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Barriers and Drivers for Solar Dryer Adoption in Nepal

A Study from Users and Producers Perspectives

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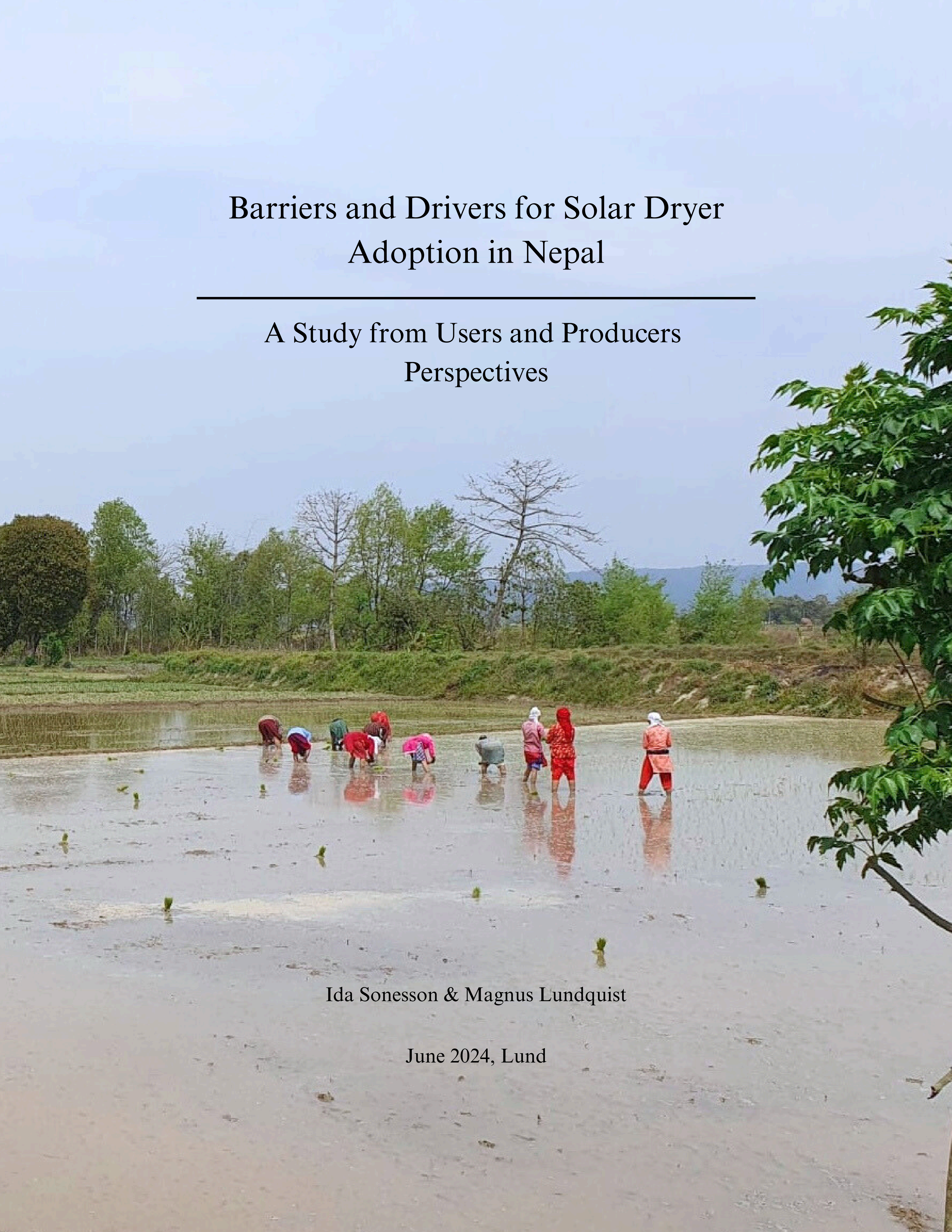
Thesis for the degree of Master of Science in Engineering

Division of Heat Transfer
Department of Energy Science
Faculty of Engineering (LTH) | Lund University



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June 2024, Lund

This degree project for the degree of Master of Science in Engineering has been conducted at the Division of Heat Transfer, Department of Energy Sciences, Faculty of Engineering, Lund University.

Supervisor at Lund University was Prof. Martin Andersson (Division of Heat Transfer).

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Abstract

This master's thesis is part of the project *SolarFood*, aimed at reducing post-harvest losses through improved solar drying techniques. The project focuses on developing locally adapted solar dryers, with short drying times while considering socio-economic factors for technology adoption and diffusion. This paper investigates adoption barriers and potential drivers for the diffusion of solar dryer technology among small-scale farmers in Nepal.

The research was carried out through a study of relevant literature, which was then analyzed together with the results from field studies done in three regions of Nepal, addressed to external stakeholders. The aim was to understand the potential for adoption, scalability, and diffusion of the solar dryers developed within the SolarFood project. Findings reveal several challenges, including farmers' limited awareness of the technology and dissatisfaction with market conditions for dried products. These persists despite government policies and initiatives in Nepal aimed at promoting the adoption of solar dryers. To overcome these barriers, this study proposes the distribution of solar dryers alongside comprehensive training programs tailored for both local manufacturers and users. These programs should focus on developing technical skills related to the maintenance, repair, and troubleshooting of solar dryers.

Moreover, for solar dryers to diffuse among farmers across Nepal, their design must be optimized and tailored to align with farmers' preferences and environmental conditions. There is potential of enhancing the current third-generation solar dryer developed within the project. This involves enhancing portability and ensuring that the materials used are readily available locally across the country, facilitating decentralized production. Technical refinements are crucial to create a dryer that not only fulfills farmers' needs but also remains both technically and economically competitive with dryers eligible for subsidies.

Overall, the study underscores the significance of socio-economic factors in ensuring the successful adoption and diffusion of solar drying technology in agricultural practices. Neighbor-to-neighbor communication is identified as a potent driver for disseminating information, with the expectation that as more farmers become acquainted with the project's solar dryer, demand for the same dryer will increase.

Key words: Solar Dryer, Nepal, Post-Harvest Losses, Adoption of Agricultural Technology, Diffusion of Innovations

Preface

This thesis is a part of the project *SolarFood: Reducing post-harvest losses through improved solar drying*, which is funded by the Swedish Research Council (project number: VR-2020-04071). It is coordinated by Prof. Martin Andersson and Dr. Henrik Davidsson at Lund University, and is a collaboration between Lund University, Royal University of Bhutan, Kathmandu University and Ruralis (Institute for Rural and Regional Research).

All photographs, figures, and tables in this thesis are taken, created, and edited by the authors unless stated otherwise.

Acknowledgements

Throughout this thesis work, we have gotten to know many wonderful people who have not only helped us realize the thesis itself but have also shown us great camaraderie and support in our everyday lives during these past months. A special thanks goes out to Prof. Bivek Baral and everyone in the research team at Kathmandu University for making our stay in Nepal an unforgettable experience, enabling the progression of this paper in a fun and truly immersive way. The hospitality and warmth we experienced with all of you have been second to none. We will be back.

We would like to thank our supervisor, Prof. Martin Andersson, for his constant encouragement and guidance, mostly provided remotely from the other side of the world, but also in person in Sweden and during a memorable experience together in Kathmandu. A big thank you also goes out to our examiner, Dr. Henrik Davidsson. Thank you both for giving us this opportunity of a lifetime. We are also grateful for the insightful feedback from Dr. Kerstin Sernhed and Dr. Elina Andersson, who guided our engineering minds through the non-technical parts of the work.

Without wanting to sound too self-congratulatory, we would also like to thank each other, recognizing that this journey would not have been the same without taking care of one another during challenging times and sharing memories of incredible treks and cultural and religious experiences. Thank you.

Lastly, with all the love we can muster, we wholeheartedly thank our fellow students and friends who have been our second family over these past six years, embarking on this university journey together. If it were not for you, the journey would surely have been cut short on multiple occasions. So thank you - your friendship is our greatest achievement.

Contents

1 Introduction

Agricultural innovations serve as critical tools in poverty alleviation by reducing production costs per unit and increasing rural incomes. However, the goal of enhancing the livelihoods of rural households through improved agricultural productivity proves elusive without a simultaneous enhancement in technology adoption. Therefore, the adoption of agricultural technology becomes a paramount concern for agricultural extension workers, policymakers, agricultural researchers, and other stakeholders, particularly in developing countries such as Nepal (Ministry of Agriculture and Livestock Development, 2023a).

As Nepal is faced with multiple challenges, including poverty, as well as food insecurity and nutrient deficiency (FAO, European Union and CIRAD, 2022), the adoption and diffusion of solar drying technology offer promising solutions to alleviate these issues. With over 300 days of sunlight annually, a mean solar radiation of approximately 4.7 kWh/m^2 per day (17 MJ/m^2 per day), and an average of 6.8 hours of sunshine daily, solar energy provides the most significant renewable generation potential in Nepal and this energy can be partly harnessed by solar dryers to dry crops (Lohani et al., 2022). The technology serves as an improved method for food preservation, reducing post-harvest losses, increasing farmers' income, and enhancing the availability of a diverse diet year-round.

According to the Intergovernmental Panel on Climate Change (IPCC, 2019), combined food loss and waste amount to 25–30 percent of the total food produced globally. For post-harvest losses of fruits and vegetables in Nepal, the figures are estimated to be even higher. Both Faqeerzada et al. (2018) and Subedi et al. (2019) report losses to the extent of 40 percent, findings that are further supported by GC et al. (2019). In lower-income countries, like Nepal, it is widely acknowledged that post-harvest losses of fresh fruits and vegetables primarily occur at earlier stages in the supply chain due to inadequate storage technology and limited awareness of post-harvest management (FAO, 2011). This problem is particularly pronounced for fruits and vegetables since their production often results in a surplus during the harvesting season, with a decrease in selling prices and unsold produce going uneaten or spoiling as a result. Moreover, in high mountain regions where food production is limited to a few months per year, solar drying techniques serve a dual purpose by preserving surplus food production and enabling year-round food availability (Ministry of Energy, Water Resources and Irrigation, n.d.).

Aside from the challenges mentioned above, Nepal is regarded as one of the most vulnerable nations to the impacts of climate change due to its geographical features. Together with the poles, the high mountains of the Himalaya face some of the most pronounced effects of climate change and projections indicate that Nepal will experience higher levels of warming compared to the global average, along with an increase in extreme weather events such as droughts and intense rainfall (ICIMOD, 2023; National Planning Commission, 2017). These impacts have profound implications across various sectors, notably the agricultural sector, which heavily relies on weather patterns (FAO, European Union and CIRAD, 2022). The adoption of solar drying technology presents an opportunity to address both climate mitigation and adaptation to climate change. By reducing the vulnerability of the drying process to external factors like rain and wind, solar drying technology can enhance the resilience of food preservation efforts without relying on fossil fuels (Mustayen et al., 2014). However, despite the existence of this technique, a question arises: why is it not more widely adopted?

In an attempt to answer this question and identify factors that facilitate or hinder the adoption and diffusion of solar drying technology, the terminology of "drivers" and "barriers" is employed. Barriers are described as any economic, institutional, technical, social, or political aspects that negatively influences the adoption of solar dryers. Conversely, drivers refer to factors within the same categories that enhance the implementation of the technology. However, given the interconnected nature of these aspects, isolating their effects can be challenging (Goel et al., 2022).

1.1 Background

1.1.1 Solar Drying: Process and Techniques

Solar drying is a preservation method where the main objective is to reduce the moisture content in a crop so that the dried product can be stored safely for a certain period of time. There are two processes involved within the drying process: heat transfer from the heating source to the product and mass transfer (in terms of moisture) from the product to the surroundings (Goel et al., 2022). Drying under controlled temperature and humidity conditions can inhibit microbial growth and preserve nutrients, all in a relatively quick drying time. For food products, like fruits and vegetables, the surrounding hot air temperature needs to range from 45 to 60 °C for safe drying (Bal et al., 2010). However, the traditional method that is most commonly used in tropical and subtropical countries is open sun drying (Mustayen et al., 2014), where the agricultural food products are put out in the open air, in direct sunlight to dry (Goel et al., 2022). Although this method can be effective (Mustayen et al., 2014) and enjoy cost advantages for small amounts of agricultural products (Bal et al., 2010), it comes with a lot of disadvantages. For larger scale farming, the method requires large areas and is a labor-intensive process.

Figure 1: Examples of open sun drying, in this case coriander seeds (left) and corn (right) drying in Madi, Chitwan. Pictures by Ida Sonesson.

Since the method is dependent on environmental conditions such as wind, solar radiation, and other ambient conditions, the results of the drying are unpredictable. Rainfall events, overnight storage, and the fact that the process is relatively slow (193 hours for drying chilies according to Rabha et al. (2017)) can cause problems like re-moisturizing of the product, insect infection, growth of microorganisms, and contamination (e.g., dust and dirt). This, in turn, can contribute to losses and a reduced quantity of high-quality products. Also, non-uniform drying can lead to the destruction of the products during storage. To overcome the obstacles associated with open sun drying, mechanical dryers have been developed and utilized. These dryers use fossil fuels to heat drying air and electricity to force dry air through the agricultural products (Mustayen et al., 2014). However, there are alternative methods for harnessing solar energy for drying in a controlled process without relying on fossil fuels. These types of sun drying practices utilize drying cabinets and can generally be divided into two categories: direct solar drying and indirect solar drying.

Direct Solar Dryer

The design of a direct solar dryer is comparatively simple, making it less expensive, easier to construct, and more user-friendly (Al-Juamily et al., 2007). The drying cabinet typically takes the form of a tent or box, utilizing a transparent cover to shield the product from rain and dust while minimizing heat loss (Mustayen et al., 2014). However, this method lacks temperature control (Al-Juamily et al., 2007) and may be susceptible to insect infestation (Mustayen et al., 2014). Moreover, prolonged exposure to sunlight can lead to loss of nutritional value and changes in the color of the agricultural product (Al-Juamily et al., 2007).

