Bank, 2021). The staple food in Cambodia is rice, which is the main source of income in rural areas (FAO, 2024b). Every year, 11.62 million tonnes of paddy rice are produced (FAO 2024b). Traditionally, rice was only grown once a year, but nowadays rice is cultivated twice a year in several regions to generate more income (World Bank, 2015). The main producers are small-scale farmers who often rely on irrigation systems which were built during the Khmer Rouge regime from 1975-1979 (MOWRAM, 2003). Irrigation development is crucial to strengthen climate resilience of smallholder farmers and food security (Durga et al., 2024), especially in areas like Cambodia where people are affected by droughts (Long et al., 2019). However, due to unequal water distribution and the location of individual fields, farmers are currently pumping water from the river or irrigation canal to their land using non-environmentally friendly diesel pumps. These diesel pumps cause high emissions and noise, and the users of the pumps are dependent on international diesel prices.

An alternative solution to the diesel pumps is the use of more sustainable solar water pumps. Apart from being more sustainable, these can supply water with lower costs than the expensive diesel. In Cambodia, there are efforts to switch from diesel pumps to solar water pumps, with different stakeholders involved in this transformation process. Technical solutions from the private sectors are developed and installed at village level with the involvement of government authorities, with development organisations often supporting this installation, and local communities being the end users of this product. However, there is a lack of policy measures by the government to promote and spread the technology throughout the country. Even though solar pumps have many advantages for irrigation and efforts are being made to install this technology, many diesel pumps are still in use across the country. The question therefore arises as to why the spread of solar water pumps is not faster. This work primarily addresses NGOs that are undertaking measures to support the implementation of solar water pumps in Cambodia.

In this thesis, stakeholder interviews were conducted to generate a broad perspective on the upscaling process of solar water pumps for irrigation in Cambodia. As the end-user of the pumps are the local communities, everyone is involved in this research to not only have the top-down perspective on the topic. Thus, a more inclusive perspective on the challenges is generated.

With this methodological framework, the following research question is addressed:

- ⇨ *What are the challenges in scaling up solar water pumps for agricultural irrigation systems from different stakeholder perspectives in Cambodia?*

This thesis begins by providing context (Chapter 2) and briefly elaborating the relevance and aim of the research (Chapter 3). It then describes the methodologies of stakeholder mapping, stakeholder interviews, and coding (Chapter 4). Subsequently, the results of the interviews are shown in establishing the challenges of upscaling solar water pumps from different stakeholder perspectives (Chapter 5). Finally, some recommendations for NGOs are outlined (Chapter 6).

2. Context

This chapter provides the thematic context of this thesis. First, the solar pumping system is explained to understand the technology broadly. Second, an overview of the agricultural sector in relation to the irrigation systems in Cambodia is given. Third, the national policy and the solar potential are outlined. Fourth, the field study, the solar water pump providers in the sector, and the different stakeholders involved in this research on solar water pumps in Cambodia are introduced.

Smallholder farmers whose land is less than 5 hectares are typical beneficiaries of the installation of solar water pumps. However, water pumps can be used for various stakeholders and matters in agriculture. To limit the scale of this thesis, the focus lies on small-irrigation systems on community level and the scaling-up of community water pumps (25-50 beneficiaries). The pump is used to increase rice cultivation in the wet season or to enable a second season of rice cultivation during the dry season from November to April (SWITCH to Solar, 2023). Sometimes vegetable cultivation is also incorporated, as it is not always straightforward to separate the crops of different farmers in the same irrigation system. The upscaling process discussed in this thesis is defined as the replacement of a diesel pump in the system where a pump already exists and not an installation of a solar water pump in a completely new area, where farmers do not use pumps at all.

2.1. Agricultural sector in Cambodia and irrigation systems

The agriculture sector is the main sector in Cambodia, with rice being the most planted crop (World Bank, 2015). Today, more than a quarter of the national GDP is generated from rice (World Bank, 2015) and 80% of people in rural areas rely on agricultural production (Cook et al., 2024). Smallholder farmers in Cambodia cultivate subsistence farming, which is increasingly exposed to external insecurity through climate change, such as droughts or flooding (ADB, 2021).

To understand the agricultural situation of the country, it is necessary to look back to the period of *Democratic Kampuchea* from 1975-1979. During this time, the Khmer Rouge with its leader, Pol Pot, forced the population to become a uniform agrarian society that mainly produced rice. Land rights were discarded and people with education, connections to the former government, or elderly people no longer had a place in society and were killed. Through the organisation of large collective farms, rice

production was intensified during this period. (Cook et al., 2024)

To increase agricultural production, countless irrigation systems were built during the Khmer Rouge regime. It is estimated that 7000 kilometres of canals and approximately 350 reservoirs were built across the country. Many of these systems have been rehabilitated since then. (Tyner et al., 2018)

Today, there are 2480 irrigation systems in Cambodia (ADB, 2021). However, due to inadequate maintenance, most of them are not sufficiently operational, which limits agricultural productivity (ADB, 2021). Especially those farmers whose land is far away from the main canal suffer from unequal water distribution and water shortage (ADB, 2021). Therefore, farmers are using tube wells to irrigate their lands, especially during dry season cultivation (ADB, 2021). Today, these irrigation systems are mainly operated with diesel pumps.

2.2. Solar water pumping system

Globally, the first solar water pumps were installed in the late 1970s. These systems have been continuously improved over time, as in the beginning many technical challenges occurred. Since 2009, the price of solar water pumps is decreasing and thus the technology is more affordable for the agriculture sector in general. (Hartung & Pluschke, 2018)

However, an example from Tanzania (Figure 1) shows that solar water pumps require high upfront costs, which is one of the main constraints to install the technology. In Figure 1 on the left side, the costs of a diesel pump over 20 years are shown. Especially the replacement costs every 5 years and the yearly fuel costs are high. Nowadays, the fuel costs are constantly rising, especially due to the global political situation (Hilali et al., 2022). On the contrary, the solar water pumps reduce energy costs and the system only requires a replacement once after 10 years (Figure 1 on the right). Consequently, the high initial costs are theoretically justifiable over the entire lifespan of 20 years. (World Bank Group, 2018)

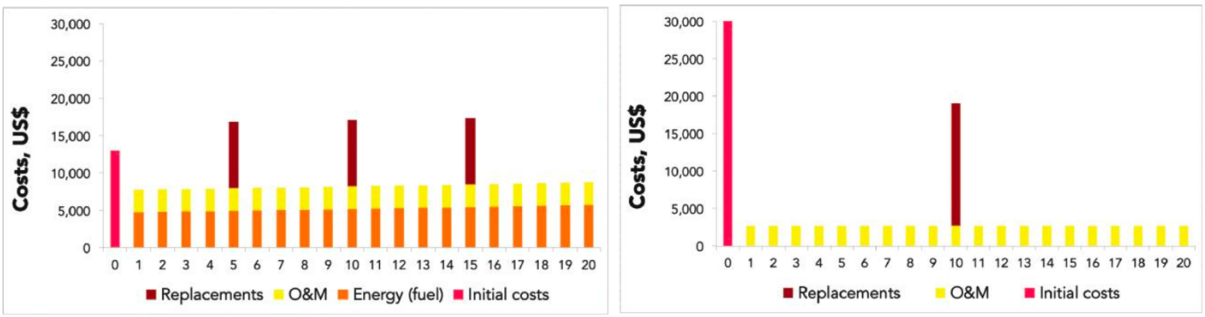


Figure 1: Comparison of costs of diesel (left figure) and solar (right figure) pumping systems (World Bank Group, 2018)

Especially smallholder farmers cannot obtain loans for solar water pumps from banks due to the high risk and the related high interest rates (Sothorn, 2020). Therefore, the solar technology is generally more affordable for stakeholders with high investment capacity, such as contract farmers, than for the less wealthy smallholder farmers (SWITCH to Solar, 2023).

Figure 2 provides a simplified illustration of how a surface solar water pumping system generally works.

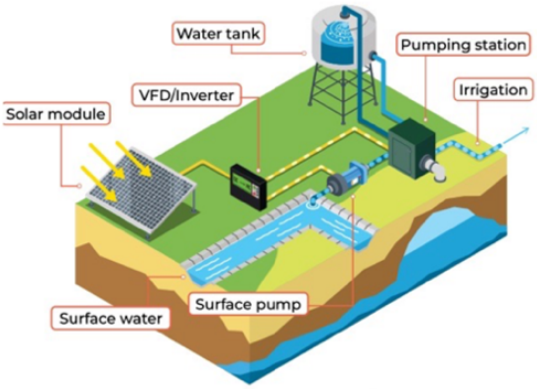


Figure 2: Surface water pumping system (Abdelfattah, 2022)

The solar radiation shines on the PV cells, where it is converted into energy. This energy drives the pump, pumping water into a tank. As soon as there is a demand for water for irrigation, this water is pumped to the fields. (World Bank Group, 2018)

Water tanks are not always available to store the water. In these cases, the farmers just pump the water from the river directly to the rice fields. This is especially the case, if there is enough water in the river all year round. Also, not having a tank reduces installation and maintanance costs. (World Bank Group, 2018)

For this thesis and the field study (Chapter 2.4), the focus lies on surface solar water pumping systems, based on a river as water source, without a water tank.

