Final Report

Solar Conduction Dryer Assessment within Smallholder Farmer Communities in Cambodia and Laos

Research and Innovation for Development in ASEAN (RIDA)

People in Need Cambodia

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Executive Summary

Smallholder farmers and family-owned agri-businesses in rural areas of Cambodia and Laos face increasing pressure to increase productive, reduce post-harvest loss and mitigate climate change impacts. Currently, limited advanced technology options exist for these agriculture actors to address these challenges. Additionally, the lack of an enabling environment, including appropriate financing and knowledgeable agriculture extension agents, inhibits the ability of wide-scale technology adoption. People in Need Cambodia (PIN), partnering with Agri House in Cambodia, Sustainable Agriculture and Environment Development Association (SAEDA) in Laos and Covestro Inclusive Business Unit as the technology expert, seek to pilot and test the effectiveness of small-scale Solar Conduction Dryers (SCD) with smallholder farmers or rural agri-businesses.

Drying is a popular post-harvest technique used by smallholder farmers and rural agri-businesses to add value, increase product lifespan, and reduce waste. The vast majority of drying is conducted in open-air environments using the sun. While this is a cost-effective option, there are many drawbacks, including waste associated with weather events, insects and rodents, the inability to efficiently dry during the rainy season or cloudy weather, and reduced end-product quality due to environmental exposure. Solar drying technologies offer an efficient drying in closed, climate-controlled conditions. PIN has tested medium- and large-scale solar dryer domes for agri-fishery purposes. These tests have produced impressed results, including increases in productivity, reduction in contamination, and short payback periods. Through this FDCO supported pilot project, the consortium team will test three SCDs each in Cambodia and Laos within three different value chains. The SCDs will be designed and constructed locally to assess supply chain capability and fabrication skillset. Performance data will be collected over a three-cycle production period to conduct a comparative analysis between traditional air open-air drying and solar conduction drying. The objective is to understand key parameters to support scale-up, this includes appropriate value chain identification, local design and construction feasibility, and a potential economic model.

1 Background

Agriculture plays a dominate economic role in Cambodia and Laos, making up approximately 23% of Cambodia's GDP and 16% of Laos' GDP. The sector is also an employment driver, particularly for women in rural areas – it is estimated that 50% of rural farming workers in Laos is comprised of women, the figure in Cambodia is 45%. Despite their important role in agriculture, women farmers are less likely to receive extension services or financial products, limiting their ability to grow and enhance their operations. Three-fourths of Cambodia's 6.8 million famers are registered as smallholders, in Laos approximately 80% of the population is engaged in agriculture with average farm sizes between one and two hectares. Despite the importance of the agriculture sector in both countries, the sector has seen only small advances in cultivation and processing technologies and much of that does not benefit smallholder farmers. Smallholder farmers also face an increased risk as a result of climate change impacts which is further heighten by limited access to and understanding of mitigation technologies.

Many smallholder farmers and family run agri-processors across Cambodia and Laos employ traditional open-air sun drying methods as part of their post-harvest process. These techniques are used within a variety of agri-fishery value chains, including mango, banana, coconut, longaan, dragon fruit, chilis, lemongrass, peppercorn, ginger, turmeric, fish, and crickets. The ability of smallholder farmers to conduct basic drying processing allows farmers to increase revenue and preserve post-harvest commodities for a longer period. And while the sun offers a free drying resource, open-air drying has many drawbacks which prevent farmers from maximizing the full value of their post-harvest yield.

Figure 1: Small fished dried under the sun in an open air environment

The traditional method of open-air, sun drying is the most widespread technique used across Cambodia and Laos. Traditional drying consists of placing post-harvest products on tarps, mats or raised platforms under the sun. This method exposes agriculture products to environmental elements and increases contamination risk from foreign materials such as dust and litter, and exposure to birds, insects and rodents. Additionally, this method of drying is time-consuming and labor intensive. Agricultural products need to be placed out each morning, and collected once the sun sets, and then placed out in the sun the next morning. This process is repeated until the product reaches a preferred dried stage based on visual identification – mainly moisture content determined by look or feel. During weather events, particularly intense rain periods during the rainy season, products need to be collected rapidly to mitigated waste. Drying times for products in open-air environments vary and could take anywhere from 1 to 12 days depending on the commodity. The process is also inefficient and dependent on local weather conditions. During the rainy season, due to rain fall events and cloudy weather, drying times increase which also adversely impacts quality. Lastly, high nutritional value crops, such as fruit, lose vitamin content due to excessive UV exposure during the drying process. As a result of these factors, smallholder farmers utilizing traditional drying techniques experience an increase in post-harvest waste, have limited opportunity to access premium markets due to poor food quality and incorporation of standard hygienic practices, and devote more labor resources to drying maintenance.