Indirect Solar Dryer

The indirect solar dryer employs solar collectors to initially capture heat from the sun. Subsequently, it conveys the hot air from the collectors to the drying cabinet, where the drying process occurs (Mustayen et al., 2014). Therefore, the drying product is never exposed to direct sunlight. The continuous flow of heated air circulating around the drying products maintains a reduced relative humidity, enhancing the potential for water absorption. Consequently, this facilitates a persistent and uniform dehydration of the agricultural products within the cabinet. Furthermore, the closed drying system protects the products from contamination and helps to maintain quality and nutritional value of the dried products. The circulation can be achieved both by natural convection, where hot dry air rises through the drying cabinet and then is let out, or by forced convection, where the air circulation is powered by some kind of fan/blower installation (Goel et al., 2022).

1.1.2 Understanding Nepal: Geography, Climate, Agriculture, and Food Security

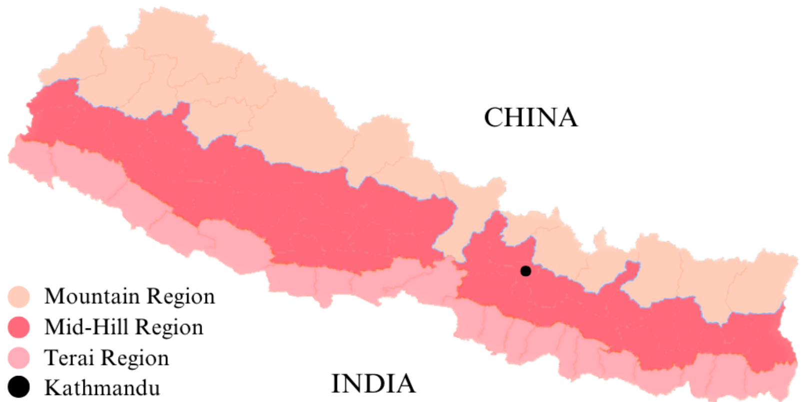


Figure 2: Geographic map of Nepal illustrating the three topographical regions; mountain, mid-hill and Terai, as well as the location of the capital, Kathmandu. (Figure inspired by O. Joshi et al. (2018)).

Geography and Population Dynamics

Nepal is situated in southern Asia, bordered by India to the east, south, and west, and by China to the north. Covering an area of approximately 147 000 km^2 (Ministry of Agriculture and Livestock Development, 2023b), the country is home to a population of 29 million inhabitants (Ministry Of Foreign Affairs, n.d.). The topography of Nepal is highly varied, with the lowest point at 70 meters above sea level and the highest point being Mount Everest, which is also the world's highest peak, at 8 848 meters. With eight of the world's ten highest peaks, Nepal is considered one of the highest countries globally (FAO, 2011). Physiographically, the country is divided into three regions: The mountain region in the north, which constitutes 35 percent of the total land area; the mid-hill region, covering 42 percent; and the Terai region in the south, comprising the remaining 23 percent (see Figure 2) (Ministry of Agriculture and Livestock Development, 2023b). The northern mountain region is defined by the Himalayan range. Due to its geography and climatic conditions, this area is less populated than the other two, accounting for only about six percent of the total population. The mid-hill region includes the capital, Kathmandu, and is characterized by its hills, valleys, and lakes. The Terai region forms a low flat land in the southern part of Nepal and includes the majority of the country's fertile land and dense forests. As a result, most of Nepal's crops are cultivated in this region, which accommodates more than 50 percent of the population (Central Bureau of Statistics, 2022).

Climate Conditions

Nepal's weather and climate are influenced by the extremely varied topography, as well as its location in a subtropical latitude. It varies from a subtropical climate in the lowlands Terai region, with warm summers and mild winters, to an Arctic climate at higher altitudes, characterized by cool summers and severe winters (CIA, 2024; Ministry Of Foreign Affairs, n.d.). In general, the country experiences four distinct seasons, along with two monsoon seasons. The summer monsoon, which ranges from June to August, contributes to more than 75 percent of the total rainfall, while the winter monsoon season, spanning from December to February, brings less than 25 percent (FAO, 2011).

Agricultural Sector

A significant 28 percent of Nepal's land area comprises agricultural land (Ministry of Agriculture and Livestock Development, 2023b), making agriculture the primary source of income for nearly two-thirds of Nepal's residents. Additionally, it contributes approximately 27 percent to the country's Gross Domestic Product (GDP). However, domestic production falls short of the population's dietary demands, leading to increased food imports, particularly from neighboring India (FAO, European Union and CIRAD, 2022).

The agricultural sector of Nepal is mainly dominated by small-scale farmers, with an average farm-holding size of 0.73 hectares (USAID et al., 2022). The primary crop, with the largest area of cultivation, is rice. Besides rice, a variety of other crops are grown, including cash crops such as oil seed, potato, tobacco, and cereal crops like paddy, maize, millet, and wheat (FAO, European Union and CIRAD, 2022). Additionally, Nepal's diverse climate supports the cultivation of various fruits and vegetables (Ministry of Agriculture and Livestock Development, 2023b). However, less than 20 percent of produce from small-scale farmers is sold through formal market channels (FAO, European Union and CIRAD, 2022).

Small-scale farmers encounter various obstacles and challenges in their work. They often lack support in critical areas such as access to credit, technical expertise, and investment assistance. Productivity frequently suffers due to the inability to invest in improved agricultural inputs such as high-quality seeds, soil enhancements, and modern technologies like irrigation systems. Moreover, production methods tend to be labor-intensive. While farmers primarily rely on family labor, additional workers must often be hired during crucial production stages, such as harvest time. However, due to limited financial resources, the wages and working conditions for hired laborers are typically substandard (USAID et al., 2022). The available labor pool also faces shortages due to significant migration, with many young men from rural areas of Nepal moving to urban areas or other countries in search of better opportunities. Consequently, this trend has a direct impact on women in rural areas, who often take on additional labor responsibilities but receive lower returns for their work (FAO, European Union and CIRAD, 2022).

In addition to the challenges mentioned above, Nepalese agriculture faces the impacts of climate change. In the Himalayas and mountainous regions, crop production faces constraints due to temperature limitations, allowing for only one crop per year. Conversely, in the Terai plains, where water supply is adequate and temperatures are favorable, three crops annually are common (FAO, 2011). However, the country's agriculture heavily depends on natural resources, coupled with limited irrigation infrastructure. Climate change makes these conditions more vulnerable, with rising temperatures and increased drought frequency posing significant threats to agricultural production. Moreover, irregular precipitation patterns, coupled with heightened risks of floods and landslides, further escalate the risk of disrupting agricultural activities (FAO, European Union and CIRAD, 2022; FAO, 2020) Consequently, this situation can contribute to increased food insecurity.

Food Insecurity and Nutrient Deficiency

Although agriculture serves as the primary income source for most Nepalese people, food security remains a significant concern in the country (FAO, European Union and CIRAD, 2022). Food insecurity is defined as the lack of regular access to sufficient safe and nutritious food for normal growth, development, and a healthy life (FAO, 2024). A considerable 52 percent of Nepalese households experience food insecurity, with rural households facing even greater vulnerability compared to urban counterparts (Ministry of Health, New ERA and ICF, 2017).

The dietary quality is closely intertwined with poverty. With 25 percent of Nepal's population living below the poverty line, there is a corresponding implication of lower dietary quality within that group (FAO, European Union and CIRAD, 2022; CIA, 2024). Additionally, one important aspect and consequence of both low dietary quality and food insecurity is nutrient deficiency, arising from limited access to nutrient-rich foods like fruits, vegetables, and animal products, often due to high costs or seasonal availability constraints. In Nepal, where Dal Bhat (lentils and rice) is a staple and food prices are rising, the risk of nutrient deficiency is pronounced. Promoting dietary diversity through interventions such as crop diversification and enhanced food preservation can effectively address nutrient deficiency sustainably (Bhandari et al., 2015).

1.2 Project Introduction

The development project in which this thesis is a part was officially initiated in January of 2020 and was initially scheduled to finish at the end of 2023. However, due to the Covid-19 pandemic, it has been prolonged until the end of 2025. In the project application, Andersson et al. (2020) state the aim of the project as developing locally adapted solar dryers with short drying times, while also considering socio-economic factors to ensure the adoption and diffusion of the technology. This is to be achieved through an iterative working process involving engineers, social scientists, and targeted small-scale farmers (Andersson et al., 2020).

In 2022 the first part of a needs assessment for the project was published through Ruralis. The study included 80 structured interviews with small-scale farmers, 65 in Bhutan and 15 in Nepal (Mustang), in order to get an understanding of what crops would be relevant for solar drying, how the current solar drying practices are carried out, and finally to come up with recommendations for future development and implementation of solar dryers through the project (Otte et al., 2022). Based on the answers and observations from the field study, several recommendations were proposed for further research and development in line with the project's aims. These included technical aspects, such as ensuring solar dryers that are adapted to the local demands (regarding drying time, protection of the crop etc) as well as making sure they are designed in a way that facilitates local production and maintenance. Mapping of existing solar dryers and their shortcomings were also recommended. The other part consists of socio-cultural recommendations, including intra-household dynamics, the potential in including farmer's associations in the development process, enabling learning environments for building and using the solar dryers and finally, especially relevant for this study, investigating adoption barriers for existing solar dryers (Otte et al., 2022).

As further work, several master's thesis projects have since been conducted to address recommendations from the needs assessment. In Nepal they have mainly focused on the technical aspects of building the solar dryer at the premises of the Department of Mechanical Engineering at Kathmandu University. The first solar dryer prototype was constructed in 2021/2022 with an incorporated heat exchanger, where mainly the relationship between airflow and drying rate was investigated (Probert, 2022; Faudot, 2022). New generations of the solar dryer have been constructed by improving the design to decrease leakage, experimenting with low-cost thermal storage, investigating heat transfer properties of different materials and components, and thereby exploring efficiency and other important factors (Karlsson, 2022; Mahmoodi, 2023; Rissler, 2023). Further technical design and investigatory recommendations are being addressed, such as heat exchanger and collector efficiency, and what these actually contribute to the system. These results among others were recently published as the latest work in the project by Aacharya et al. (2024).

The design is that of an indirect solar dryer that utilizes forced convection, facilitated by an inlet fan with adjustable speed and an internal fan to address heat locking at the top of the dryer. Both fans are driven by electricity, which can be provided by a small photovoltaic panel. A schematic illustration of the working mechanism can be seen in Figure 3. The schematic was made for the second generation dryer by Aacharya A., but has remained unchanged for the third generation dryer since the difference between them consists only in the material and dimensions of the product. The inlet air comes through point 1 and is forced upwards by the blower. The air is preheated along the heat exchanger by the outgoing air on the hot side, and then enters the collector part at point 2. The air is heated by the absorber and enters the drying chamber at point 3. By forced convection, thanks to the inner fan at point 6, the air passes through the drying trays and works its way around the baffle plate. At point 4 the hot and moist air enters the hot side of the heat exchanger, leaves it at point 5, and is then exhausted at the outlet. The latest (third generation) dryer can be seen in Figure 4, which has been redesigned so that the glass cover can be removed to clear out accumulated dust inside the dryer, since this appeared as a problem for the user. The material used for the body of the dryer is a mild steel sheet. In the figure the external and internal fans have not been reinstalled after the work done on the dryer, but their positions can be seen as two holes, the external fan on the outside at the front (left side in the figure), and the internal fan on the inside at the middle of the baffle plate. There are 14 trays for drying with a total area of approximately 4.5 m^2, while the collector area is approximately 1 m^2. Following experiments with apple slices, the time needed to reduce the moisture content from 86 to 10 percent (weight by weight) is 10 hours (Aacharya, 2023). The tentative production cost for the third generation dryer in the project amounted to the minimum cost of approximately 35 000 NPR (see Appendix G for more detailed expenses).

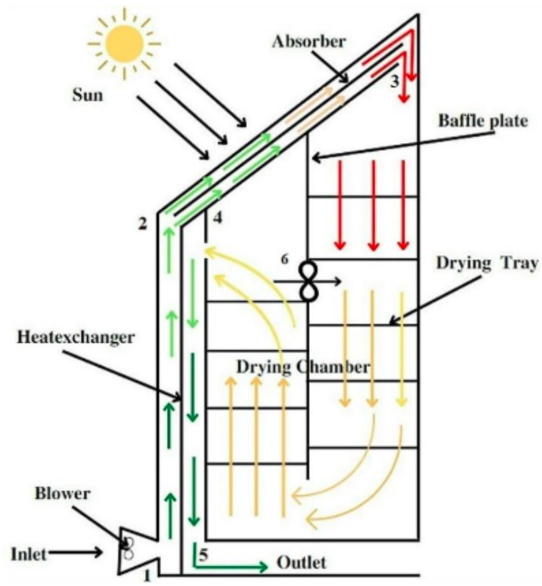


Figure 3: Schematic of inner workings of the dryer, with permission of A. Aacharya (2023).

Figure 4: Third generation dryer (picture by Magnus Lundquist). See Appendix G for cost calculations.

1.2.1 Key Findings from Prior Social Surveys in the Project

In addition to the already mentioned survey by Otte et al. (2022) in the Mustang district, another field study was made of an additional 15 household interviews in the mid-hill district of Kavre, as part of the project and master thesis by Aacharya (2023). The survey was designed in the same way as the one in Mustang. Aacharya (2023) presents how farmers in Kavre dry some produce in the open sun, and how post-harvest losses are a major concern for cash crops such as tomatoes. The majority of the farmers in both Mustang and Kavre had no knowledge about the governmental subsidies for solar dryers. The presented results highlight the lack of information about solar drying technology, as well as the importance of market dynamics for the farmers. In contrast to Kavre, it was found that project intervention regarding solar dryer technologies had been undertaken in Mustang, but that these had not had the desired impact due to technical problems such as capacity and maintenance, and that adoption of such practices was rare (Aacharya, 2023).