Before installing a solar water pumping system, various aspects must be studied in a situation analysis to ensure that the pump is installed in the right place. Aspects such as the water requirement, the water source, the flow rate, the water storage tank, the location of the PV panels, and the solar potential must be considered when designing the system. (World Bank Group, 2018)

The advantages and disadvantages of solar water pumps compared to conventional diesel water pumps are shown below.

Advantages of solar water pumps

- There is no need to buy expensive imported fossil fuels, as sunlight is used to generate electricity (ADB, 2015; World Bank Group, 2018).
- No greenhouse gas emissions. Thus, it is an environmentally friendly technology to mitigate climate change. (World Bank Group, 2018)
- Long lifespan of about 20 years. However, single components of the system (e.g. the pump itself) need to be replaced after 7-10 years. (World Bank Group, 2018)
- It is an installation of renewable energy technique in rural areas (Hartung & Pluschke, 2018). Therefore, solar water pumps can be used by communities that lack access to national grid systems (ADB, 2015).

- The solar water pump system can be expanded by adding a PV cell at any time, or reduced as required, and is consequently flexibly adjustable (World Bank Group, 2018).
- Reduced costs in the long run compared to diesel pumps, because solar water pumps have high initial costs, but no costs for fossil fuels later on (Hartung & Pluschke, 2018).
- Prices of solar panels have decreased over time and therefore, solar water pumping systems are economically viable compared to other energy sources (Hartung & Pluschke, 2018).
- Potential to increase yields and incomes through improved access to water all year round. Food security can also be enhanced as a resulting effect. (Hartung & Pluschke, 2018)
- Reduction of manual irrigation effort allows time for other activities which can diversify incomes (Hartung & Pluschke, 2018).
- Job potential, especially in the private sector in terms of technology development and production, suppliers, trainings, and maintenance of the systems (Hartung & Pluschke, 2018).
- This thesis focuses on surface water pumping systems. However, there is potential for a climate adaptation strategy by using groundwater for irrigation instead of water from precipitation, as precipitation patterns are changing due to climate change (Hartung & Pluschke, 2018).

Disadvantages of solar water pumps

- High initial investment costs (World Bank Group, 2018) which are not affordable for many smallholder farmers (Hartung & Pluschke, 2018).
- Not a universal solution and requires a time-consuming assessment of a suitable location (Hartung & Pluschke, 2018).
- High-risk investment (Hartung & Pluschke, 2018).
- The maintenance of solar pumps is sometimes difficult because specialised suppliers and technicians are not available in some rural areas (World Bank Group, 2018).
- Theft and damage to solar panels, as they may be installed in remote areas (World Bank Group, 2018) and there is often no insurance available (Hartung & Pluschke, 2018).
- Risk of excessive groundwater extraction (World Bank Group, 2018).
- If a solar water pump is installed only as part of a project that ends after a certain period of time, this can lead to a non-functioning system because there is a risk that everyone who has the specific knowledge and money will simply leave (Bard, 2013).
- Lack of trainings and thus, also ownership of the pump on local level (Hartung & Pluschke, 2018).
- Lack of trust between different stakeholders (Hartung & Pluschke, 2018).
- Cannot be used during night (Herman, 2021).

In Cambodia, the exact numbers of solar as well as diesel pumps are not publicly available. But it can clearly be observed on site, that there are many more diesel pumps in place than solar water pumps.

2.3. National policy on solar power and solar potential in Cambodia

There are different strategies for national planning in place in Cambodia. The main policy instrument and thus the driving force for national development in Cambodia is the *Rectangular Strategy for Growth, Employment, Equity and Efficiency*, which has reached phase 4 now (Royal Government of Cambodia, 2018). This strategy has four focus areas, namely people as top priority, roads, water, and electricity (Royal Government of Cambodia, 2018). The *Pentagonal Strategy for Growth, Employment, Equity, Efficiency and Sustainability* is the new published governmental strategy for the next 25 years and thus the successor to the *Rectangular Strategy* (Royal Government of Cambodia, 2023). It focuses on five key priorities (people, roads, water, electricity, and technology) and strives for economic growth, job-creation, poverty reduction, capacity strengthening, and sustainable socio-economic development (Royal Government of Cambodia, 2023). However, both these policies are concerned mostly with high-level strategies and do not directly mention solar energies or even solar water pumps. This shows that these topics are not core issues in national Cambodian policies. However, these topics are discussed in more specific plans regarding electrification.

In general, improvements in the electricity sector have been made. In 2020, 81% of households in Cambodia had access to grid electricity (SWITCH to Solar, 2023). Focusing on the energy transition towards renewable energies, there are two main policies by the Ministry of Mines and Energy (MME) in place. The *Power Development Masterplan 2022-2040 (PDP)* promotes renewable energies, and the minimalization of environmental impacts through energy production (MME, 2022a). Thus, through this strategy, solar energy should be supported and improved (MME, 2022a). The *National Energy Efficiency Policy 2022-2030 (NEEP)* intends to reduce power demand, energy consumption, and thus greenhouse gas emissions by 2030 and goes along with the *PDP* (MME, 2022b). Renewable energy is a growing sector in Cambodia, also due to the government initiating various strategies (Aquarii, 2023).

Looking specifically at solar energy, the MME defined the *Principles for Permitting the Use of Rooftop Solar Power in Cambodia* which boosts clean energy (MME, 2023). The objective of these guideline is that approved rooftop solar projects are allowed to feed excess power into the national grid system (MME, 2023). However, these guidelines are just for rooftop PV systems, and do not apply to solar water pumps. Therefore, there are no national strategy or regulations in place at the moment which encompass solar water pumping systems.

Moreover, the development of sustainable energy sources in Cambodia is still ongoing (ADB, 2015). Reasons for this are lack of funding, data, and experience (ADB, 2015). Just recently, the *Circular Strategy on Environment 2023-2028* was published by the Ministry of Environment (MOE), which outlines clean, green, and sustainable actions (e.g. promoting green energy) with the aim of ensuring sustainability in the field of environment and development (MOE, 2023).

An essential part for the installation of solar water pumps is the existing solar potential. Three different factors are decisive in determining whether solar energy is suitable, namely the level of solar radiation, the proper area for installing the PV cell, and the efficiency of the solar energy technology. (ADB, 2015) Figure 3 shows the photovoltaic power potential in Cambodia. There is a huge potential with areas up to 4.3 kWh/kWp on average a day. Only at the coast, in the *Cardamon Mountains* in the south-west, and in the north of the provinces of *Stung Treng* and *Ratanakiri* on the border to Laos is the photovoltaic potential lower. However, if you compare these areas with the average potential in Switzerland, which is around 3.0 kWh/kWp per day (The World Bank, 2020), this is still very high. Therefore, the installation of solar energy at suitable locations in Cambodia is a very reasonable way to generate sustainable energy.

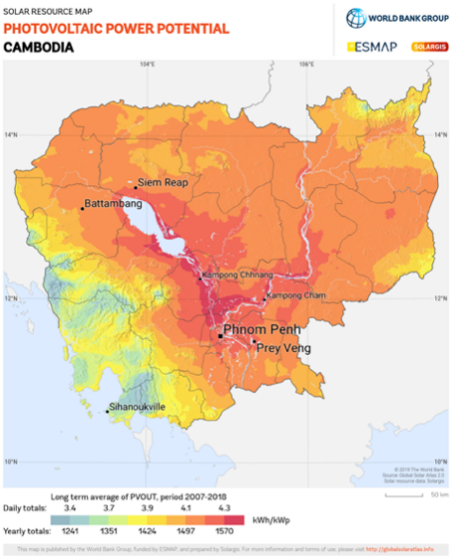


Figure 3: Photovoltaic Power Potential in Cambodia (The World Bank, 2020)

2.4. Field research in Oddar Meanchey province and stakeholders

Ou Run village, where data was collected, is located in Thlat district in Oddar Meanchey province, in north-western Cambodia. 706 people in 127 households live in this village. Figure 4 shows a satellite image of the irrigation system in this village, where a development project installed a solar water pump in 2021. The blue cross illustrates the PV system (see also figure 5), which generates energy to pump water from the river to the canal (in blue). 26 households, which have their lands along the canal and the reservoir that is situated at the end of the canal, are beneficiaries of the solar water pump.

This location was selected for the field study as it is still one of the poorest regions in Cambodia (ADB, 2014). The poverty rate is around 22%, with the majority of this population working in agriculture, fishery, or forestry (MOP, 2024). Reason for this are for instance the remote location or that the Khmer Rouge followers were in this region until the 1990s (Sryneath & Sothorn, 2017). Further, many smallholder farmers still use diesel pumps and spend around $200 on diesel per rice cultivation season. This means, if people grow rice twice a year, some people spend around $400 just on fuel.

Furthermore, as a previous project from an NGO already installed a community solar water pump in this region, there are farmers which have access to the pump, and others which have no access to it. Therefore, a variety of stakeholder could be interviewed in one village (see Appendix 2).



Figure 4: Satellite image of irrigation system in Ou Run village, Thlat district, Oddar Meanchey province (Google Maps, 2024)



Figure 5: Photovoltaic System in Ou Run village, Thlat district, Oddar Meanchey province (own photo, 2023)

There are no official numbers on how many suppliers of solar water pumps are currently operating in Cambodia, so no holistic overview can be given. Nevertheless, a brief description is provided to give a rough understanding of the sector. There are government agencies in place which are installing solar water pumps as for example United Nations Development Programme (UNDP) in Battambang (Va, 2023). Also, projects with support from other governments, such as Switzerland, Netherlands, Sweden, and Czech Republic are in place. Mostly, NGO projects which implement solar water pumps (e.g. Caritas Switzerland, HEKS Cambodia, People in Need) are also supported by governments. Having a look at the private sector, with companies providing and installing the technique, there are various stakeholders such as Solar Green Energy Cambodia (SOGE), Cambodia Energy Solutions, Pteah Baitong, Energy Lab, or Agros. Most of them focus on solar technology in general and have solar water pumps as a sub-category in their service range. There are differences between the private suppliers. SOGE, for example, specialises in developing its own technologies for communal pumping stations, while Agros specialises in pumping systems for individuals. However, the details between all the private companies are not explained further.

One major point of this thesis is to have a study that is as inclusive as possible and combines various stakeholder perspectives from different geographical levels. Therefore, the following stakeholders were involved in the research process:

1. **Local level (Ou Run village)**: Two smallholder farmers with access to a community solar water pump, two smallholder farmers without access to a community solar water pump, the water group which is responsible for the community solar water pump in the village (four people), and

the village chief.

2. **Regional level (Oddar Meanchey province)**: Deputy director of the Provincial Department of Agriculture, Forestry and Fisheries (PDAFF).
3. **National level (Cambodia)**: Two representatives from solar companies from the private sector, one representative from an NGO which installed a solar water pump, two representatives of an NGO who plan to install solar water pumps, one representative of an NGO who is installing solar water pumps.

How these stakeholders were selected is described in more detail in the stakeholder analysis (see Chapter 4.1).

3. Relevance

Globally, the transition to solar water pumps can contribute to fulfil several interrelated Sustainable Development Goals (SDGs) (UN, 2021). Especially because sustainable energy has a positive impact on all other SDGs (UN, 2021). The transformation process from diesel to solar water pumps lies at the interface between SDG 2 (no hunger), 7 (renewable energy), and 13 (climate action) and can contribute positively towards the achievement of all these goals (UN, 2021). For instance, carbon-based energy sources are used with diesel pumps, which has a negative impact in the form of greenhouse gases released into the atmosphere and further, influence air pollution (UN, 2021). Also, smallholder farmers are dependent on expensive, imported fossil fuels (ADB, 2015). By using renewable energies (SDG 7), greenhouse gas emissions can be reduced, which has a positive impact on the achievement of SDG 13 (UN, 2021). Moreover, through increasing the number of solar water pumps, it is likely that yields can be increased through improved access to water, also in remote areas, which at the same time leads to improved food security (SDG 2) (UN, 2021). Therefore, the transformation to solar water pumps can be seen as a relevant climate change mitigation strategy to decrease global warming (UN, 2021). In particular, solar water pumps are a positive solution regarding the achievement of the Agenda 2030 and hence, to strive for a sustainable future.

However, compared to other greenhouse gas emission that drive climate change, the use of solar water pumps only emits a small proportion (Ritchie et al., 2020). Furthermore, CO2 is not the only greenhouse gas that influences our climate, as methane, for example, also contributes significantly to global warming (Ritchie et al., 2020). This point needs to be kept in mind, but will not be discussed further, due to the scope of this thesis.

In Cambodia, there are still a lot of diesel pumps in use. The question therefore arises, why people install solar water pumps in the first place or why people stay with diesel pumps, in other words what challenges occur in the upscaling process.

A key aspect of upscaling the technology is that every national context varies in terms of projects in place, technology development, stakeholders, and governmental support (Lefore et al., 2021). Although some stakeholders, especially from the private sector and development organisations, are in favour of promoting solar water pumps, the nationwide literature is very scarce. This policy thesis thus aims to make a first contribution to fill this gap by identifying the challenges of scaling up solar water pumps in the specific Cambodian context with the involvement of various stakeholders.

As NGOs are potential implementation partners for the installation of solar water pumps in Cambodia and have the capacity to support the upscaling process in practice, they are the main addressees of this thesis. By answering the research question and identifying the challenges in upscaling solar water pumps (see Chapter 1) some general recommendations for NGOs are then outlined. These recommendations can help NGOs tackle potential challenges in planning their implementation of community solar water pumps.

4. Methodology

First, a stakeholder mapping was done to identify the main stakeholders in the system (Chapter 4.1). To answer the research question, a qualitative research design was used. 13 different stakeholders involved in solar pumps for irrigation systems in Cambodia were interviewed (Chapter 4.2). Afterwards, all interviews were transcribed, and a qualitative content analysis was conducted in order to extract the main statements of the individual stakeholders (Chapter 4.3).

4.1. Stakeholder mapping

Including all stakeholders involved in the project is key for understanding the system and to successfully implement the technology (Gibbons, 2022). Therefore, to get a comprehensive perspective on solar water pumping for agriculture in Cambodia, a stakeholder mapping was conducted first.

This method involved several steps. The first step was to identify different stakeholders, which was done through brainstorming, research, and exchange. As the system is quite complex, clustering the stakeholders was helpful. The second step was about prioritising the stakeholders in the system. As not all stakeholders have the same influence and interest in a project, a prioritisation of them was done. With the Stakeholder-Matrix (Appendix 2, Figure 9) it was possible to list stakeholders according to their interests and influence. The third step was to create an understanding of the various interest groups and their interests and needs. The fourth step was to compile the information already available and define which information was missing and should be generated by the interview. (Engel, 2023)

4.2. Semi-structured qualitative interviews

By conducting stakeholder interviews, the needs, preferences, and expectations of everyone involved in the project are researched (Olaniyi, 2023). The following quotation gives a clear definition:

"*A **stakeholder interview** is a conversation with a person who has a vested interested in a project with a goal of gathering insights to drive the project's success*." (Gibbons, 2022). For this thesis, the goal was to interview some key actors in the system of solar water pumping for agriculture in Cambodia.

One challenge was to develop the interview guide for multiple stakeholders with different backgrounds and interests. Therefore, a customized interview guide needed to be developed (Pouilly, 2020). Essential for conclusive interviews is a well elaborated set of questions, especially with stakeholders with different backgrounds and geographical levels (Hupmobile, 2022; Olaniyi, 2023). Therefore, clusters of different focal points of scaling up of solar pumping in Cambodia were identified (Figure 6) to have a common narrative for all conversations. In the following, this made it easier to compile the different perspectives of upscaling of solar water pumping.

1 Background information and past experiences	2 Switching from diesel to solar water pump	3 Expanding the technology	4 Future perspective	5 Other examples and comparisons
•Background: person/ community/ organisation/ •Experiences with SWPs	•Reasons to switch •Advantages SWP •Disadvantages SWP	•Why still diesel pumps •Process experience •Challenges of upscaling •Financing	•Needs •Expectations •Government strategy	•Other communities •Other countries

Figure 6: Clusters for interview guide (own figure, 2024). SWP stands for solar water pump.

Before each interview, the most important points to be addressed were defined. The predefined questions were open so that interviewees could express their opinions and share their experiences. Around 5-7 main questions were highlighted for each stakeholder to be sure to get essential information to answer the research question. If there was time, a bundle of other facultative questions of "second priority" were prepared to get more detailed information about the individual stakeholders' perspective on solar water pumping. The interview guide template is attached in Appendix 4.

Every one-hour-interview started with an introduction of myself, information and purpose of the study, data collection, length and format of the interview, and an agreement on recording of the interview. Then, the main part was conducted with the predefined questions. In the end, the stakeholders were asked if anything else want to be shared which might have been forgotten to ask. Moreover, the next steps of the thesis were outlined. To inform and protect the stakeholders and their individual statements, a consent form in Khmer and English (Appendix 5) was handed out informing on the anonymity of the research. For stakeholders operating at the national level, consent was either given during the interview itself or through the consent form. All interview results were used in a completely anonymous manner.

4.3. Coding

All the interviews were transcribed afterwards with the programme MAXQDA24. The level of detail in the transcription was based on the spoken language wherever possible. The interviews at local level were all conducted in Khmer. For these, a translation into English was transcribed. To ensure a standardised transcription (Rädiker & Kuckartz, 2019), the following predefined rules were considered:

- Verbatim transcription to reproduce the interview as complete as possible. If the interview was conducted in Khmer, the direct translation from the translator on site was transcribed.
- A time code was added when changing speakers.
- In the case of non-speaking, it is shown in brackets: e.g. (things), (laughs), etc.
- If a part of the recording is not clearly understandable, this is also indicated in brackets: (incomprehensible).
- If there is a long exchange in Khmer, it is indicated as (KH).
- If a crucial part was missing, it is written in square brackets.