To comply with the project's overall goals, the next step, i.e. this thesis, is to do further surveys investigating adoption barriers and potential drivers for the diffusion of the technology, both from a user as well as producer perspective.

1.3 Aim and Research Questions

The aim of this master's thesis is to gather and compile information from external stakeholders targeted by the project: small-scale farmers, test farmers, and potential manufacturers of the solar dryer. This approach is intended to provide a comprehensive understanding of barriers and drivers for adoption and diffusion of the solar dryers developed within the SolarFood project. Thus, the report seeks to address the following research questions:

- What are the perceived barriers and drivers in literature and among farmers to the widespread adoption of solar dryer technology in the chosen regions of Nepal? What strategies can be developed to address these barriers and facilitate scalability and diffusion of the technology?

- What are the usage patterns, practical experiences, and perceptions of solar dryer technology among small-scale farmers in the chosen regions of Nepal? How do these insights inform the potential for scalability and diffusion of the technology?

- What are the challenges faced by potential producers of solar dryers in terms of manufacturing and distribution? How do these challenges impact the potential for scalability and diffusion of the solar dryers?

- Which specific design elements or features of the solar dryer may need modification or enhancement to enable scalability and diffusion in the investigated regions of rural Nepal?

Hopefully, gaining a deeper understanding of the user and producer perspective regarding solar dryers will facilitate the fulfillment of necessary steps to implement and spread the technique among more farmers.

1.4 Limitations

The study is limited to investigating the opportunities for the adoption of solar dryers among small-scale farmers Nepal. Therefore, tunnel dryers and the commercial-scale perspective are excluded from this study. Furthermore, since the study is part of the SolarFood project, the main objective has been to explore the possibilities of diffusion for the solar dryer developed within the project. As a result, the conditions for implementing other dryers, such as mixed solar dryers, which are driven by both solar and some other form of thermal energy, are excluded from the study.

2 Methodology

2.1 Literature Study

The literature study was conducted using reports authored by institutional authorities and peer-reviewed articles to ensure the reliability and academic rigor of the study. Initially, information was gathered to clarify the terminology related to adoption and diffusion. Subsequently, various articles were examined to gain a general understanding of the barriers and drivers of solar dryer technology diffusion and adoption. To deepen the understanding of the specific case of Nepal, the study further explored articles specifically addressing the Nepalese context and the potential for solar drying techniques within the country. Institutional reports and policy documents were primarily utilized to provide an overview of the political circumstances affecting the adoption of solar dryers. This information was supplemented, to the greatest extent possible, by articles that reviewed the same documents and assessed their actual implementation.

The literature study was primarily conducted using the Google Scholar database. To refine the results and ensure source quality, the relevance of the articles was evaluated, with a preference for recent publications. Most articles were selected from the time frame of 2020-2023. However, due to limited knowledge related to the specific case of Nepal, the time span was extended to 2002-2023 within that area. Given the longstanding nature of the diffusion of innovation theory, sources such as Rogers (1962) and Feder et al. (1985) were considered relevant despite their older publication dates. Additionally, an exception was made for the policy documents used, as some of them were implemented before 2020 but remain current within Nepali politics.

Apart from the sources utilized in the literature study, additional references have played a crucial role in shaping the introduction and background of this study. These sources primarily include previous papers and articles within the project, as well as external sources stemming from these.

2.2 Field Studies

The field studies involved interviews with various stakeholders regarding solar dryers, including farmers utilizing solar dryers, farmers not utilizing solar dryers (potential users), those participating as "test farmers" using the project's solar dryer, and potential producers of the solar dryer. These interviews aimed to gain a general understanding of the barriers and drivers to solar dryer adoption in the investigated regions. They were conducted using a semi-structured interview method, which combines elements of both structured and unstructured techniques. This method employs a predefined set of questions or topics while allowing flexibility in the sequence and wording of questions during the interview. This adaptability enables interviewers to ask additional questions for further exploration and clarification based on respondents' responses and interests. Three questionnaires and one logbook were created based on this approach, all designed to address the research questions. These can be found in Appendices A-D. The questionnaires were developed using insights from previous studies within the project as well as knowledge from the literature study, enabling analysis and comparison of the interview results with findings from the literature.

2.2.1 Interviews with Farmers

The field study consisted of semi-structured interviews with farmers in all three general agro-climatic zones of Nepal, ten in the Chitwan district (Terai region), eleven in Kavre (Mid-hill region) and nine in Manang (Mountain region). A district map of Nepal can be seen in Figure 5 below with the chosen districts highlighted. The field surveys in Manang, Chitwan and Kavre were conducted in February, March and April of 2024, respectively. Two questionnaires were utilized, depending on whether or not the interviewed farmer was currently using a solar dryer at the time of the survey. Both questionnaires encompassed questions regarding socio-economic background, agricultural practices, and any knowledge or perceptions related to solar dryers (see Appendices A and B). All 30 interviews were conducted in person with the assistance of research assistants from Kathmandu University who translated both the questions and the farmers' responses. Overall, the questionnaires remained consistent across all interviews, with the exception of one additional question added after the interviews in Manang. As a result, farmers in Chitwan and Kavre were asked whether they experienced post-harvest losses with their current drying technique.

Figure 5: District map of Nepal with survey districts marked in red.

Manang

The district of Manang, located in the Gandaki Province, lies in the northwestern part of the western region of Nepal, within the mountainous region. Renowned for trekking, it is a popular destination among tourists. With a population of approximately 5 700 (according to the 2021 census), Manang has the lowest population density in Nepal, with only three people per km^2 (Ministry of Agriculture and Livestock Development, 2023b). In contrast to its neighbor Mustang, no improved road has been constructed to connect it with the larger national H04-road. The only road linkage to bigger cities is the mountain road following the Marsyangdi river north from Bandipur. As explained in the background, the mountain region experiences cool summers and severe winters, resulting in a short growing season where sustenance has to be procured to last throughout the lean period. Apart from agricultural practice, the seasonal tourism surge is an important income for many residents in this area. The majority of the interviews were conducted in the village of Manang, but a few farmers were also interviewed in the villages of Khangsar, Pisang and Chame. One of the nine interviews was done as a group session with six women. The farmers were selected through social connections in a snowball effect, whereby the initial farmer knew someone, who subsequently knew another, and so forth. This was the most efficient way of finding farmers who were using some type of solar dryer, but does entail the risk of only interviewing a certain type of farmers.

Figure 6: Group interview in Manang. Picture by Ida Sonesson.

Chitwan

Chitwan is situated in the low-lying Terai region, in the southwestern corner of Nepal's central region, as part of Bagmati province. The population reaches around 720 000, with a density of 325 per km^2 (Ministry of Agriculture and Livestock Development, 2023b). The district is most known for its national park, a popular tourist attraction where it is possible to see endangered one-horned Asian rhinos, as well as the Bengal tiger. The favourable climate in this region eliminates any kind of lean season, and multiple crops can, in contrast to Manang, be grown all year-round. The roads and overall transportation infrastructure holds a higher standard in this part of Nepal, which makes for faster linkage to the big markets in Kathmandu and Pokhara. All the interviews in Chitwan were conducted in the municipality of Madi, south of the national park and bordering to India. The farmers were selected randomly by door-to-door visits since there was no prior personal connection to the location. This method can be beneficial for the randomization of the interviewees, but could also implicate biases unknown to the project team.

Figure 7: Interview with farmer household in Madi, Chitwan. Picture by Ida Sonesson.

Kavre

Located just East of Kathmandu in the mid-hill region of Bagmati province, the district of Kavre holds a population of around 365 000 and a population density of 261 per km^2 (Ministry of Agriculture and Livestock Development, 2023b). The interviews were carried out in the proximity of Kathmandu University, in the town of Dhulikhel, by family connections from an employee at the University. The region holds a few bigger cities, and Dhulikhel has a comparably well-functioning road linkage to Kathmandu which takes about one and a half hours.

Figure 8: Interview with farmer household in Dhulikhel, Kavre. Picture by Ida Sonesson.

2.2.2 Interviews with Potential Solar Dryer Producers

To gain insight into potential obstacles in the production of the third-generation solar dryer developed within the SolarFood project, three local craftsmen were interviewed, one in Panchkhal (Kavre), one in Dhulikhel (Kavre) and one in Kathmandu. They were provided with the latest construction manual for the solar dryer (see Appendix E), and were interviewed based on a specific questionnaire (see Appendix C). This involved questions about the producers' knowledge of solar dryers, any difficulties in understanding and constructing the solar dryer based on the design manual, and their perceptions regarding the market potential for manufacturing the dryers. The interviews took place at the end of April 2024. The interviews in Panchkhal and Dhulikhel were conducted in person with one supervisor and one manager, respectively. In contrast, the interview with the craftsman in Kathmandu was conducted remotely, with the CEO/Chief Engineer of the welding workshop. The workshop in Panchkhal was the one that had been enlisted to build the latest solar dryer, which made it relevant to ask the questions in a corresponding manner.

Figure 9: Interview with local craftsmen in Panchkhal, Kavre. Picture by Ida Sonesson.

2.2.3 Collecting Experiences from Test-Farmers

As mentioned in the project introduction, the latest version of the third-generation solar dryers was completed during the study period in Nepal. These were subsequently distributed to two farmers (hence-forth called "test-farmers") in Panchkhal in mid April of 2024. After two weeks a study visit was conducted to investigate the test-farmers' experiences with the solar dryers. This was documented with the use of an experimental logbook which the test-farmers would henceforth be encouraged to fill out for future reference in the project (see Appendix D). The logbook includes quantitative components, such as the weight of the crop before and after drying and the required drying time. Additionally, it contains questions covering more qualitative aspects, such as the farmers' opinions on the quality of the dried product, user-friendliness of the dryer, and suggestions for improvement. However, on the mentioned study visits the questions were only based on the questions in the logbook, and followed a more semi-structured path with follow-up questions in order to get the most out of the farmers' first impressions of the dryers.

Figure 10: Visit to test-farmers in Panchkhal, Kavre. Picture by Ida Sonesson.

2.3 Qualitative Analysis

The interview responses were analyzed concerning three distinct aspects: general information, barriers and drivers, and their implications for the technical aspects of solar dryers. This categorization corresponds to the research questions and enhances a comprehensive understanding of the data. General information provides a sweeping background of the farmers in each district. To navigate the perceived barriers and drivers among the interviews, the collected interview data was analyzed based on the categories related to barriers and drivers found in the literature study. The technical aspects of the solar dryers stem from the farmers' requests, the experiences of farmers who have utilized solar dryers, the experiences of the test-farmers, and also the producer perspective and their design inputs.

3 Literature Study

3.1 Dissemination, Diffusion and Adoption: A concept explanation

The term "dissemination" refers to the active spreading of something, such as an innovation or idea. The definition in Cambridge Dictionary reads: *"Disseminate: to spread or give out something, especially news, information, ideas, etc., to a lot of people"* (Cambridge Dictionary, n.d.). In contrast, the term "diffusion" is regarded as the subsequent natural continued spread of ideas or practices. Diffusion of innovation theory is an old social science theory. In Rogers (1962) defining work "Diffusion of Innovations", the author presents his definition of diffusion as a five-step process; awareness, interest, evaluation, trial and finally adoption, where the adoption process itself is *"the mental process an individual passes from first hearing about an innovation to final adoption"* (Rogers, 1962). Since then, there have been numerous studies on factors influencing the adoption of innovations, particularly concerning new agricultural technologies and practices, given that a significant portion of the population in less developed countries relies on agriculture for their livelihoods. Despite numerous studies converging on a list of factors, and development projects attempting to address these, Feder et al. (1985) assert that immediate and uniform adoption is rare and varies over time and across socioeconomic backgrounds. The authors highlight that while some innovations have been well received and readily adopted, others have been embraced by only a small number of farmers, contrary to theoretical expectations of higher adoption rates (Feder et al., 1985).

3.2 Barriers and Drivers of Solar Drying Technology in General

To understand why the adoption of commercially available solar dryers has not reached a higher degree of smallholder ownership, Goel et al. (2022) identifies both barriers and drivers to the implementation of solar drying technology. Although all are interconnected to some extent, the barriers are divided into four different themes: (i) technical and institutional, (ii) social and environmental, (iii) economic and financial, and (iv) policy and political barriers. The technical and institutional barriers include a lack of technical expertise, which covers both a shortage of trained or qualified manpower for demonstrating, installing, teaching, servicing, managing, and maintaining solar drying technologies, as well as a lack of minimum requirements for solar dryer technology performance in terms of efficiency, durability, etc. Unsatisfactory institutional involvement in the development of solar energy technology is also part of the first theme which is defined by lack of cooperation and collaboration between different institutes, ministries, departments, etc., for the implementation of solar dryer technology. Additionally, Goel et al. (2022) identify important barriers of a more social nature, such as a lack of public awareness and obstacles in social acceptance. Economic barriers also play a significant role and include high investment costs, lack of funding/credit, and unsatisfactory market conditions, both for the dried products and for the production and distribution of solar dryers. The political barriers encompass lack of government policies and incentives that promote solar drying technology, as well as political instability. Identified drivers include the decentralized nature of solar dryers, which is beneficial for rural areas, as well as the generation of employment opportunities and reduced dependency on fuels for drying. In conclusion, the authors present suggestions to promote solar drying systems, including the development of progressive policies within the solar systems sector, promoting research, and providing training to farmers. Furthermore, there should be a focus on designing cost-effective solar dryers that are affordable for the farmers (Goel et al., 2022).