To analyse the collected interview data, a qualitative content analysis was conducted. The category system can be established either deductively through concept-based or inductively through the empirically collected data (Flick, 2016; Rädiker & Kuckartz, 2019). In this thesis, an inductive category system was developed and used, which was orientated directly on the 13 conducted interviews and the research question. In doing so, primarily factual and thematic categories were developed. According to Rädiker & Kuckartz (2019), there are three different ways of structuring the category system, either through a linear listing of the individual codes, through hierarchical structures in the form of several levels with main and sub categories, or through a network system. For this study, a hierarchical coding structure was used (Figure 7), with the idea of establishing sub categories for the different geographical levels of each stakeholder. The idea behind the four main categories was to first understand why diesel pumps are still in use, to understand why people switch to solar, to extract the challenges, and identify possible solutions to address these challenges.

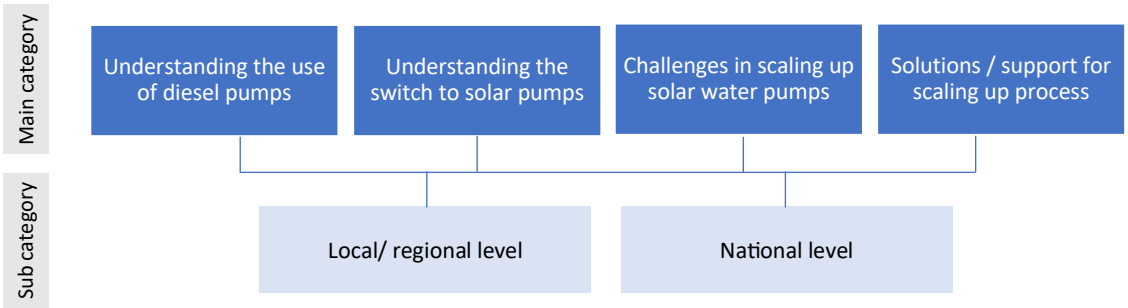


Figure 7: Coding system for data analysis (own figure, 2024)

5. Results: Challenges of upscaling solar water pumps from different stakeholder perspectives

The conducted stakeholder interviews enable to investigate numerous challenges that influence the distribution of solar water pumps in the Cambodian context. However, it must be considered that the results cannot be seen as a universal study, as the number of interviewed persons is too small for that. It is rather intended to create a foundation from which initial insights can be gained.

The initial observation on site that there are many more diesel pumps in place than solar water pumps could be confirmed by different stakeholders. There are also figures on this, but they are not communicated publicly. The identified challenges of scaling up solar water pumps from the perspective of all stakeholders involved have been clustered and are discussed in the following by summarising the main points, including certain quotes from the interviews and sometimes including links to secondary literature. In the following, SH stands for stakeholders interviewed (see Appendix 2).

Environmental challenges

First of all, the changing climate poses planning challenges, which was mentioned by a representative of the private sector: "*I think one of the other big challenge in big-scale project is also the source of water. As a company, we can study the source of water, make sure that they will be almost sure that they will have water, but actually with the environmental changes, we cannot be sure.*" (SH 8, 2023).

For the installation of the technology, flooding is a major constraint: "*most of the big challenges will be the flooding. Because we need to make sure that there is no risk of flooding or we need to anticipate the risk of flooding.*" (SH 8, 2023).

The risk of flooding events is also mentioned in a report from the Asian Development Bank (ADB, 2021), which can lead to damage on infrastructure. Further, more frequent droughts are also an impact of climate change and can have an influence on the water source, for instance water scarcity during dry season from November until April. These increasing risks due to the changing climate needs to be considered already in planning.

Cultural challenges

One main challenge that could be examined with this research is that local traditions, especially in agriculture, are deeply anchored in the culture. This was mentioned by various stakeholders on different scales, for instant by the local authority: "*No, they [smallholder farmers] actually know the benefits, they can earn, they can grow. But they just the mindsets and these traditions. So, it is all about their traditions, they stick to it.*" (SH 6, 2023). Also, development organisations mentioned this point:

"*But particularly also here in Cambodia they are not very open up. They have their traditional way they like the most. Let's say it like this.*" (SH 13, 2024). This behavioural change from cultivating rice one time a year during rainy season to planting also in dry season is not seen as necessary for everyone, which is shown also by the following quote from a smallholder farmer: "*It [the installation of solar water pump] is not really change anything about my farming, because I remain doing farming during rainy season.*" (SH 2, 2023). Also, people mentioned that they already have a working diesel pump and they do not see the added value in buying a new pump.

There is a risk that development projects are not adapted to the needs of the project beneficiaries. It is therefore important that the switch from diesel to solar water pumps is adapted to the needs of the beneficiaries. More efforts must be made than just providing the technology on the supply side. To achieve a change in behaviour, the needs and the corresponding behaviour at local level must be understood to adapt the intervention accordingly. Involving people in the intervention process from the beginning can positively influence the switch to solar water pumps and ultimately lead to a possible behaviour change. (Heider & Flanagan, 2017)

Planning challenges

Another challenge is to find the right location for the installation of the community solar water pump. The water group mentioned about the procedure of planning: "*So, the initial assessment was just done by the department. We were involved later on, in a later stage*." (SH 5, 2023).

Further, geographical conditions play a key role, for example whether there is enough water in the river for irrigation throughout the year. On the one hand, this is needed so that the farmers have enough water for rice cultivation. On the other hand, the private company investing in the installation of solar water pumps will reach the break-even point faster because farmers have water for two rice harvest seasons and the companies can collect fees twice a year. In addition, different crops need different amounts of water, which must be calculated for every local system. Thus, no generalised location assessment approach exists.

According to Hartung and Pluschke (2018) solar water pumps are not a fit-for-purpose solution and depend on a holistic location assessment. Therefore, planning is needed on the geographical conditions (e.g. water source), demand side (e.g. crops that people want to grow), as well as on the supply side (e.g. type of pumping system) which is complex and time consuming.

In addition, it was mentioned that it can be a challenge to find a suitable location for the solar water pump because people should trust the technology and have to pay fees for the pump. These fees have to be paid per hectare for each harvest season to repay the private sector's investment. The repayment

period depends upon the system, but is usually four to six years. The water group is typically responsible for collecting the fees.

Moreover, the installation of a community pump brings with it the challenge of having or establishing a responsible water group for management. For example, a representative of an NGO mentions this: "*That it is very hard to cooperative farmer group association. Because in term of time management they don't have much. […] They need people to care the solar. Eh, they still work as a volunteer base, so it is very hard to manage all of that."* (SH 10, 2023).
In Cambodia, there are Farmer Water User Communities (FWUCs) on irrigation schemes in place that are recognised by the government (ADB, 2021). However, these groups need to be strengthened, because cooperation with the Provincial Department of Water, Resources, and Meteorology (PDWRAM) often does not work and water infrastructure and supply suffer as a result (ADB, 2021). However, these communities form a framework that can be built upon.

Next to the mentioned planning challenges, there is often also pressure from project timelines. Often a fixed date is set for the installation of the solar water pump in order to have enough time for implementation: *"For now, we [NGO] can piloting because of time constrains."* (SH 11, 2023).

Financial challenges

The high instalment costs of solar water pumps were mentioned by every stakeholder interviewed. The quote of a smallholder farmer clearly shows this challenge at local level: "*So, the people who remain to the diesel is that they don't have this big amount of money to buy solar in the beginning. It is a big investment. And also, all the expend, doing farming a lot throughout the year, getting income for just enough for the daily expenses. So that is why people still remain to the diesel. Even dough they know that solar is good, is easy, saves energies, and we see the success of the model farmers, but they are still not able to use solar."* (SH 1, 2023). This challenge was also recognised by the local authority: *"Regarding to the money, they [smallholder farmers] don't have enough money to install."* (SH 6, 2023). Likewise, stakeholders from development organisations mentioned this challenge: "*(…) one issue is with regards to financial capabilities of farmers, (…) smallholder farmers have issues with regards to access to finance*" (SH 12, 2023).
One reason for the high costs was given by a government representative: "*(…) also the fact of the costs. Because the, if this product is so expensive by the fact of import tax and all these things*" (SH 7, 2023).

This challenge of lack of money is also mentioned in numerous studies (Hartung & Pluschke, 2018; World Bank Group, 2018; Durga et al., 2024) and can therefore be seen as one of the main challenges

in the roll-out of the technology in Cambodia. The fact that a large amount of money is required in advance has already been explained in Chapter 1.2.

However, not only at local level, but also at national level, there are challenges regarding cash flow, which was mentioned by a representative of a development organisation: "*The middle companies they need to sell more, but they have all of them they are sharing a problem related to the cash flow. So, they don't have cash. And it is very difficult for them to let's say to find investors in the markets, because the range of investment that they need they call it, the death rate. Because it is like over 100'000 dollars, but it is less than for example 5 million dollars. And it is very complicated here in Cambodia to find investors that are ready to invest in this kind of companies.*" (SH 13, 2024).

Market challenges

There are several related challenges in terms of market establishment and the upscaling of the technology, which is shown by this quote from an NGO: "(…) *the challenge with scaling up the technology is personally in my opinion is on the supply side on the companies. Their distribution models, their cash flow issues, their capabilities basically to reach many, many farmers. And then this is also tied to investment, lack of investment in many of these companies for instance. Lack of interest from investors, but it's a bit of a risky business.*" (SH 12, 2023). Therefore, also private companies are taking loans from Microfinance Institutions (MFI) which have a big interest rate, because of the high-risk investment. Likewise, it is hard to get a loan for the smallholder farmers for solar water pumps from MFI. MFI do not promote loans on solar water pumps, "*because they have already their agriculture options. So, they don't see the need at the moment to create green agricultural options.*" (SH 13, 2024).

Besides cash flow, the lack of management skills also makes it difficult to establish a market for solar water pumps, which was stated by an NGO representative: "*Whatever, they [private company] created everything from nothing, it is crazy. They are super good in what they are doing. What is missing is their management skills*." (SH 13, 2024).

Moreover, especially in the past, there were cheap solar water pumps of poor quality on the market which had no maintenance system. This had a negative influence on the public perception of the technology. There are also development projects in Cambodia that provide solar water pumps for free, which was mentioned by an NGO representative as a challenge to establish a sustainable market in the long run because it creates false incentives: "*But after, these farmer at the province they want if for free. Because they will say, my neighbour got it for free (…). So, it depends always the way you are approaching this kind of project. Especially, when we are speaking about in such economic sector. (…)*

You should use different kind of approaches, but never give it for free or you are destroying the future market actually." (SH 13, 2024).

Policy

Another key challenge is, that there is currently no financial support from the government for solar water pumping technology. There is an intention towards green energy and support of solar panels for housing. Currently government policy support for solar water pumps is difficult to find and a NGO representative says: "*I think that in the next years it will never happen*." (SH 13, 2024).

A related challenge is that three ministries (MAFF, MME, MOWRAM) are involved and need to work together to find a sustainable way of supporting the technology, which makes things complicated. The challenge of the lack of financial support from the government, e.g. in the form of subsidies, is also described in Chapter 2.3.

Technical challenges

Even though there are private companies investing in research, technological improvements are still necessary because, for instance, the efficiency of installed solar panels decreases every year, and the pump has to be replaced after around 10 years.

Also, the solar water pump is a fixed system that cannot be moved, which poses challenges for smallholder farmers as they sometimes have to change the location of the pump.

There is a warranty of 4 years on the system, during which the private companies are responsible for maintenance. They do provide some trainings for the farmers, but it is not sufficient to the point that the farmers can maintain the system themselves. There is also a lack of ownership, as the system is not always fully handed over to the community after the payback period.

A further challenge was mentioned by a private company representative: "(…) *in Cambodia there is a lack of technicians and really ehm, senior engineers there is a lot of junior engineers*." (SH 8, 2023).

Challenges in providing information

Also, while interviewing on local level, a lack of knowledge regarding how solar water pumps work became apparent. This was also observed and mentioned by a representative from a private company that provides the technology: "*And actually after two meetings or one or two sites a day, we invested that they [farmers] don't have any idea of the solar system. They don't understand how is work. They can also think that the solar energy can work during the night.*" (SH 8, 2023). This shows, that even if there are ongoing awareness campaigns, "*many work have been done to like spread this information [about solar water pumps]*" (SH 6, 2023), there is room for improvement.

Another challenge mentioned by a smallholder farmer is to contact the suppliers of solar water pumps: "*But the point is we have the challenge like how to communicate with the company to facilitate and get in touch with the company to come and build the product*." (SH 4, 2023).

These aforementioned challenges in the distribution of solar water pumps in Cambodia are multifaceted and complex. After clustering, it is noticeable that many of the challenges can be categorised either on the demand or the supply side of the implementation of the technology. Figure 8 therefore compiles a simplified summary of the results.

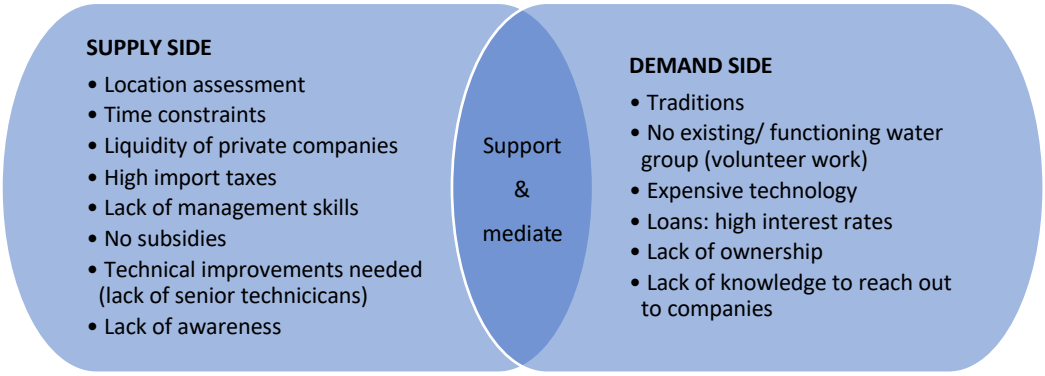


Figure 8: Summary of research - Challenges of scaling up solar water pumps in Cambodia (own figure, 2024)

After the detailed study of the challenges that arise when upscaling solar water pumps in Cambodia, it can be concluded that the implementation of the technology is by no means a simple task for implementing organisations. The numerous challenges show how complex and complicated the whole implementation process is. A lot of challenges also overlap with the disadvantages of solar water pumps identified in Chapter 1.2.

Furthermore, the question arises in what manner NGOs are responsible for establishing a market for solar water pumps, as it is at first hand the task of private companies and the government. In addition, as stated in Chapter 2.3, huge improvements in the electricity sector have been recently made, as in 2020, 81% of households in Cambodia had access to grid electricity (SWITCH to solar, 2023). It is therefore also conceivable to switch to electricity powered pumps in the future if electricity access is heading towards 100% and government-subsidised energies, such as rooftop solar systems, can be utilised. Likewise, the lack of governmental support, i.e. subsidies, make it very difficult to improve and scale up the technology in future. Other countries in Asia, for example India, have this support and are doing well in scaling up the technology and establishment a market of it (Hartung & Pluschke, 2018).

Consequently, before organisations consider supporting the technology, they must be aware that this requires a high level of effort, organisation, and collaboration. On the one hand, the implementation of the technology must be clearly linked to the outcome of the project to make a relevant change. On

the other hand, the needs of the beneficiaries must be prioritised and developed together to create a sustainable, long-term vision. Therefore, at the interface between the supply and demand side is where the role of NGOs can be seen. They can provide **support with financing and management** and **mediate coordination** between stakeholders, which can subsequently lead to an upscaling of the technology. If NGOs decide to implement community solar water pumping systems in Cambodia, the next chapter provides some general recommendations for scaling up the technology.

6. Conclusion and recommendations for upscaling of solar water pumps

Through the interviews, it was possible to identify issues for upscaling solar water pumps in the Cambodian context (Chapter 5). To sum-up, there are multifaced challenges on the demand and on the supply side of the system (Figure 8). In the following, recommendations for NGOs to overcome the challenges are outlined to support and mediate the upscaling process of the technology. The recommendations are based on the results of the stakeholder interviews or, if indicated, on information from literature.

- **Behavioural Change**: It is essential to involve the population in the implementation of a community solar water pump. Agriculture traditions and, above all, the culture should be considered and respected by the installation of solar water pumps (i.e. whether the smallholder farmers are open to cultivate rice twice a year or if one time is sufficient). In addition, by involving the local population from beginning, trust can be built up among different stakeholders.
- **Inclusive planning**: The lessons learned from previous projects and from various organisations can be used as one of the first planning steps.

  The geographical conditions need a standardised assessment (land cover, elevation, slope, rainfall, groundwater, etc. (Gebregziabher et al., 2017)), which is carried out by the private companies. The role of the NGO can be supportive by coordinating the process, e.g. providing access to the communities.

  On the demand side, existing FWUCs can be involved in the planning process, for example by organising participatory workshops with the communities to understand their specific needs. As the national policy is unlikely to change, the provincial authorities (PDAFF or PDWRAM) can be involved in the planning process to strive for an inclusive long-term approach.

  On the supply side, support can be provided in selecting the type of solar pump system or with general management support. For example, time management can be supported, which must also be in line with the project schedule.
- **Awareness raising of the technology**: Awareness can be increased, especially at local level. This can be done, for example, by organising workshops together with PDAFF, FWUCs, and the private sector and by disseminating information and contact details in the form of leaflets. Supporting

the private sector by showing people the advantages of the technology can also raise awareness. Furthermore, it can be beneficial to work with sales agents at provincial or district level.