Another study focusing on identifying barriers for the implementation of solar drying technology, conducted by Dwivedi et al. (2023) in India, goes even further and categorizes six barrier categories, with a total of 23 sub-barriers, based on an exhaustive literature study and interview work. Using a prioritizing scheme, the authors assess the order of importance of these barriers. The results show that the most important ones are political barriers regarding political instability and governmental policy framework. These are followed by economical barriers such as lack of credit and high initial investment cost. Technical barriers include lack of technical expertise as well as lack of research and development facilities. Importance is also given to institutional barriers, namely challenges with license acquisition (due to non-ideal bureaucracy, transparency and nepotism) and lack of coordination between relevant institutions. Lack of public awareness/information is the main identified socio-cultural barrier. To overcome these barriers, Dwivedi et al. (2023) put forth a list of suggestions which include; providing attractive incentives and credit schemes for both manufacturers and users, establishment of dedicated and effective marketplaces, increasing availability of effective dryers, promoting research and technical expertise through training programs and discussion forums, and also investing in awareness programs towards potential consumers about climate and energy security as well as the latest technological advancements (Dwivedi et al., 2023).

Continuing on the same theme, Machala et al. (2022) also presents a study on overcoming barriers to improved solar drying adoption in India. The article outline the challenges associated with shifting small-scale farmers' drying practices away from traditional open sun drying, despite the income losses (averaging 34 percent according to the study) incurred due to both wastage and lower quality of the dried products. Furthermore, the authors also emphasize the significant advantage of improved solar drying: enhanced product quality leading to higher market revenue for farmers. However, barriers to adoption primarily stem from economic factors, including high investment costs, limited access to credit and lengthy or uncertain payback periods for financially constrained smallholding farmers. Lack of awareness is also cited as a constraint, and market conditions are identified as critical in technology adoption. The authors propose multi-season use and various financial schemes as viable solutions to drive adoption in developing regions worldwide (Machala et al., 2022).

Udomkun et al. (2020) also highlights the economy, in terms of high investment costs, as a significant barrier to the adoption of solar drying technology, as discussed in the article *Review of Solar Dryers for Agricultural Products in Asia and Africa: An Innovation Landscape Approach*. This, coupled with several other contributing factors including a lack of information, technology, and financing, as well as poor institutional and legal frameworks, and inadequate regulations and legislation on renewable energy, compounds the challenge. To overcome these barriers, Udomkun et al. (2020) provides the following recommendations to scale up solar drying: governmental support and encouragement of renewable energy policies and the use of solar technologies, enhancement of the financial system for the agricultural sector (for example, providing financial assistance to small and medium-scale farms in the form of energy subsidies and micro-loans), and the introduction of agricultural cooperatives at multilateral levels. Additionally, it is recommended that solar dryers are developed based on local climate, economic conditions, and practical experience, along with providing training to solar drying users. Udomkun et al. (2020) also highlights the importance of spreading information to raise awareness of dryer applications and accelerate the adoption of the technology (Udomkun et al., 2020).

Unlike Machala et al. (2022), Goel et al. (2022), and Udomkun et al. (2020), the study conducted by Matavel et al. (2022) primarily aimed to identify the drivers related to the adoption of solar drying technology, rather than focusing solely on the barriers. In the report *Effect of Passive Solar Drying on Food Security in Rural Mozambique*, Matavel et al. (2022) conducted a study based on data from 634 households in rural Mozambique. Their objective was to identify the determinants of farmers' choice to use solar drying and to evaluate the effect of a passive solar dryer on food security. The study primarily found that the use of solar drying, combined with associated training, significantly increased the food security status of the participants. Furthermore, the study identified social characteristics such as gender, age, household size, land size, market orientation, neighbor-to-neighbor communication, and membership in an association as factors increasing the likelihood of adopting solar dryers (Matavel et al., 2022).

The study also showed that the adoption of solar dryers was more likely among women and older farmers. In the discussion section, Matavel et al. (2022) correlated household and land sizes as indicators of economic resources, with larger farms associated with higher economic status and a greater likelihood to adopt new technologies. Similarly, larger household sizes may indicate the availability of family labor, potentially allowing for engagement in off-farm activities and contributing to additional income. This can lead to an improved household economy and, thus, increase the likelihood of adopting new technologies. Furthermore, farmers who sell their products are probably more likely to adopt post-harvest technologies, as these can provide both better quality products and higher market value. The preservation feature of solar drying also provides the possibility to sell products when demand is high and supply is low. Neighbor-to-neighbor communication and membership in an association drive adoption, serving as influential sources of information and providing training opportunities (Matavel et al., 2022).

However, Matavel et al. (2022) encountered some limitations of the solar dryer implemented in the study area, both technical and economic ones. The solar dryer fell short in terms of capacity since several rounds of drying were required to dry large quantities of food. Additionally, due to the initial investment cost, the dryers had to be shared among households, which may not have allowed them to dry enough product for the entire lean period. In conclusion, the authors propose future research to evaluate the costs of solar dryers in relation to their durability, in order to assess a cost-benefit ratio. They also emphasize the importance of governmental support to facilitate the construction and dissemination of solar dryers (Matavel et al., 2022).

3.3 Barriers and Drivers of Solar Drying Technology in Nepal

In an early study by C. Joshi et al. (2002), the prospects and barriers for food conservation in Nepal, in the form of improved solar drying were investigated. The authors present the efforts and accomplishments that had been made so far, especially focusing on projects and political/institutional policy efforts, and what still needed to be addressed for a wider diffusion and development of solar drying systems. C. Joshi et al. (2002) present how various projects distributed solar dryers throughout the country, accompanied by information and awareness campaigns, as well as training programs for manufacturers and users. However, these efforts were found to have had varying degrees of success due to several factors. Among the identified problems for continued diffusion were initial investment costs, lack of information among the general public, absence of wide-scale governmental promotional programs, and the lack of competence regarding the design, manufacturing, and usage of the solar dryers. Inadequate resources for maintenance and follow-up work, as well as issues related to political instability, are also mentioned as barriers that impaired continued spread. It is mentioned that the basic needs required for manufacturing and operating solar dryers were potentially available for rural communities, and that a positive trend was possible and could lead to a more widespread promotion and adoption of solar drying techniques, but only with the help of further political and institutional efforts (C. Joshi et al., 2002).

Another early study by Karki et al. (2004) investigated more general determining factors on technology adoption for small-scale farmers in Nepal. This was done through an interview survey of 120 rural small-holding farmers. The authors conclude that important factors affecting the farmers' willingness to adopt new agricultural technology included availability of credit, education level, farm size and especially project intervention with extension services (Karki et al., 2004). Identified barriers for adoption of new technology are mainly related to low income and dependence on subsistence farming (no off-farm income) which highly increased the farmers' risk aversion. Suggested drivers for technology adoption align with the recommendations presented by C. Joshi et al. (2002) regarding project interventions with extension services. These interventions involve teaching operation and maintenance, as well as providing support mainly to overcome financial barriers and to enhance the dissemination of information and local expertise (Karki et al., 2004).

Suvedi et al. (2017) performed a study to shed more light on factors affecting farmers' willingness in adopting new agricultural technologies as well as participating in extension programs. From a survey of 198 interviews in rural hill-regions of Nepal, they found that the most significant things affecting farmers' adoption-willingness were closely linked to extension-related activities, which aligns with the findings of Karki et al. (2004). The major influencing factors were training, membership in some kind of farmers group/association as well as off-farm employment (which negatively impacted the adoption probability, contradicting Karki et al. (2004)). What especially influenced the degree of participation in extension activities was found to be education level, age, household-size and distance to the extension centers/workers (Suvedi et al., 2017). The authors point out that lack of information and low rate of extension-service official's visits were the biggest perceived barriers for farmers participating in extension programs and getting their services. Suvedi et al. (2017) suggest that raising farmers' level of participation in extension programs and hence increasing possibilities of technology adoption is integral. This should be done by closer cooperation between the farmers and local institutions, both governmental and private sector, where efforts should be made towards better working monitoring, group meeting attendance, training and financial support (Suvedi et al., 2017).

A study by Kumar et al. (2020) also investigates what factors governs the adoption and diffusion of improved agricultural technologies and practices in rural Nepal. It included a survey of almost 2000 people where half had been beneficiaries of a USAID-led KISAN-project (USAID: United States Agency International Development. KISAN: Knowledge-based Integrated Sustainable Agriculture and Nutrition), and the other half had been non-beneficiaries. The authors suggest that their findings highlight several barriers to the adoption of improved techniques, with the most significant ones including limited market access, insufficient knowledge/information, and the financial constraints faced by farmers. Additionally, in line with Suvedi et al. (2017), they found that private sector involvement in disseminating information, as well as organization in local farmers' associations, were important drivers for adoption (Kumar et al., 2020).

In a more recent study, Panta et al. (2023) did a survey of 180 small-scale vegetable farmers in the Bagmati province of Nepal. The aim of the study was to assess the determinants of technology adoption in the agricultural sector since the authors felt there exists limited knowledge and understanding regarding this topic. The study found that the most significant factors were level of education, access to extension services and farm size, which are supported by Karki et al. (2004) and Suvedi et al. (2017). Furthermore, important barriers against adoption were found to be if the household was headed by a woman (contradicting Matavel et al. (2022)) and, as also found by Kumar et al. (2020), inaccessibility to markets (because of infrastructural constraints such as distance and bad roads) (Panta et al., 2023). Following their results, the authors suggest significant strengthening of agricultural education and programs with training, where also women are included and exposed to improved technology. Further recommendations, with the aim of increasing the levels of adoption, are to increase investments in infrastructure regarding transportation and markets as well as engaging better extension services with heightened technical knowledge (Panta et al., 2023).

As previous articles have focused on the adoption of agricultural innovations in Nepal, Suman (2021) shifts the focus to the implementation of renewable energy technologies (RETs) within the country. In the article "Role of Renewable Energy Technologies in Climate Change Adaptation and Mitigation: A Brief Review from Nepal," the author examine the potential for RET adoption, emphasizing the benefits of RETs. They note that women and children in Nepal spend over six hours daily on chores such as processing subsistence crops, which could be alleviated through the introduction of RETs. However, the article also acknowledges several barriers hindering RET adoption in Nepal, including lack of skilled manpower, technology, knowledge, and equipment, compounded by the geographical challenges posed by Nepal's mountainous terrain. Moreover, the author highlight additional obstacles such as limited access to global resources, a questionable political system and weak financial resources. These factors collectively impede the extension and widespread adoption of RETs in Nepal.

To address these barriers and promote RET adoption in Nepal, Suman (2021) provides several recommendations. Firstly, the government should compile comprehensive data on all energy systems and establish an open-access database that is regularly updated to provide transparent information on the current state of renewable energy systems in the country. Additionally, awareness campaigns should be conducted to disseminate information about RETs, and the concept of cooperatives should be expanded nationwide to facilitate decentralized energy solutions. Furthermore, local governments should lead in developing and implementing energy sector policies to ensure local access to RETs and the efficient utilization of local resources. Moreover, subsidies should be extended to more households annually to incentivize RET adoption. Finally, both academic and non-academic researchers should focus on scientific research related to the potential, challenges, and barriers of promoting RETs in Nepal's evolving political landscape. However, there are inherent drivers of RETs such as their decentralized nature, reduced fossil fuel dependency, and the expansion of local job opportunities they create (Suman, 2021).

3.4 Governmental Approaches to Solar Dryer Adoption in Nepal

3.4.1 Agricultural Policies and Food Security Initiatives

Nepal, as a member of the UN, is committed to the Sustainable Development Goals (SDGs) and therefore strives to integrate these goals into its national context. The report titled *NEPAL Sustainable Development Goals - Status and Road map: 2016-2030* (National Planning Commission, 2017) has been crafted as a developmental framework to assess the national prioritization of the goals and outline an action plan for achieving them by 2030. The interventions related to agriculture encompass various initiatives, including enhancements in food and nutrition security, the expansion of rural roads, and the promotion of modern agricultural commercialization. Additionally, the framework aims to reduce post-harvest food loss from 15 percent in 2015 to less than one percent by 2030 (National Planning Commission, 2017).

In addition to this framework, there is the Agriculture Development Strategy, which comprises an action plan and road-map for the agricultural sector, with the goal of addressing the needs for food and nutrition security. Implemented by the Nepalese government in 2015, extending to 2035, the strategy places particular emphasis on increasing food production, improving farmers' income, enhancing market access, reducing post-harvest losses, and ensuring food safety (Ministry of Agricultural Development, 2015).

There are several other policy documents related to the topic of food security and nutrient deficiency. The article *Nutrition and Food Security in Nepal: A Narrative Review of Policies* (Adhikari et al., 2023) identifies and analyzes 30 of them, including nine policies, five strategies, eight acts, five strategic plans, and three guidelines, to explore gaps in existing policies and provide recommendations to stakeholders. These documents, implemented between 1970 and 2021, have been studied through eight predetermined themes: nutrition intervention, food security, food system, capacity building of human resources, nutrition education, nutrition governance, research, and monitoring and evaluation.

Among the 30 documents examined, two policies, two strategies, one act, and two strategic plans directly relate to the theme of food security. Notably, the Agriculture Development Strategy is highlighted for its specific programs aimed at reducing post-harvest losses. Additionally, two policies, three acts, and two strategies address the processing, storage, distribution, and marketing of food products. The National Nutrition Policy and Strategy from 2004 stands out for advocating improvements in storage and preservation of food items, enhancing technical knowledge of food processing, and promoting better storage practices to prevent nutrient loss. It also emphasizes training for farmers on food processing and safety (Adhikari et al., 2023).

Adhikari et al. (2023) identifies food security and a sustainable food system as robust policy agendas in Nepal. However, challenges persist in translating policies into actions, including unequal distribution of agricultural resources and inadequate food storage, processing, and conservation facilities. To address these challenges, upcoming policies should focus on, among other things, adopting and equitably distributing modern agricultural technology. Additionally, there is a need for adequate technical and financial support for conducting action research, which should be provided for in policies.

Overall, the review concludes that while nutritional improvement should involve a wide range of interventions, Nepal has primarily focused on short-term measures. Moreover, many policies lack a clear mechanism for effective implementation and monitoring of progress (Adhikari et al., 2023). This observation is further supported by Mishra et al. (2023), who also identifies the lack of implementation and monitoring as barriers to effective agricultural policy fulfillment in the article *Agribusiness and Supply Chain Development Policies in Nepal: A Review from Temporal Dynamics*. The article highlights that many policies often remain in draft stages due to factors such as the absence of supporting legislation and financial resources. Urban migration is also identified as a significant barrier to the implementation of policies, plans, and projects. The exodus of competence and force of labor from rural areas has deprived agriculture of essential capital, resources, and labor, while simultaneously intensifying pressure on infrastructure and peri-urban areas in already densely populated major cities. Similarly, frequent changes in government have disrupted leadership continuity, further complicating the implementation of policies (Mishra et al., 2023).