- **Management skills**: Supporting the private companies' management skills can help for market development of solar technology in the agriculture sector. This may include location assessment or support in drafting project proposals.
- **Technology development and skills training**: Promoting research development of the technology around solar water pumps can strengthen the sector in Cambodia. Consequently, the price of the technology would decrease as not everything needs to be imported and thus, no tax payment is required.

  Furthermore, trainings on village level on pump maintenance and operation is supportive to strengthen ownership of the system. In addition, skills training on water delivery system would bring improvement to utilize the water in an efficient manner for agricultural practices (SWITCH to Solar, 2023).
- **Blended finance**: There are different financing models. On the one hand, a main point is to introduce end-user (smallholder farmers) financing mechanism to mitigate the high upfront costs of solar pumping systems. On the other hand, NGOs can act as an investor for private companies to have liquidity for the installation allowing the farmers to pay back the money in rates. For example, the NGO could provide 50% of the money and the private sector invests 50%, which is repaid by the farmers by rates. It is important that the repayment period is calculated realistically. In this financial model, the NGO can share the investment risk with the private company. It should also be considered that the smallholder farmers have the option of owning the pump once they have reached the break-even point so that they can take over ownership.
- **Partnerships**: To successfully upscale the technology, partnerships with different stakeholders are essential to build synergies and to use the full spectrum of knowledge available (SWITCH to Solar, 2023). The technology needs pilots for upscaling where different business models are tested. This is really a learning by doing process, where changes are made iteratively, and the system is adapted based on results from the ground. Here, NGOs can provide cash-flow liquidity to the companies to be able to invest up-front and test the models together. Through assessment of feasibility, there is a greater chance to reach scale and developing business models.

To summarise, the many challenges involved in upscaling solar water pumps need to be considered before and during implementation. Furthermore, NGOs should not compete with the private sector, as the private sector is the main actor to build the market and lead the process. As shown above, the role of the NGO is rather to act as a consultant between the different stakeholders or to provide initial investments to scale up the technology.

References

Abdelfattah, A. (2022). Solar Powered Water Lifting for Irrigation. Fundamentals and Essentials of Solar Energy. Food and Agriculture Organization of the United Nations [FAO], Land and Water Division (NSL). Accessed at: https://www.fao.org/3/cc4123en/cc4123en.pdf on 29 February 2024 on 29 February 2024.

Asian Development Bank [ADB] (2014). Cambodia Country Poverty Analysis. Accessed at: https://www.adb.org/sites/default/files/institutional-document/151706/cambodia-country-poverty-analysis-2014.pdf on 24 April 2024.

ADB (2015). Renewable Energy Developments and Potential in the Greater Mekong Subregion. Accessed at: https://www.adb.org/publications/renewable-energy-developments-and-potential-gms on 01. on 01 October 2023.

ADB (2021). Cambodia Agriculture, Natural Resources, and Rural Development Sector Assessment, Strategy, and Road Map. Accessed at: https://www.adb.org/sites/default/files/publication/718806/cambodia-agriculture-rural-development-road-map.pdf on 01 March 2024.

Aquarii (2023). Renewable Energy Sector in Cambodia: Full Guide 2023. Accessed at: https://aquariibd.com/the-renewable-energy-sector-in-cambodia-full-guide/ on 12 March 2024.

Bard (2013). Solar-Powering Cambodia: Daniel Pacheco ’07. Accessed at: https://www.bard.edu/news/details/?id=11768 on 06 October 2023.

Cook, B. R., Satizábal, P., Touch, V., McGregor, A., Diepart, J. Utomo, A., Harrigan, N., McKinnon, K., Srean, P., Tran, T. A., Babon, A. (2024). Historical Agrarian Change and its Connections to Contemporary Agricultural Extension in Northwest Cambodia. In: Critical Asian Studies, 56:1, https://doi.org/10.1080/14672715.2023.2298430.

Durga, N., Schmitter, P., Ringler, C., Mishra, S., Manuel, S., Abena Ofosu, M., Pavelic, P., Hagos, F., Melaku, D., Verma, S., Minh, T., Matambo, C. (2024). Barriers to the uptake of solar-powered irrigation by smallholder farmers in sub-saharan Africa: A review. Energy Strategy Reviews, 51, https://doi.org/10.1016/j.esr.2024.101294.

Engel, R. (2023). Stakeholderanalyse - Erklärung und Beispiel. Accessed at: https://www.edworking.com/de/blog/startups/stakeholderanalyse-erklarung-und-beispiel on 03 October 2023.

Flick, U. (2016). Qualitative Sozialforschung: Eine Einführung, 7. Edition, Reinbek bei Hamburg, Germany: Rowohlt Verlag GmbH.

Food and Agriculture Organization of the United Nations [FAO] (2024a). Country Papers: Large rice-based irrigation systems in Cambodia. Accessed at: https://www.fao.org/3/ai408e/ai408e06.htm on 28 February 2024.

FAO (2024b). Cambodia. Investment Forum 2023. Hand-in-Hand Initiative. Accessed at: https://www.fao.org/hand-in-hand/hih-IF-2023/cambodia/en#:~:text=Rice%20is%20the%20staple%20crop,commodity%20(USD%201%20billion) on 11 March 2024.

Gebregziabher, G., Biazin, B., Haileslassie, A., Chali, A., Schmitter, P., Hagos, F., Lefore, N., Barron, J., Tegegne, D., Dubale, T. (2017). Solar powered water pumping can boost smallholder income: A business model based on action research from LIVES and Africa RISING sites. Accessed at: https://www.researchgate.net/publication/312474487_Solar_powered_water_pumping_can_boost_smallholder_income_A_business_model_based_on_action_research_from_LIVES_and_Africa_RISING_sites on 14 March 2024.

Global Solar Atlas (2024). Cambodia. Accessed at: https://globalsolaratlas.info/download/cambodia on 28 February 2024.

Gibbons, S. (2022). Stakeholder Interviews 101. Accessed at: https://www.nngroup.com/articles/stakeholder-interviews/ on 03 October 2023.

Hartung, H., Pluschke, L. (2018). The benefits and risks of solar-powered irrigation - a global overview. FAO. Accessed at: https://www.fao.org/3/I9047EN/i9047en.pdf on 01 October 2023.

Heider, C., Flanagan, A., E. (2017). Putting Behavior Change at the Center of Development and Evaluation. Accessed at: https://ieg.worldbankgroup.org/blog/putting-behavior-change-center-development-and-evaluation on 13 March 2024.

Herman, F. (2021). Advantages and Disadvantages of Solar Water Pumps. Accessed at: https://futurepump.com/advantages-and-disadvantages-of-solar-water-pumps/ on 14 March 2024.

Hilali, A., Mardoude, Y., Essahlaoui, A., Rahali, A.,El Ouanjli, N. (2022). Migration to solar water pump system: Environmental and economic benefits and their optimization using genetic algorithm Based MPPT, Energy Reports, 8, https://doi.org/10.1016/j.egyr.2022.08.017.

Hupmobile (2022). Stakeholder interviews. Accessed at: https://participatory.tools/tools/stakeholder-interviews/ on 18 October 2023.

Long, S. (2019). Scaling up access to renewable energy financing in Cambodia. Case Study Analysis for Small and Medium Agri-Food Businesses. Accessed at: https://www.nexusfordevelopment.org/wp-content/uploads/2023/11/NexusforDevelopment_Report_Scaling-up-access-to-renewable-energy-financing-in-Cambodia_EN.pdf on 17 October 2023.

Lefore, N., Closas, A., Schmitter, P. (2021). Solar for all: A framework to deliver inclusive and environmentally sustainable solar irrigation for smallholder agriculture. Energy Policy, 154, https://doi.org/10.1016/j.enpol.2021.112313.

Ministry of Mines and Energy [MME] (2022a). National Energy Efficiency Policy 2022-2030 [NEEP]. Accessed at: https://data.opendevelopmentmekong.net/library_record/decision-no-78-on-promulgation-of-the-national-energy-efficiency-policy-2022-2030/resource/f995ab4f-23dc-45f0-8d92-4ed1bbe7e4b8 on 21 August 2023.

MME (2022b). Power Development Masterplan 2022-2040 [PDP]. Accessed at: https://climate-laws.org/documents/power-development-master-plan-2022-2040-6097?id=power-development-master-plan-2022-2040-0f75 on 12 March 2024.

MME (2023). Principles for Permitting the Use of Rooftop Solar Power in Cambodia. Accessed at: https://energylab.asia/principles-for-permitting-the-use-of-rooftop-solar-power-in-cambodia on 12 March 2024.

Ministry of Environment [MOE] (2023). Circular Strategy on Environment 2023-2028. Accessed at: https://www.moe.gov.kh/wp-content/uploads/2023/11/Circular-Stratesy%E2%80%8B-for-Environment-2023-2028-1.pdf on 12 March 2024.