3.4.2 The Renewable Energy Subsidy Policy

Directly linked to the adoption and dissemination of solar dryers is the Renewable Energy Subsidy Policy of 2016 (Ministry of Population and Environment, 2016). This policy aims to promote the adoption of renewable energy by offering subsidies for the installation of renewable energy technologies, including solar thermal systems such as solar dryers. The overarching objective of the policy is to attain universal access to clean, reliable, and affordable renewable energy solutions by 2030.

Under this policy, the government offers subsidies covering up to 75 percent of the total investment cost for solar dryers, depending on the size of the system and the region of the purchaser. The institutional agreement outlined in the policy designates the Alternative Energy Promotion Centre (AEPC) as responsible for providing technical assistance, evaluating subsidy applications, and selecting companies for the manufacturing, supply, and installation of renewable energy technologies. At the local level, responsibility lies with the local bodies for promoting, collecting demand and disbursing the subsidy. Both AEPC and the local bodies share the responsibility of regular on-site monitoring. Additionally, the policy stipulates the establishment of a third-party entity tasked with monitoring and evaluating the impact of subsidies, as well as conducting field verification of installed renewable energy systems or projects (Ministry of Population and Environment, 2016). The policy from 2016 was updated in 2022 without any specific changes regarding solar thermal systems (ICIMOD, 2023). This means that the provided subsidy for a solar dryer with the size of 0.28-1.86 m^2 can be a maximum of 60 percent of the total cost or 22 500 NPR, whichever is lower, or a maximum of 40 percent of the total cost or 15 000 NPR, whichever is lower, depending on the region.

The annual number of distributed solar dryers by the AEPC can be obtained from their website, which documented a steady decline from a peak of 596 distributed solar dryers in 2008/2009, to the latest documented value of 22 dryers distributed in 2015/2016 (AEPC, n.d.). In his masters thesis, Ghimire (2017) presents the costs of different types of direct solar dryers distributed by the AEPC along with their correspondent subsidy for the years 2004-2012. The cost of a flat plate type solar dryer, with 10 kg capacity, is presented to be 14 400-20 000 NPR. Correcting the costs for inflation rates, the cost for the dryers today would be 32 000-45 000 NPR (WorldData, n.d.).

In the article *Current status, prospects, and implications of renewable energy for achieving sustainable development goals in Nepal*, Lohani et al. (2022) asserts that the use of renewable energy contributes to advancing various SDGs, including SDG2 (Zero Hunger), by providing energy for food processing and storage. Similarly, ICIMOD (2023) argues that renewable energy supports multiple development objectives such as food security and health in the report *Renewable energy in Nepal: Key findings and policy recommendations*. Suman (2021) also emphasizes the role of renewable energy technologies in enhancing health and food security. This by enabling families to save time on household chores, thus allowing them to focus on growing, cooking, and providing nutritious meals to their children, thereby reducing malnutrition (Suman, 2021). All three papers underscore the importance of the Renewable Energy Subsidy Policy as a key strategy for achieving the SDGs, a sustainable energy system and adaptation to climate change.

However, both Lohani et al. (2022) and Suman (2021) note that renewable energy related policies have failed to meet their targets to significantly increase the renewable energy technology consumption. Lohani et al. (2022) attributes this failure to the lack of coordination between ministries, departments, and stakeholders in implementing the strategies and action plans aligned with energy policies, as well as to the setting of overly ambitious targets without concrete plans and programs to achieve them. Additionally, ICIMOD (2023) discusses concerns regarding the economic security of public funds associated with the Renewable Energy Subsidy Policy. The author suggests that since capital subsidies have increased over time, additional public funds or grants will be necessary to complete the projects, raising questions about the sustainability of the funding mechanism (ICIMOD, 2023).

4 Qualitative Analysis

4.1 General Findings from Field Survey

Manang

In Manang, eight individual interviews and one group interview were conducted. The group response is treated as a single unified response. The majority of the interviewees were women, and five of them were either using or had previously used solar dryers, all of which were of the direct type (see Figure 11 below). Most of the interviewees listed farming as their main source of income and had been involved in agriculture for over 20 years. All interviewees cultivated crops for both self-consumption and sale, with the main marketing channel being direct sales to consumers. The most commonly cultivated and dried crops were apple, mushroom, and radish. Other crops mentioned by the farmers included carrot, nettle, cheese, cauliflower, mustard leaves, coriander, and buckwheat leaves. Everyone agreed that drying is a crucial part of their farming business, and most respondents considered the market for their dried products to be excellent. The drying time was estimated to be well over two days for most farmers utilizing open sun drying, while it was reduced to two days for the majority of farmers using a direct solar dryer.

Among the farmers with experience using solar dryers, two had obtained their dryers through various projects, one had purchased the dryer with a government subsidy, one received the dryer as a gift from her brother, and one received her dryer from her husband, who had built it himself (see Figure 12). Three of the farmers had been using the dryers for one to five years, while two had been using them for less than a year. Among those who had used the dryers for a longer period, two had encountered technical issues. For instance, the woman whose husband built her dryer faced problems when her cat attacked the plastic cover while drying cheese, resulting in holes in the cover. The women from the group interview had received their dryers from the Suaahara project approximately 10 years ago. However, they stopped using them due to durability issues with the plastic cover of the direct solar dryers.

Figure 11: Direct solar dryer used in Pisang, Manang. Picture by Ida Sonesson.

Figure 12: Home-built solar dryer in Manang. Picture by Ida Sonesson.

Chitwan

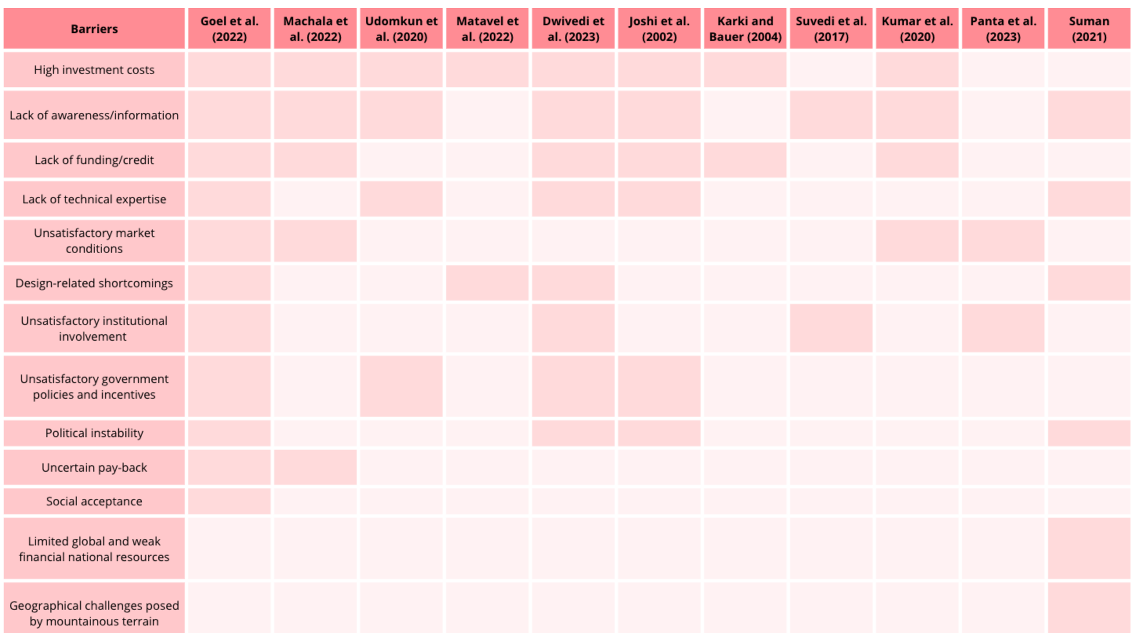
The ten interviewed farmers in Chitwan were predominantly women. None of the farmers were using any kind of solar dryer, and only one of them had ever heard of the technology. No farmer had any further knowledge about available subsidies or other initiatives regarding solar drying. The majority were cultivating crops both for sale and self-consumption, with their main market channel being to sell their produce to a wholesaler. The main crops used for drying were maize, paddy, wheat, and mustard seeds. Only a few farmers dried certain types of vegetables, such as cauliflower and radish, primarily in cases of over-production and mostly for self-consumption. All farmers viewed drying as a crucial activity, which they all carried out using open sun drying, a process that took more than two days to complete. When asked about post-harvest losses, the vast majority mentioned that spoilage, especially of maize and rice, was a problem they experienced when drying the crops. Since very few dried any kind of vegetables, their answers were mainly centered around grains.

Kavre

In Dhulikhel, Kavre, all interviewees except one were women. None of the farmers were using or had ever used a solar dryer, and only a few had heard of the technology before. Most of those who were aware of it were part-time employees at Kathmandu University and had seen the prototypes of the project solar dryer being built. None were aware of available subsidies for solar dryers. The majority of the farmers claimed that agriculture was their main source of income, with most having worked in the agricultural field for more than 20 years. Most cultivated crops both for sale and self-consumption, while the remaining farmers grew produce only for sale. Roughly 50 percent of the farmers sold their products directly to consumers, while the other half used wholesalers as their main market channel. The main crops grown and dried were radish, spinach, and grains, all of which took more than two days to dry in the open sun; some crops could take up to a week to dry. Drying their crops was seen as a crucial activity for all farmers, and most experienced post-harvest losses due to rain, wind, dust, and insect infestations.

4.2 Barriers and Drivers of Solar Dryer Adoption

In the literature study, thirteen barriers and fifteen drivers were identified relating to the adoption and utilization of solar dryers. Notably, certain barriers and drivers recurred across multiple sources, indicating their significance in the context of solar drying technologies. Figures 13 and 14 below compile all the identified barriers and drivers, along with the articles in which they were cited.



Barriers	Goel et al. (2022)	Machala et al. (2022)	Udomkun et al. (2020)	Matavel et al. (2022)	Dwivedi et al. (2023)	Joshi et al. (2002)	Karki and Bauer (2004)	Suvedi et al. (2017)	Kumar et al. (2020)	Panta et al. (2023)	Suman (2021)
High investment costs											
Lack of awareness/information											
Lack of funding/credit											
Lack of technical expertise											
Unsatisfactory market conditions											
Design-related shortcomings											
Unsatisfactory institutional involvement											
Unsatisfactory government policies and incentives											
Political instability											
Uncertain pay-back											
Social acceptance											
Limited global and weak financial national resources											
Geographical challenges posed by mountainous terrain											

Figure 13: A compilation of the barriers identified in the literature study. A darker shade of red indicates that the category was identified in the article.

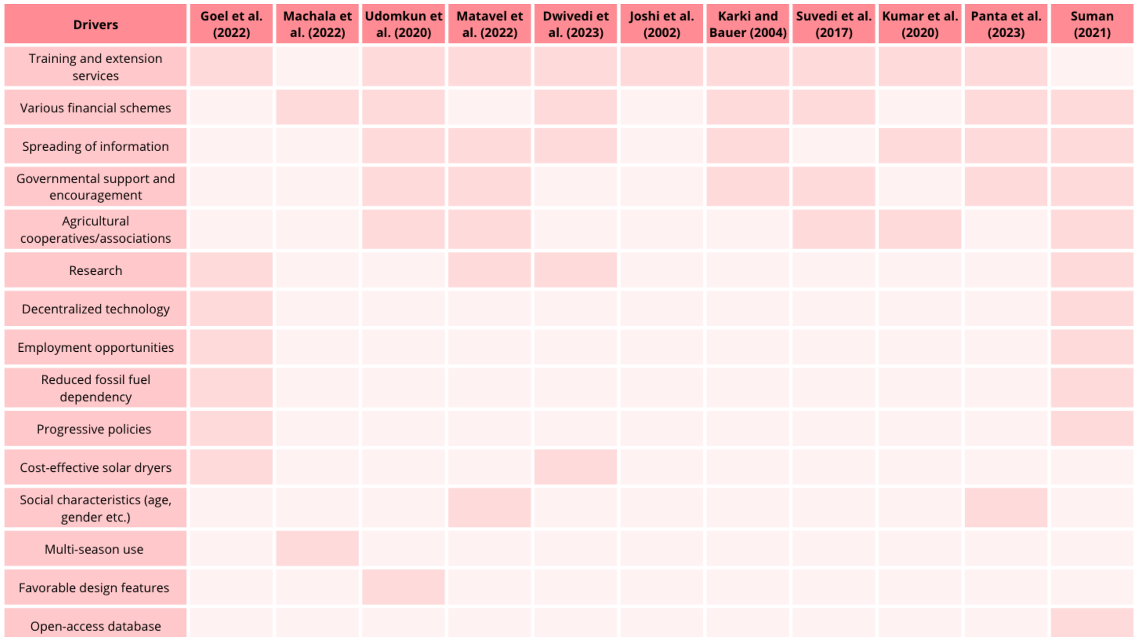


Figure 14: A compilation of the drivers identified in the literature study. A darker shade of red indicates that the category was identified in the article.

Subsequently, the interview data was examined to determine the presence of these same barriers and drivers. The categories identified in both the literature study and the interviews are presented in Figures 15 and 16. Interestingly, six common barriers and five common drivers were identified in both the literature study and the interviews.

During the field study, it was found that the most frequently mentioned barrier to the adoption and diffusion of solar dryers in Nepal was the lack of awareness and information about the technology. This finding aligns with the literature, where a lack of information is commonly cited as a barrier to adopting new agricultural techniques (see Figure 13). However, this issue can be compounded by other existing barriers such as lack of technical expertise, design-related shortcomings, unsatisfactory government policies, institutional involvement, political instability, and unsatisfactory market conditions. These challenges were also emphasized in the literature and during the field survey as obstacles faced in Nepal.

In response to the lack of awareness and information as a barrier, the dissemination of information emerges as an important driver of innovation, both among the respondents and in the literature, as shown in Figure 16. The barriers and drivers in Figures 15 and 16, and how they interact, will be further analyzed and discussed in the following sections.

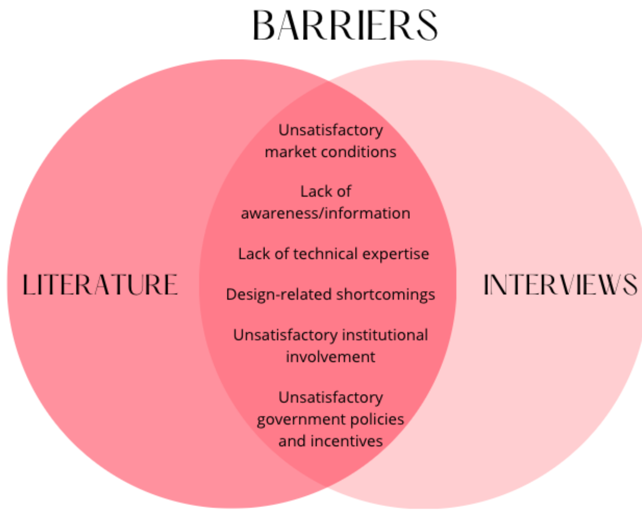


Figure 15: A Venn diagram showing the barriers that overlap between the literature study and the interviews.

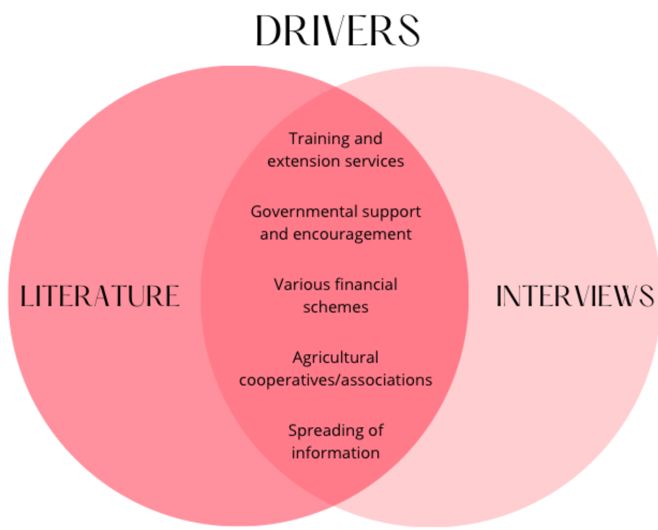


Figure 16: A Venn diagram showing the drivers that overlap between the literature study and the interviews.

Political Initiatives and Economical Factors

Political aspects of solar dryer adoption emerged as both barriers and drivers in both the literature study and the field survey. During the interviews government policies and initiatives were mentioned as a barrier, with a lack of responsibility for information distribution being the primary concern. As outlined in the literature study, there are governmental initiatives and various agricultural policies in Nepal aimed at promoting new post-harvest techniques and encouraging the adoption of solar dryers. The renewable energy subsidy policy seems to be the most direct of these initiatives, offering financial incentives to facilitate investments in solar dryers. Various financial schemes such as subsidies was cited in the literature study and also suggested by the interviewed farmers as a successful driver of agricultural innovation adoption (see Figure 16).

However, accessing data on the outcomes of these governmental efforts remains challenging. Policy analysis included in this study criticize the translation of policies into action, as well as the effectiveness of implementation and progress monitoring, often noting failures to achieve their intended targets. This criticism is supported by the lack of knowledge among the farmers included in the survey, where only four were aware of the government's solar dryer subsidy, and among them, only one farmer who utilized solar dryers had actually applied for it. Moreover, gaining insight into the economic extent of the public funds that finance the subsidies is challenging. This concern is also expressed by ICIMOD (2023) in the literature study and the significant decline in the number of solar dryers distributed by governmental agencies since 2008/2009, as reported by AEPC (n.d.), may imply budget constraints within the government. However, it could also suggest a lower demand for dryers, although this contradicts the idea that as more dryers are distributed among farmers, awareness about them will increase, thereby increasing demand as well.

Yet, the demand also depends on the users perception of the dryer and it is possible that the 596 farmers who invested in solar dryers back in 2008/2009 were not satisfied with them, leading to decreased demand among other farmers. Another perspective is that the subsidy rates for solar thermal systems remain identical in the updated version of 2022 as in the first version from 2016, as stated by ICIMOD (2023) in the literature study. Consequently, this does not account for the inflation of material and labor costs, potentially making the solar dryer too expensive for farmers to afford even with the subsidy. The decline in the number of solar dryers distributed by government agencies, coupled with the testimonials from farmers about the lack of subsidy awareness, reinforces the belief that increased dissemination and adoption of solar dryers might have a better chance if the initiative is taken by the private sector and other NGOs.

Yet, high investment costs were one of the most frequently cited barriers in the literature study, and financial schemes such as subsidies are a means to cope with and overcome this barrier. Although none of the farmers mentioned high investment costs as a barrier, many of them considered investment cost to be one of the determining factors for investing in a solar dryer. This suggests that the economic aspects of solar dryers are still of great importance. However, an alternative approach to overcoming this barrier is to develop a more affordable solar dryer that is accessible to farmers without relying on financial schemes provided by the government. This will be further discussed in a later section.

To further problematize the political aspects of solar dryer adoption in terms of governmental policies, it appears from the literature study that the information provided by the government in these policies does not always align with other external sources. In the background, Faqeerzada et al. (2018), Subedi et al. (2019) and GC et al. (2019) estimate post-harvest losses in Nepal to be around 40 percent. However, the Sustainable Development Goals report (National Planning Commission, 2017) presents the significantly lower figure of 15 percent. Although estimating post-harvest losses is challenging, questions arise when the figure presented by the government not only fails to correspond to other literature but is also significantly lower than the global average of 25–30 percent reported by the IPCC (2019). While it is challenging to ascertain the government's motives for understating the issue of national post-harvest losses, besides presenting itself in a more favorable light, it impacts the reliability of these kinds of documents and, consequently, the government's credibility, as these documents are an extension of their work and values.

Market Conditions
However, the government is not solely responsible for disseminating information about new technologies, and political barriers are not the only factors inhibiting the adoption of solar drying techniques. This study indicates that there is dissatisfaction with market conditions for dried products in Nepal, which could impede the progress of solar dryers. In the literature, this dissatisfaction is often attributed to limited market accessibility caused by infrastructural constraints. However, during the field survey, dissatisfaction primarily stems from low demand for dried products. Nevertheless, this demand could potentially increase with improved quality of the dried products. More than half of the respondents reported experiencing post-harvest losses during traditional open sun drying practices, attributed to factors such as rain, wind, dust, insects, pests, and fungal attacks. This suggests that the quality of dried products from open sun drying may vary, consistent with findings in the literature on open sun drying.

The significance of the market in terms of information dissemination and the adoption of new agricultural technology has been emphasized in numerous interviews. Farmers highlighted that the demand for solar dryers would increase with the establishment of a robust market for dried products, and that a thriving market for these products would encourage investment in the technology. Market conditions, including accessibility and demand for dried products, vary across different districts. In Manang, the predominant dried crops, such as apples, mushrooms, and radishes, are typically sold directly to consumers. There is an overall favorable perception of market conditions for dried products in this region. Given that Manang is a remote village situated in the mountainous region of Nepal, products primarily circulate within a localized market heavily reliant on tourism. Nevertheless, the demand for dried products in this area remains high, partly owing to the extended lean season and restricted access to external markets during this period. This demand could motivate investments not only for commercial purposes but also for self-consumption to preserve food for the lean season. Moreover, tourists consider dried apples an ideal trekking snack and souvenir from the region. These market dynamics likely contributed to the broader awareness and utilization of solar dryers in this district compared to others.

The market conditions in Chitwan and Kavre differ significantly from those in more remote regions like Manang, primarily due to their less isolated locations and warmer climates. These factors result in shorter or non-existent lean seasons and easier access to external markets. Consequently, there is a year-round availability of fresh fruits and vegetables, which leads to a different demand for dried products. In these regions, people primarily dry fruits and vegetables for self-consumption, leading to a general perception that such dried products lack commercial viability. This perception is also prevalent among small-scale farmers who find that the quantities they produce are too small to justify investing in a dryer. A potential strategy for farmers in these regions to access commercial markets with their drying practices is by producing refined and more competitive products. However, for this to occur, information about dried products with the potential for competitiveness and economic success in the market may need to be promoted alongside the promotion of solar dryers. For instance, consider a farmer in Chitwan who cultivated bananas but had never heard of banana chips. When introduced to the concept, she expressed great excitement. Additionally, one of the test farmers proposed the idea of drying vegetables, such as tomatoes, during periods of low market prices for fresh produce, then selling them later when market prices rise to maximize profits. Given the significant impact of Indian import prices on the Nepalese market, this strategy could serve as an effective means to mitigate market price fluctuations.

Projects, Associations and Neighbour to Neighbour Communication

The market condition may not be the sole reason for the broader awareness and utilization of solar dryers in Manang compared to Chitwan and Kavre. It appears that Manang has been the focus of various projects, which could have contributed to this phenomenon. For instance, both the women in the group interview and another farmer in Manang who utilized solar dryers had acquired their equipment through different projects. The women's group obtained their dryers from the Suaahara project, an initiative led by USAID in collaboration with the Government of Nepal, aimed at improving the health and nutritional status of women and children. According to the women in the group interview, around 20 households in Manang received a dryer through this project. The other farmer received the dryer from MED-PA (Micro Enterprise Development Program), a project implemented by the Government of Nepal with the goal of poverty reduction. As documented in the literature, initiatives like these can also play a significant role in disseminating information and serve as a driver for adoption of new technique.

Another significant driver that can contribute to the dissemination of information regarding solar dryers, as outlined in the literature, is membership in an agricultural cooperative or association. About 50 percent of the farmers who were aware of solar dryers were also members of such associations, with one stating that their knowledge of the technique originated from that affiliation. During the field study, it was further mentioned that being part of an association or similar organization is an important factor in disseminating information and promoting the widespread adoption of solar dryers. However, according to the findings of the field survey, one of the most influential drivers of information dissemination appears to be neighbor-to-neighbor communication. This phenomena is also underlined in the literature study as a factor increasing the likelihood of adopting solar dryers. Three of the respondents who were aware of the dryers had learned about them from either a friend or another acquaintance who utilized solar dryers or had some knowledge about the technology. While this may seem like a small number, other insights from the interviews highlight the significant impact of this communication channel. Several interviewees emphasized the increase in trust when a person in the vicinity tries the solar dryer and has a positive experience, which then encourages more people to try it themselves. Additionally, one farmer mentioned that after successfully applying for subsidies, she acquired a machine for cutting apples, which prompted her neighbors to follow suit. Moreover, one of the test farmers expressed that since the dryer was distributed two weeks ago, the entire village has shown great interest in it, with many other households expressing a desire to use it as well. This knowledge could potentially inform how the project's solar dryer is most easily and successfully spread among the Nepalese farmers.

Training and Extension Services

As depicted in Figure 14, training and extension services emerge as a frequently cited driver in the literature for the adoption of solar dryers. This aspect was also brought up during interviews as a means to facilitate wider adoption of solar dryers. This result suggests that pairing solar dryers with training could be an effective dissemination strategy. In the literature, Matavel et al. (2022) highlights that solar drying, when combined with associated training, significantly enhances the food security status of participants. Conversely,

C. Joshi et al. (2002) underscores that distributing solar dryers with training programs still encounters challenges for sustained diffusion. These challenges encompass barriers previously outlined in this thesis, along with others like lack of competence in the design, manufacturing, and usage of solar dryers, as well as insufficient resources for maintenance and follow-up work. Among the surveyed farmers, only one mentioned receiving solar drying training. This farmer, based in Manang and utilizing solar drying technology, acquired training through local competence-sharing among farmers. This approach was vital in his initial exposure to solar dryers. However, he emphasizes that obtaining information requires taking proactive steps. Additionally, he was aware of other agricultural training initiatives by the local government agency. The success of training in his case is evident, as he now operates two solar dryers in his farming business, experiencing both shorter drying times and no post-harvest losses. It's noteworthy that this farmer's usage of the dryers spans less than a year, suggesting limited exposure to issues such as the ones mentioned by C. Joshi et al. (2002). Such issues were encountered by the women in the group interview who no longer used their dryers due to maintenance challenges and a lack of local expertise. Lack of local expertise was also identified as a main barrier in the examined literature (see Figure 13). Thus, this underscores the significance of training for both local manufacturers and users to overcome barriers and advance the widespread adoption of solar dryers.

4.3 Technical Aspects of the Solar Dryer

When asked about the most important features they would consider if they were to invest in a solar dryer, the farmers' responses varied slightly depending on location. However, the main qualities mentioned by them, as well as by the test farmers and potential manufacturers, included size (both in terms of capacity and portability), price, drying time, durability, and user-friendliness, as depicted in Figure 17 below.