Ministry of Planning [MOP] (2024). Query IDPoor Data. Oddar Meanchey. Accessed at: https://app.idpoor.gov.kh/public-data-query#publicindividualdata on 05 April 2024.

Ministry of Water Resources and Meteorology [MOWRAM] (2003). Irrigated Agriculture. Accessed at: https://data.opendevelopmentmekong.net/dataset/552538d1-bf95-4bf3-a335-0643a7950656/resource/ba711d37-f121-458f-918c-1ba6acd2b086/download/76a83577-5ce4-4042-92e4-4a7b86510818.pdf on 21 August 2023.

Olaniyi, E. (2023). How to Prepare and Conduct Stakeholder Interviews. Accessed at: https://blog.uxtweak.com/stakeholder-interviews/ on 5 October 2023.

Overton, L. C., Chandler, D. P. (2023). Cambodia. Encyclopedia Britannica. Accessed at: https://www.britannica.com/place/Cambodia on 17 August 2023.

Pouilly, L. (2020). Conducting stakeholder interviews: 12 Golden Rules. Accessed at: https://think.design/blog/conducting-stakeholder-interviews-12-golden-rules/ on 18 October 2023.

Ritchie, H., Roser, M., Rosado, P. (2020). CO_2 and Greenhouse Gas Emissions. Accessed at: https://ourworldindata.org/co2-and-greenhouse-gas-emissions on 01 March 2024.

Rädiker, S., Kuckartz, U. (2019): Analyse qualitativer Daten mit MAXQDA, Berlin, Germany, Springer. https://doi.org/10.1007/978-3-658-22095-2.

Royal Government of Cambodia (2023). Pentagonal Strategy-Phase I for Growth, Employment, Equity, Efficiency and Sustainability: Building the Foundation Towards Realizing the Cambodia Vision

2050. The Royal Government of Cambodia of the Seventh Legislature of the National Assembly. Accessed at: https://mfaic.gov.kh/files/uploads/1XK1LW4MCTK9/EN%20PENTAGONAL%20STRATEGY%20-%20PHASE%20I.pdf on 04 March 2024.

Royal Government of Cambodia (2018). Rectangular Strategy for Growth, Employment, Equity and Efficiency: Building the Foundation Toward Realizing the Cambodia Vision 2050. Phase IV of the Royal Government of Cambodia of the Sixth Legislature of the National Assembly. Accessed at: https://www.mfaic.gov.kh/files/uploads/LVSOWKCT85MR/20180907_Rectangular_Strategy_IV_Khmer.pdf on 04 March 2024.

Sothorn, K. (2020). The Use of Credit by Rice Farmers in Takeo. In: Cramb, R. (eds). White Gold: The Commercialisation of Rice Farming in the Lower Mekong Basin. Palgrave Macmillan, Singapore. https://doi.org/10.1007/978-981-15-0998-8_15.

Sryneath, C., Sothorn, K. (2017). Briefing Note. Economic Development and Local Service Delivery at Sub-National Government Level in Oddar Meanchey Province. Accessed at: https://pcasia.org/pic/wp-content/uploads/simple-file-list/20171227_Economic-development-and-local-services-at-Otdar-Meanchey_En.pdf on 25 April 2024.

SWITCH to Solar (2023). SWITCH to Solar Project. Solar Water Pump – Summary of Market Study Results. Accessed at: https://switchtosolarkh.org/publication/ on 23 August 2023.

The World Bank (2020). Download solar resource maps and GIS data for 200+ countries and regions. Source: Global Solar Atlas 2.0, Solar resource data: Solargis. Accessed at: https://solargis.com/maps-and-gis-data/download on 01 March 2024.

Tyner, J., Munro-Stasiuk, M., Coakley, C., Kimsroy, S., Rice, S. (2018). Khmer Rouge Irrigation Schemes During the Cambodian Genocide. In: Genocide Studies International, 12. https://doi.org/10.3138/gsi.12.1.07.

United Nations [UN] (2021). Leveraging Energy Action for Advancing the Sustainable Development Goals. Accessed at: https://sdgs.un.org/sites/default/files/2021-06/2021-POLICY%20BRIEFS_3.pdf on 28 September 2023.

Vilela, M. (2023). Section 12. Conducting Interviews. Accessed at: https://ctb.ku.edu/en/table-of-contents/assessment/assessing-community-needs-and-resources/conduct-interviews/main on 18 October 2023.

Va, V. (2023). How solar-powered water pumps are boosting productivity and resilience for Cambodia's farmers. Accessed at: https://www.undp.org/cambodia/blog/how-solar-powered-water-pumps-are-boosting-productivity-and-resilience-cambodias-farmers#:~:text=The%20pumps%20are%20providing%20a,the%20resilience%20of%20their%20crops on 28 September 2023.

World Bank Group (2018). Solar Pumping: The Basics. Washington, DC. Accessed at: http://hdl.handle.net/10986/29267 on 25 October 2023 on 01 October 2023.

World Bank (2015). Cambodia - The Agriculture, Irrigation, and Rural Roads Sectors: Public Expenditure Review. Accessed at: https://openknowledge.worldbank.org/entities/publication/e6c4a3d6-e90f-5411-9e97-fce626269f0d on 28 February 2024.

World Bank (2021). Employment in agriculture – Cambodia. Accessed at: https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=KH on 17 August 2023.

Appendix

A1 Documentation of AI-based tools used in this thesis

I hereby acknowledge that I used the following AI-based tool for writing my MAS thesis.

Table 1: Used AI-based tools (own table, 2024)

AI-based tool	How it was used	Sections or scope
DeepL	Editing of text / improve readability and check grammar and spelling	Entire work

A2 Stakeholder identification

The following questions were asked to identify the stakeholders in the system:

- Who is making decisions on various levels (community, local, regional, national)?
- Who might have resources to contribute?
- Who will be affected by positive/ negative impacts of the project?
- Who will be responsible for implementing measures to mitigate the negative impacts?
- Whose cooperation, expertise or influence would be helpful for the success of the project?
- Who are the most vulnerable, least visible, and voiceless for whom special consultant efforts may have to be made?
- Who supports or opposes the changes that the project will bring?
- Whose opposition could be detrimental to the success of the project?

Table 2: Stakeholders (own table, 2023)

Stakeholder	Short description
Stakeholder 1	Smallholder farmer 1, person with disability, uses diesel pump, no access to SWP
Stakeholder 2	Smallholder farmer 2, uses no pump at all, access to SWP
Stakeholder 3	Smallholder farmer 3, woman, uses diesel pump, no access to SWP
Stakeholder 4	Smallholder farmer 4, person with disability, uses diesel and solar water pumps
Stakeholder 5	Water group (4 people)
Stakeholder 6	Local authority - village chief
Stakeholder 7	Deputy Director of PDAFF
Stakeholder 8	Private Company 1 - SWP
Stakeholder 9	Private Company 2 - SWP
Stakeholder 10	Finished NGO-project who installed SWP
Stakeholder 11	Ongoing NGO-project who plan to install SWP
Stakeholder 12	Ongoing NGO-project who plan to install SWP
Stakeholder 13	Ongoing NGO-project with SWP

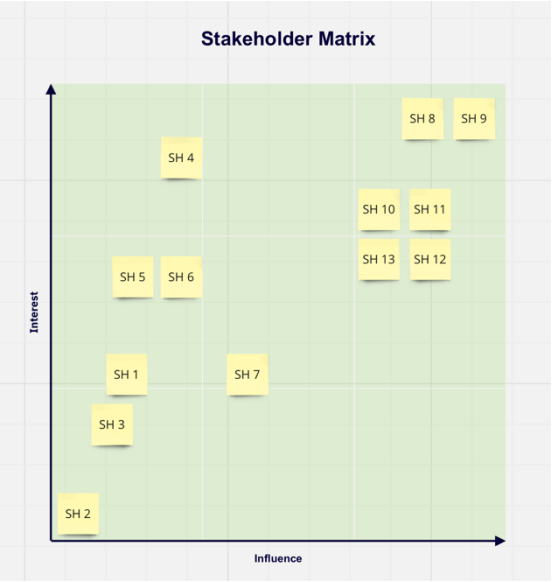


Figure 9: Stakeholder Matrix (own figure, 2023). SH stands for stakeholders.

A3 Schedule for data collection

Figure 10 shows the schedule of the interview on local level, as well as the visit of the irrigation system with a solar water pump in Ou Run village, Thlat district, Oddar Meanchey province (Chapter 2.4). The interviews with stakeholders 8 – 13 (Appendix 2, Table 2) were conducted online.