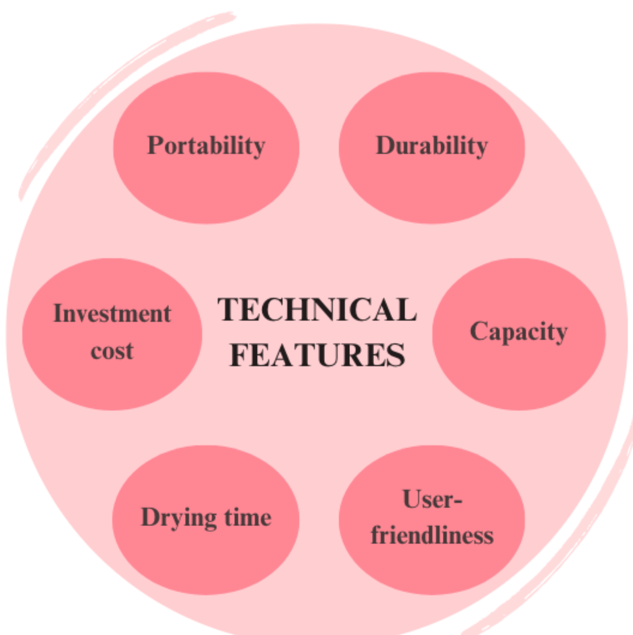


Figure 17: An illustration of the important technical qualities of solar dryers mentioned in interviews with farmers, test farmers, and producers.

Portability and Capacity

Portability emerged as a critical feature for potential investment, especially highlighted by the interviewed farmers in Manang and Kavre. During visits to farmers testing the project dryers, the significance of portability was further underscored. Both farmers emphasized the inadequacy of the current dryers in terms of portability, hindering placement in desired locations such as rooftops, where easy connection to power outlets is feasible and were they could avoid obstructions and safeguarding against potential damage. The dryer's weight, approximately 100 kg, needed eight men during distribution, highlighting the need for a lighter design. The interviewed welding workers also noted the challenge posed by the heavy steel sheets in the current dryer, affecting both portability and construction ease. Furthermore, it complicates transportation on Nepal's bumpy roads, with university officials citing risks such as glass cover breakage during distribution. An alternative solution could involve designing a dryer that can be dismantled and reassembled. However, further research is required to ensure its optimal performance. Several farmers also raised concerns about dryer capacity, predominantly grain farmers in Chitwan, advocating for solar dryers tailored to their needs. Conversely, test farmers in Panchkhal found the dryer's capacity suitable for drying vegetables during harvest, but suggested benefits from increased capacity for grain drying.

Analysis of the data reveals that while portability reigns as a priority in Manang and Kavre, capacity holds greater significance in Chitwan. Geographical and climatic factors likely explain this disparity, with Chitwan's year-long growing season necessitating higher drying capacity during harvest. Conversely, the milder winters and flat terrain in Chitwan allow for placement of larger, heavier dryers on farms without concerns about snow. In higher altitudes, where production is lower, portability assumes greater importance due to seasonal movements. Several Manang farmers using direct solar dryers (see Figure 11) expressed satisfaction with their dryer's size and portability, suited to their small-scale production and seasonal needs.

While this thesis does not encompass solar dryers designed for drying of grains, it could serve as a future research topic. Targeting specific regions and adapting designs to local conditions is crucial for project success, given the significant variations in geographical and climatic conditions.

Drying time, Durability and User-friendliness

Both drying time, durability and user-friendliness were mentioned as important investment considerations by several interviewed farmers. The durability feature was mostly emphasized by those farmers in Manang who had previous experience with solar dryers, which highlights its importance in regards to a sustainable long-term usage. Both test-farmers in Panchkhal expressed high satisfaction with the dryers' performance after two weeks of use, finding them easy to operate. During this limited period, one farmer had used the dryer more extensively and reported satisfactory results. For instance, chili, which typically takes seven days to dry, was fully dried in just two days without using the fan. In contrast, the other farmer, who had only used the dryer once, did not observe a significant improvement in drying time compared to open sun drying. However, the same farmer remained positive about the dryer due to its superior protection against dust, rain, and other environmental factors. None of the two dryers had been used with the built-in forced convection system since they were not connected to a power source, which indicates that continuous monitoring should be done during a prolonged time where the dryer is used correctly in order to obtain a proper perception of the dryers' performance. It is quite perplexing that the dryer worked at all without any fans activated.

Additional concerns regarding user-friendliness and the overall practicality of the dryer included the trays used to hold the vegetables, which were found to be non-uniform and prone to deformation. This resulted in imperfect fits and occasional tray failure, especially when heavier items were placed on them. To address this issues, one farmer suggested adding better support for the trays, such as slots or a firmer netting material. Additionally, concern was expressed about the short and exposed electricity wires for the fan, making it difficult to connect the dryer to a power source and raising durability concerns, particularly in inclement weather or in the presence of animals like rats. However, there are plans to address at least one of these issues by eventually powering the fan with a solar panel, eliminating the need for a nearby electrical outlet. Another area for improvement identified by the farmers was the dust filter for the fan inlet, which is currently an external cloth that proved vulnerable to damage.

Regarding the existing direct solar dryers in Manang, the majority of the farmers were quite satisfied with the overall performance, apart from the mentioned durability problems with the plastic covers. The drying time for the majority of the crops were two days or less, but the biggest win for the farmers was understood to be the time saved in not having to carry the drying crops in and out during the night, or constantly having to worry about potential bad weather or contamination. In this point lies the real gain with using some sort of solar dryer, and although simple in design, the dryers did fill the farmers' basic needs. This raises the importance of weighing simplicity against high performance in terms of drying rate and efficiency, since the main goal is for farmers to actually be able to use it without difficulties.

Economy and Manufacturing

As mentioned earlier, many interviewed farmers highlighted investment cost as a key factor for investing in a solar dryer, which supports one of the postulated objectives of the SolarFood project; that the solar dyer should be affordable to the small-scale farmer. As mentioned the production cost for the project dryer amounted to approximately 35 000 NPR, which the manufacturer in Panchkhal who built the solar dryer expressed to be the minimum cost as the dryer design and material costs stood at the time of construction. When asked about potential reduction in costs if up-scaling in production would occur, none of the interviewed manufacturers would anticipate significant cost reduction, but would rather attribute any potential savings to fluctuations in the market prices of materials. The cost can be compared to the costs for some of the solar dryers distributed by the Nepalese government, presented in the literature study to be approximately 32 000-45 000 NPR today when correcting for inflation. These values match those indirectly presented in the governments renewable energy policy. Keeping in mind that these dryers are eligible to subsidies, the investment cost for the farmer would most probably be lower than that of the project dryer (down to 15 000-20 000 NPR, compared to the current project dryers' 35 000 NPR) although it is hard to properly compare without a common capacity unit, and hard to know how reliable these values really are. However, if this is the case, the project dryer would need to become at least 15 000 NPR cheaper to cost-wise compete with the governments dryers. A more holistic perspective is to factor in the difference in performance, durability and the other mentioned qualities of the dryers, since these might compensate for a higher price.

Regarding manufacturing aspects, all craftsmen interviewed stated that they only produce products based on specific requests. They expressed that constructing the project solar dryer's design posed no particular difficulty, and they didn't anticipate needing extensive assistance. However, two of them mentioned that an improved manufacturing manual, such as one with a three-dimensional outline, would be beneficial to minimize ambiguity. Only one of them, the workshop manager in Kathmandu, had prior knowledge of solar dryers, which he acquired through the National Innovation Center in Kathmandu.

The interviewee in Panchkhal, who supervised the construction of the two project solar dryers, identified some technical obstacles during the building process. These included the already mentioned difficulty of folding the steel sheets, partly due to their thickness, suggesting that finding an alternative solution would be more efficient. Another challenge highlighted by the Panchkhal supervisor was the difficulty in obtaining insulation, particularly for those located far from Kathmandu. This concern was echoed by the workshop manager in Kathmandu. Since one of the projects' aims is to design a solar dryer which can be made locally, this point indicates that further work is needed regarding material choices. Additionally, the supervisor in Panchkhal noted the difficulty in fitting the glass cover and ensuring airtight construction, another aspect that would need to be thoroughly investigated if the design of the dryer is changed to be made more portable. The potential manufacturers estimated that constructing one unit would take approximately one week if all materials were readily available. However, in Panchkhal, the actual construction time was reported to be 3-4 days under similar conditions. All agreed that scaling up production would not be an issue, rather the opposite since it would mean more income for the workshop, although the lead times could increase when extending the work force and ordering materials. Taking into consideration the mentioned problems with transportation, material supply and the constraints in local conditions, the best way forward could be to distribute the knowledge rather than the dryer itself, apart from maybe a few demonstration units for educational purposes. Initial training of local craftsmen through dedicated training programs could be an effective way to ensure the production of properly functioning units. This approach may also prove to be a more efficient dissemination of know-how compared to in-situ training, especially during the initial launch phase.

4.4 Result Validity

In total, 35 interviews were conducted and contributed to the findings of this study, with approximately ten conducted in each of the three topographical regions. However, given that Nepal comprises multiple distinct ethnic groups and diverse living and climate conditions, the results are not fully representative of the entire population, nor even of the regions or districts where the interviews were conducted. However, the aim of such interviews are not to quantitatively reach a generalization, but rather to investigate the presence of different qualitative aspects. Since the responses within the same district somewhat align, it can be inferred that the answers provide some insights into the general perception of solar dryers in that area.

Additionally, the survey faced challenges due to the authors' lack of local context and proficiency in Nepalese, necessitating collaboration with local expertise. Consequently, field visits were coordinated and supervised by researchers from Kathmandu University. Moreover, the language barrier impacted the nuances that could be found from the respondents' answers, further emphasizing the reliance on local assistance for accurate interpretation and understanding.

5 Conclusions & Recommendations

The results reveal a close interconnection between identified barriers and drivers, creating a complex landscape for the adoption and diffusion of solar dryers in Nepal. Summarizing the findings from the various themes discussed above, the situation can be briefly described as follows:

Government policies and initiatives, such as the renewable energy subsidy policy, aim to promote the adoption of solar dryers. However, challenges persist, including limited awareness of subsidies among farmers, outdated subsidy rates, and potentially, national budget constraints (although obtaining a comprehensive understanding of this is challenging). Consequently, the private sector and NGO initiatives may play a crucial role in overcoming barriers and promoting solar dryer adoption. Moreover, there is a dissatisfaction with market conditions, including limited market accessibility and low demand for dried products, which could hinder solar dryer adoption. Market dynamics vary across different regions, influencing the demand for dried products and thus also the utilization of solar dryers. Strategies to improve market conditions, such as producing competitive dried products and promoting market-driven drying practices, may enhance solar dryer adoption. Nonetheless, the findings underscore that one major obstacle hindering solar dryer adoption in Nepal is the lack of public awareness. While projects and initiatives led by NGOs and government agencies can facilitate the dissemination of solar dryers and information, another influential source of information appears to be neighbor-to-neighbor communication. This form of communication, coupled with membership in agricultural associations, emerges as significant drivers of solar dryer adoption, fostering trust and interest among farmers. Furthermore, training and extension services seems to be essential drivers for solar dryer adoption, as highlighted in the literature. Limited awareness and access to training programs among farmers may hinder the effective utilization of solar dryer, whereas continuous training and support could serve as effective tools for addressing challenges related to equipment maintenance and usage, especially among new users. Knowledge about these identified barriers and drivers can guide strategic decisions aimed at promoting the widespread adoption of solar drying technology. Particularly for this project, this knowledge can primarily inform efficient dissemination methods for the project's solar dryers, aiming to create beneficial conditions for widespread adoption and usage.

However, for the project solar dryer to spread it first needs to meet all the technical requirements in order to be a feasible option, both for users and manufacturers. The expressed importance of portability in Manang and Kavre, together with the experiences of the current project solar dryer, indicates that the current design needs to be further developed towards a more portable model. Some minor design elements should also be addressed, namely a more protected wiring, a lasting dust filter, and ensuring the integrity of the drying trays. A decreased capacity could be acceptable in these regions in favor for increased portability, while the opposite is true for lower regions such as Chitwan, where the dryer could be designed for drying of grains rather than vegetables. This could however be a separate project for future research, whilst specifically focusing on the conditions of the mountainous and mid-hill region should be the main ambition for this project.

Regarding manufacturing, material choices should be made with local availability in mind. Therefore, the insulation could benefit from having an alternative material that could be acquired to a more local extent, opening up to a more decentralized production. These implications should be dealt with whilst taking into consideration that keeping the cost as low as possible is essential for the project dryer to be a feasible option for small-scale farmers, able to compete with solar dryers eligible to subsidies, and thus also decreasing governmental dependence.

At the current stage of the project, two third-generation dryers have been distributed to two test farmers. However, with the finalization of the design, a possible next step could be to produce as many dryers as the project budget allows and distribute them among small-scale farmers in targeted rural areas of Nepal. By increasing the distribution of dryers, it could raise awareness and stimulate demand, thereby overcoming the barrier of lacking information, enhancing the successful driver of neighbor-to-neighbor communication. To maximize the impact of this strategy, it's beneficial to produce the dryers in a decentralized manner. This approach not only enhances local expertise and facilitates maintenance but also generates employment opportunities and improves dryer availability.

Moreover, the distribution could come alongside with training programs. Beyond basic usage, training programs could focus on developing technical skills related to the maintenance, repair, and troubleshooting of solar dryers. This would empower users to address common issues independently and ensure the longevity of the equipment. Training initiatives could also include education on the environmental benefits of solar drying compared to traditional methods, such as reduced carbon emissions and conservation of natural resources. This would foster a deeper understanding of the sustainable aspects of solar drying practices.

6 Future Research

During the work on this paper, several areas have emerged as suitable topics for future research. As an extension of the project, a solar dryer specifically designed for drying grains could be developed for the lower regions (Terai). Additionally, the feasibility of developing a dryer suitable for both vegetables and grains could be investigated for the mid-hill region. Research into combined system solar dryers that are effective in all weather conditions would also be beneficial for the project.

From a broader perspective, further studies surveying market possibilities are recommended. Examining consumer preferences and market trends for dried products could offer valuable insights into potential opportunities for farmers to diversify their product offerings and cater to evolving consumer demands. This could include exploring emerging markets for specialty dried products or value-added products that fetch higher prices in domestic and international markets.

Furthermore, a thorough survey of how the changing political landscape in Nepal affects various aspects of solar dryer adoption would be valuable. This would inform how the work can be structured to minimize vulnerabilities and ensure sustainable implementation.

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Appendix

Appendix A: Questionnaire for Farmers without Solar Dryers

Questionnaire for Farmers without Solar Dryers

General Information
Time and date:
Family name:
Location:
Contact information:
Age:
Educational Background:

Living situation
How many people live in your household? Adults: Children:
Size of production area:
Is farming your main income-generating activity? **If no, what is?**
How long have you worked in agriculture? ○ Less than 10 years ○ Between 10 to 20 years ○ Above 20 years

1

Questionnaire for Farmers without Solar Dryers

Agricultural production on your farm	
Do you mainly cultivate for self-consumption or for selling purposes? ○ Self-consumption ○ Selling purposes ○ Equal parts ○ Depends on the harvest	
If you do sell part of your produce, please fill in the following fields:	
Yearly Selling Amount (Kg):	Tentative Yearly Worth (NRS):
Are you part of an agricultural cooperative or association? **If yes, please state which one.** ○ Yes ○ No	
Who do you sell your products to? ○ Directly to consumer ○ Wholesaler ○ Other (please specify):	
To whom would you prefer to sell your products? ○ Directly to consumer ○ Wholesaler ○ Other: Why?	

2

Questionnaire for Farmers without Solar Dryers

Solar drying practices
Drying method(s) used: ○ Open sun drying ○ Direct solar dryer ○ Indirect solar dryer ○ Mixed mode ○ Other (please specify):
If applicable, what type of crops do you dry?
If applicable, what is the approximate time taken for drying your crops? ○ Below 5 hrs. ○ 1 day ○ 2 days ○ More than 2 days
During which season do you dry crops?
Is drying a crucial activity for you in your farm business? ○ Yes ○ No
How is the market for your dried product(s)? ○ Excellent ○ Very Good ○ Satisfactory ○ Poor
Have you heard of solar dryers? ○ Yes ○ No
If the answer was **yes** to the previous question; from where have you heard about it?
Do you know about the subsidies provided by the government for Solar Dryers? ○ Yes

3

Questionnaire for Farmers without Solar Dryers

○ No
Are you aware of any other initiatives to promote/support solar drying offered by the government, NGOs or any other actors (trainings, subsidies, micro-credits/loans)? If **yes**, please state the initiative. ○ Yes ○ No
Are you interested in using a solar dryer? ○ Yes ○ No
What is the main cause that you haven't invested in one already?

Solar dryers
What would be most important to consider if you were about to invest in an improved solar dryer? (Example: investment cost, size, portability, drying time, drying capacity, flexibility in use)
In your opinion, what are the most important barriers against improved solar drying technologies in your village/region?
What do you think is necessary for this kind of technique to be more widely adopted and spread in your village/region and other areas in rural Nepal?
Could collective investment in shared dryers among households be an option? Why / why not? ○ Yes ○ No
Do you use any other type of renewable energy technology?
Anything else you would like to mention?
Comments during the interview:

4

Appendix B: Questionnaire for Farmers Utilizing Solar Dryers

Questionnaire for Farmers Utilizing Solar Dryers

General Information
Time and date:
Family name:
Location:
Contact information:
Age:
Educational Background:

Living situation
How many people live in your household? Adults: Children:
Size of production area:
Is farming your main income-generating activity? **If no, what is?** ○ Yes ○ No
How long have you worked in agriculture? ○ Less than 10 years ○ Between 10 to 20 years ○ Above 20 years

1

Questionnaire for Farmers Utilizing Solar Dryers

Agricultural production on your farm
Do you mainly cultivate for self-consumption or for selling purposes? ○ Self-consumption ○ Selling purposes ○ Equal parts ○ Depends on the harvest
If you do sell part of your produce, please fill in the following fields: Yearly Selling Amount (Kg): / Tentative Yearly Worth (NRS):
Are you part of an agricultural cooperative or association? **If yes, please state which one.** ○ Yes ○ No
Who do you sell your products to? ○ Directly to consumer ○ Wholesaler ○ Other (please specify):
To whom would you prefer to sell your products? ○ Directly to consumer ○ Wholesaler ○ Other: Why?

2

Questionnaire for Farmers Utilizing Solar Dryers

Solar drying practices
Drying method(s) used: ○ Open sun drying ○ Direct solar dryer ○ Indirect solar dryer ○ Mixed mode ○ Other (please specify):
If applicable, what type of crops do you dry?
If applicable, what is the approximate time taken for drying your crops? ○ Below 5 hrs. ○ 1 day ○ 2 days ○ More than 2 days
During which season do you dry crops?
Is drying a crucial activity for you in your farm business? ○ Yes ○ No
How is the market for your dried product(s)? ○ Excellent ○ Very Good ○ Satisfactory ○ Poor
Do you know about the subsidies provided by the government for Solar Dryers? ○ Yes ○ No
If the answer was **yes** to the previous question; have you used the subsidy? ○ Yes ○ No
Are you aware of any other initiatives to promote/support solar drying offered by the government, NGOs or any other actors (trainings, subsidies, micro-credits/loans)? **If yes, please state the initiative.** ○ Yes ○ No

3

Questionnaire for Farmers Utilizing Solar Dryers

Solar dryers
For how long have you been using the solar drying technique? ○ Less than 1 year ○ 1 – 5 years ○ 5 – 10 years ○ More than 10 years
How did you dry your crops before using the solar dryer?
How did you get in contact with/get information about the solar drying technique?
From where/who did you get your solar dryer/dryers?
What benefits do you see/experience with using solar dryers?
Do you face any problems with current drying practices? (Example: Technical, duration, Quality, Acceptability on Market)
Do you have any ideas about what could be improved in the drying process?
Do you feel that the solar dryer has been a good investment? ○ Yes ○ No
If the answer was **no** to the previous question; Why not?
What would be most important to consider if you were about to invest in an improved solar dryer? (Example: investment cost, size, portability, drying time, drying capacity, flexibility in use)
In your opinion, what are the most important barriers against improved solar drying technologies in your village/region?
What do you think is necessary for this kind of technique to be more widely adopted and spread in your village/region and other areas in rural Nepal?
Could collective investment in shared dryers among households be an option? Why / why not? ○ Yes ○ No
Do you use any other type of renewable energy technology?
Anything else you would like to mention?
Other comments during the interview:

4

Appendix C: Questionnaire for Potential Producers of Solar Dryers

Questionnaire for Potential Producers

General Information
Time and date:
Family name:
Location:
Contact information:
Age:
Educational Background:
What is your role within your profession?
For how long have you been in your profession?

Solar dryers
Have you previously heard about solar dryers? ○ Yes ○ No
If you answered **yes** to the previous question: How did you get in contact with/get information about the solar drying technique?
Do you think that it is easy to understand how to build the solar dryer based on the design?
Do you see any potential difficulties with producing the solar dryer based on the design? (Material, tools needed, specific design elements etc.) If **yes**, state which ones: ○ Yes: ○ No
Do you think you would be able to build the dryer based on the design without training/help?

1

Questionnaire for Potential Producers

How long time do you think it would take to build one unit of the dryer?
How much would it cost to build a solar dryer?
What do you think about the possibilities to scale up production (amount) of solar dryers?
Would placing a larger order result in a lower price for the dryer? If so, by approximately how much?
Do you produce for selling purposes or do you only produce based on requests? ○ Selling purposes ○ Based on request ○ Both
If you are producing for selling purposes: How do you advertise the products you manufacture?
If you are producing for selling purposes: What do you think about the market possibilities for solar dryers?
Are you producing any products that utilizes renewable energy?
Anything else you would like to mention?
Other comments during the interview:

2

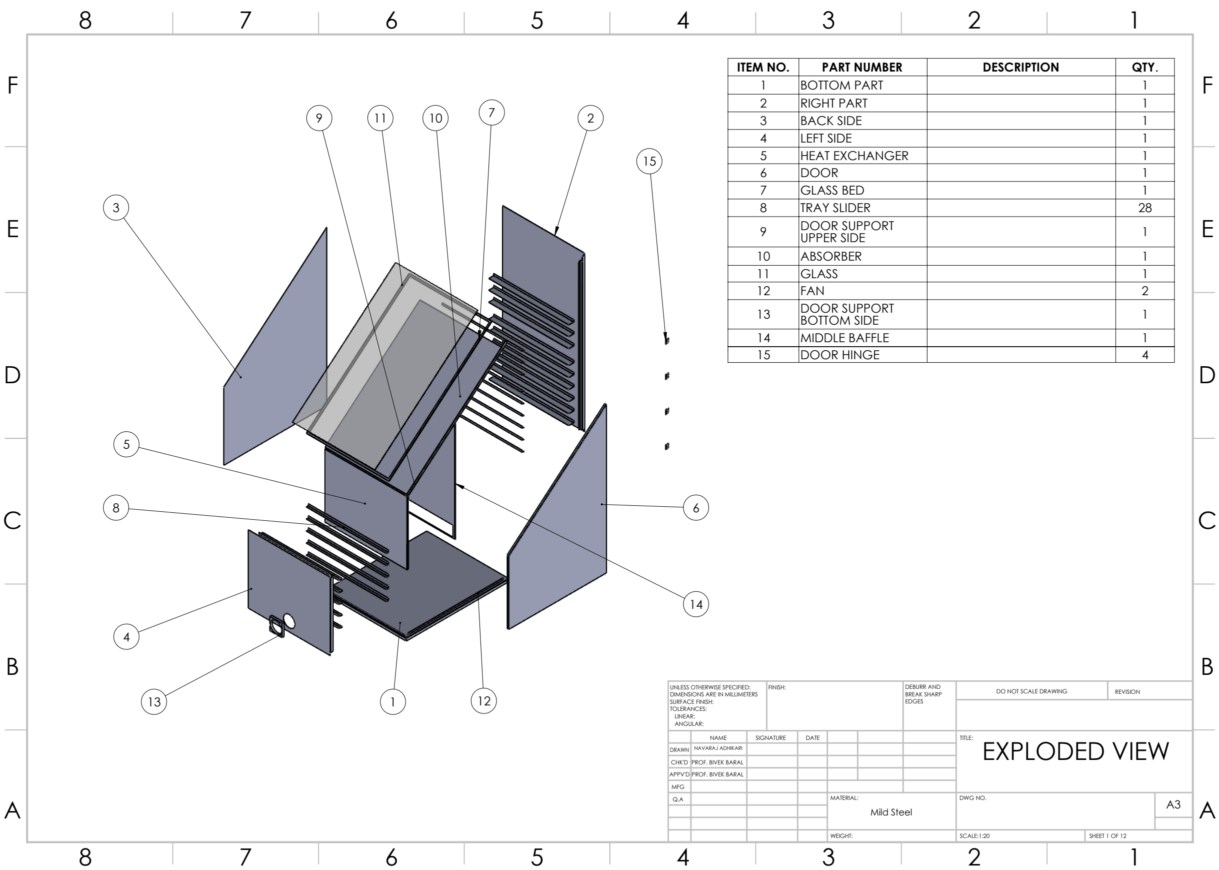
Appendix D: Logbook for Test Farmers Utilizing Project Developed Dryers

The SolarFood project, Kathmandu University. Contact: Prof. Bivek Baral

Solar Drying Experiment: User's Logbook [Take a picture of the product prior to as well as after the drying]	
Date:	Weather during the drying process:
Type of crop(s) dried:	Preparation (sliced/whole):
Time in:	Time out:
Weight of the crop before drying:	Weight of the crop after drying:
Person(s) involved in the drying process (including crop preparation, monitoring, handling of the dryer and the dried products):	
How do you rate the taste, aroma, color, texture, etc. of the dried product? Comments?	
Is the drying and quality of the dried product even in different parts of the dryer? Comments?	
Comments on the user-friendliness of the dryer (what worked well, what worked less well, were there any challenges in any stage of the drying process?):	
Ideas for improvement of the dryer (e.g. design, size, drying time, drying capacity, flexibility in use):	

1

Appendix E: Drawing of the Third-Generation Dryer developed within the Project



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	BOTTOM PART		1
2	RIGHT PART		1
3	BACK SIDE		1
4	LEFT SIDE		1
5	HEAT EXCHANGER		1
6	DOOR		1
7	GLASS BED		1
8	TRAY SLIDER		28
9	DOOR SUPPORT UPPER SIDE		1
10	ABSORBER		1
11	GLASS		1
12	FAN		2
13	DOOR SUPPORT BOTTOM SIDE		1
14	MIDDLE BAFFLE		1
15	DOOR HINGE		4

Appendix F: Tentative Manufacturing Expenses 3rd Generation Solar Dryer

S.N	Particular	Unit	Quantity	Rate	Amount (Rs.)	Remarks
1	Solar Dryer Sheet Metal (1mm thickness)	Pieces	2	4000	8000	Used to make solar dryer body
2	glass (5 mm thickness)	Pieces	1	2300	2300	Used for glazzing in solar collector
3	13 mm Foil Insulations	Metre	4	800	3200	Used to insulate the dryer
4	White Silicon	Pieces	3	250	750	Used to seal the porous part of the dryer
5	Dendrite	Litre	1	700	700	Used to stick foil insulation
6	SS wire mesh	Kg	10	330	3300	Used to make the trays
7	DC fan (12 V, 0.1-0.4 A)	Pieces	2	250	500	Used to blow the air inside the dryer
8	Angle Support (2mmx2mmx1mm)	Kg	12	125	1500	Used to support the tray inside the drying chamber
9	Door Hinge	Pieces	4	45	180	Used on door of the dryer
10	Nut- bolt and Screws	Pieces	10	60	600	Used to support the fan
11	Door Handle 6"	Pieces	1	60	60	Used on door of the dryer
12	Maroon Paint	Litre	1	760	760	Used to paint the dryer body
13	Metal Primer	Litre	1	400	400	Used to paint the dryer body
14	Enamel	Litre	1	575	575	Used to paint the dryer body
15	Tarpin oil	Litre	1	160	160	Used to paint the dryer body
16	Thinner	Litre	1	425	425	Used to paint the dryer body
17	Manufacturing Cost				12000	
				Total cost:	35410	
						Author: Navaraj Adhikari