Data collection in OMC
30-31 October 2023

Monday, 30th October 2023

Hours	Activities	Participants
09:00-11:00	Travel from Siem Reap to OMC	MRM officer & Eileen
11:00-12:00	Briefing with OMC staff	OMC team, MRM officer & Eileen
14:00-15:00	**Interview 1:** PDAFF	OMC field coordinator, MRM officer & Eileen
15:00-16:20	Travel from OMC to Anlong Veng	OMC field coordinator, MRM officer & Eileen

Logistics:

- Transportation: Car from Siem Reap
- Overnight stay in Anlong Veng (OMC field coordinator, MRM officer & Eileen)

Tuesday, 31st October 2023

Location: Ou Run village, Thlat District, Oddar Meanchey Province

Hours	Activities	Participants
07:30-08:30	Field visit of irrigation system (Thlat commune, Ou run village)	OMC field coordinator, MRM officer & Eileen
08:30-09:30	**Interview 2:** Village chief (Ou Run village) 1 person	
09:40-10:40	**Interview 3:** Water User Group (solar water pump) (3 people)	
10:50-11:50	**Interview 4:** Smallholder farmer 1 who uses solar water pump (1 farmer)	
12:00-13:20	Lunch break	
13:30-14:30	**Interview 5:** Smallholder farmer 2 who uses solar water pump (1 person)	
14:40-15:40	**Interview 6:** Smallholder farmer 3 who doesn't use solar water pump (1 Person)	
15:40-16:40	**Interview 7:** Smallholder farmer 4 who doesn't use solar water pump (1 person)	
16:40-18:00	Travel back from Anlong Veng to Siem Reap	

Logistics:

- Transportation: Car from Siem Reap

Figure 10: Schedule for data collection on field level (own document, 2023)

A4 Interview guide

Figure 11 shows the interview guide. This document was adapted before each stakeholder interview to better fit the current interview.

Interview guide – Template

This guide supports to answer the following research question: "What is the challenge in scaling up solar water pumps for agricultural irrigation systems from different stakeholder perspectives in Cambodia?"

Introduction (5min)
Introduction about the research: introduction of myself, information and purpose of the study, data collection and other interview partners, length and format of the interview, agreement on recording the interview, clarification of anonymity.

* Green colour = mandatory questions

1. Background information and (past) experiences with solar water pumps (8min)

Personalized questions:
1.1.

2. Switching from diesel to solar water pump (10min)

2.1. Why do people use/ install solar water pumps?
2.2. What (social, environmental, and ecological) opportunities do solar water pumps bring?
2.3. What are the disadvantages of solar water pumps?

Personalized questions:
2.4.

3. Expanding the technology (20min)

3.1. Why are still a lot of diesel pumps in use?
3.2. How do you experience the expanding of solar pumps (in Cambodia)?
3.3. What is the challenge of scaling up (expanding) solar water pumps wider and faster?

Personalized questions:
3.4.

4. Future perspective (15min)

4.1. What is the demand for solar water pumps among the various stakeholders in Cambodia?
4.2. What is needed to scale up the technology in future wider and faster?

Personalized questions:
4.3.

5. Optional: Other examples and comparisons (if time)

Personalized questions:
5.1

Finish (2min)
Conclusion: Thank you for your time, interview consent form (in person/ email), results will be shared as soon as they are ready (2024).

1

Figure 11: Interview Guide - template (own document, 2023)

A5 Interview consent form

Interview consent form

ប្រធានបទការសិក្សាស្រាវជ្រាវ (Research project title): ឧបសគ្គនៃការដំឡើងម៉ាស៊ីនបូមទឹកដើរដោយថាមពលពន្លឺព្រះអាទិត្យសម្រាប់ប្រព័ន្ធធារាសាស្ត្រនៅកម្ពុជា - ការវិភាគលើទស្សន:ភាគីពាក់ព័ន្ធផ្សេងៗគ្នា។ (The challenge of scaling up solar pumps for irrigation systems in Cambodia - An analysis of different stakeholder perspectives.)

កម្មវិធីសិក្សា (study program): NADEL, ការសិក្សាក្រោយឧត្តមសិក្សា ផ្នែកអភិវឌ្ឍន៍ និងកិច្ចសហប្រតិបត្តិការ, ETH Zürich (NADEL, Post-graduate studies in Development and Cooperation, ETH Zürich)

និស្សិតនិងអ្នកសម្ភាសន៍ (student and interviewer): Eileen Schilliger

ឈ្មោះអ្នកចូលរួម (research participant's name): _____

កាលបរិច្ឆេទនៃការសម្ភាសន៍ (date of Interview): _____

ខ្ញុំសូមបញ្ជាក់ពីការយល់ព្រមសម្ភាសន៍ក្នុងគម្រោងស្រាវជ្រាវខាងលើ។ ខ្ញុំត្រូវបានគេជូនដំណឹងអំពីគោលដៅ និងជំហានបន្ថែមទៀតនៃគម្រោងស្រាវជ្រាវ ក៏ដូចជារបៀបដែលព័ត៌មានដែលមាននៅក្នុងការសម្ភាសន៍នឹងត្រូវបានយកទៅប្រើប្រាស់។ ទម្រង់ការយល់ព្រមអោយសម្ភាសន៍នេះគឺចាំបាច់ដើម្បីធានាថាអ្នកចូលរួមទាំងអស់ដែលចូលរួមក្នុងដំណើរការនេះ យល់ពីគោលបំណងនៃការចូលរួមរបស់ពួកគាត់ និងយល់ព្រមចំពោះលក្ខខណ្ឌនៃការចូលរួមរបស់ពួកគាត់។ ដូច្នេះ តាមរយៈការចុះហត្ថលេខាលើឯកសារនេះ អ្នកបញ្ជាក់ថាអ្នកយល់ព្រមជាមួយនឹងចំណុចខាងក្រោម៖ :

(I hereby confirm to being interviewed in the above-mentioned research project. I have been informed about the goal and further steps of the research project as well as how the information contained in the interview will be used. This consent form is necessary to ensure that all the participants involved in the process understand the purpose of their involvement and agree to the conditions of their participation. Therefore, by signing this document you confirm that you agree with the following points):

- ខ្ញុំចូលរួមដោយស្ម័គ្រចិត្តក្នុងការសិក្សានេះ។ (I am voluntarily taking part in this project.)
- ការថតសម្លេងនឹងត្រូវបានយកទៅសរសេរកត់ត្រា និងវិភាគដើម្បីប្រមូលព័ត៌មានសំខាន់ៗដើម្បីឆ្លើយសំណួរស្រាវជ្រាវ។ (The recorded interview will be transcribed and analysed to gather important information to answer the research question.)
- ការថតសម្លេងសម្ភាសន៍គឺសម្រាប់តែអ្នកសម្ភាសន៍ និងអ្នកគ្រប់គ្រងការងារប៉ុណ្ណោះ។ (The recording of the interview is only accessible to the interviewer and the supervisor of the work.)
- ការសម្ភាសន៍អាចត្រូវបានដកស្រង់ដោយផ្ទាល់នៅក្នុងនិក្ខេបបទ។ (The interviews may be quoted directly in the thesis.)
- លទ្ធផលនឹងត្រូវបានរក្សាទុកជាអនាមិកនៅក្នុងការស្រាវជ្រាវ ទោះជាយ៉ាងនេះក្តី មុខតំណែង និងប្រភេទនៃអង្គការអាចបង្ហាញឱ្យដឹង។ (The results will be kept anonymised in the paper, however, the position and the type of organisation may be apparent.)
- និក្ខេបបទចុងក្រោយនឹងត្រូវផ្សព្វផ្សាយជាសាធារណៈ។ (The final thesis will be made publicly available.)

កាលបរិច្ឆេទ (date): _____

ឈ្មោះ (Name): _____ **ហត្ថលេខា** (Signature): _____

Figure 12: Interview consent form (own document, 2023)

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

A6 Declaration of originality

The signed declaration of originality is a component of every semester paper, Bachelor's thesis, Master's thesis and any other degree paper undertaken during the course of studies, including the respective electronic versions.

Lecturers may also require a declaration of originality for other written papers compiled for their courses.

I hereby confirm that I am the sole author of the written work here enclosed. I have compiled it in my own words. Parts excepted are corrections of form and content by the supervisor. Contributions from artificial intelligence-based (AI) tools are described in annex 1 of this work. All contributions from artificial intelligence-based tools have been reviewed and edited as necessary. I take full responsibility for the content of the work.

Title of work (in block letters):

THE CHALLENGES OF SCALING UP SOLAR WATER PUMPS FOR IRRIGATION SYSTEMS IN CAMBODIA - AN ANALYSIS OF DIFFERENT STAKEHOLDER PERSPECTIVES

Authored by (in block letters):

For papers written by groups the names of all authors are required.

Name(s):	**First name(s):**
SCHILLIGER	EILEEN LISA

With my signature, I confirm that

- I have committed none of the forms of plagiarism described in the 'Citation etiquette' information sheet.
- I have documented all methods, data and processes truthfully.
- I have not manipulated any data.
- I have mentioned all persons who were significant facilitators of the work.

I am aware that the work may be screened electronically for plagiarism.

Place, date	**Signature(s)**
BERN, 28.04.2024	E. Schilliger

For papers written by groups the names of all authors are required. Their signatures collectively guarantee the entire content of the written paper.