As least developed countries with a high agrarian populations, Cambodia and Laos are considered high-risk countries for climate change impacts. One potential impact the SE Asia region is expected to experience is an increase in the frequency and unpredictability of severe and intense rainfall events. Historically, across SE Asia the dry season was mostly devoid of rainfall; however, as climate change impacts begin to take hold the region's dry season is experiencing an increase in rain events. In 2022, Cambodia's annual cashew crop yield dropped by 35%, the key contributing factor was unseasonable and intense rain events which prevented germination as a result of flowers being knocked off trees during rain events. An increase in unpredictable and unseasonable rainfall events will have an adverse impact on open air drying across Cambodia and Laos, as evidence by the impact on Cambodia's 2022 cashew crop. For open air-drying farmers, these climatic events will further increase post-harvest waste, decrease quality, and add to the amount of labor required to manage post-harvest processing activities as farmers need to quickly cover and uncover crops during these events. Additionally, the farmers least likely to adapt to these changing conditions are smallholder farmers due to lack of financial resources and knowledge of possible solutions. Climate change impacts will have adverse impacts in the agri-fishery sectors in Cambodia and Laos, and there is a need to develop, test, and scale technology solutions which will aid in smallholder's ability to adapt.

Figure 2: Large-scale solar dryer dome suitable for medium to large sized processors

For the last four years, People in Need (PIN) Cambodia, has been supporting the development and scale up of two start-up solar dryer companies in Cambodia – Harvest the Sun and Kasekor Chhalt. These companies offer large-scale solar drying dome solutions to medium and large agri-fishery processors. The solar dryers are built from polycarbonate sheets, and utilize exhaust fans and LPG heating elements to create optimal and controlled drying environments which have proven to decrease drying time, reduce contamination and increase overall yield. Solar dryer domes are a relatively new technology to Cambodia, with only a few dozen being used across the country. In Laos, there are only two known solar dryer domes which have been installed and actively used – one outside of Vientiane for a rice cooperative and one in Paksong at a coffee cooperative. At present, solutions offered by both companies only target medium- to larger-scale agri-fishery processors due to costs, and therefore, are not viable for smallholder farmers or family owned agri-processors seeking post-harvest drying solutions. This project seeks to test a smaller solar conduction dryer (SCD) that can offer similar benefits of the larger models to smallholder farmers. There are currently no known solar conduction dryers being used by smallholder farmers in Cambodia or Laos. This novel technology has been designed and successfully tested by Covestro Inclusive Business in India, but has yet to be tested in either Cambodia or Laos. The project team seeks to assess and understand a variety of factors that could lead to a wider adoption of the technology. This includes i) characteristics of smallholder farmers and family operated agri-processors who could benefit from SCDs ii) the performance of SCDs within different value chains – including volume, drying times, and product quality, and iii) a return on investment of SCDs based on local conditions.

2 Research Questions and Objectives

PIN, in partnership with Agri House in Cambodia and the Sustainable Agriculture and Environmental Development Association (SAEDA) in Laos, seek to implement and test solar conduction dryers promoted by Covestro's Inclusive Business unit in Vietnam. Covestro's Solar Conduction Dryer (SCD) is a solar powered food dehydrator which can help to reduce up to 30% of post-harvest loss, increase storage of fruits and vegetables up to a year without any preservatives, and increases retainment of nutritional value. Covestro offers an SCD design template which local implementers can tailor to their specific contextual needs. SCDs are a new, and currently untested technology in both Cambodia and Laos, which can provide a controlled drying environment that adds value to post-harvest processing. SCDs eliminate exposure to environmental elements, protect against UV exposure, increase drying efficiency, and reduce climate change vulnerability. Moreover, it's compact size and reasonable market price are ideal for wide-spread adoption within Cambodia and Laos' smallholder farmer population. At present, the only solar drying options available in Cambodia and Laos require a high up-front investment and a large footprint, making them unrealistic options for rural, economically challenged farmers. The results of the objectives identified below will aid in the develop of a business case for SCDs and the potential of the technology to be adopted and scaled.

Generally, this project seeks to understand if solar conduction dryers are applicable within smallholder farming communities of Cambodia and Laos. And, if used effectively and are cost-competitive, can the dryers prevent post-harvest waste and offer alternatives sources of income for smallholder farmers, and in particular women smallholder farmers. If successful, an opportunity exists to scale the use of these types of dryers across both countries – allowing for more economic opportunity and resiliency from climate change impacts within rural, smallholder farmer communities.

Figure 3: Solar Conduction Dryer developed by S4S Technologies in partnership with Covestro

More specifically, this pilot project seeks to accomplish four main objectives:

1. Identification of farmers or rural agri-businesses and value chains for solar conduction dryers: Through this activity, the project team seeks to understand the characteristics of smallholder farmers who could benefit from the utilization of the technology. This will help inform the business case of the technology, particularly understanding customer size and potential to scale. The project seeks to work with farmers, particularly women farmers who make up over 50% of the agriculture workforce, who have access to different value chains, with a specific focus on fruit, spice and fish, which can be dried using SCDs and have ability to be sold in the local market.

2. Understanding of local SCD material sourcing and construction: The research question targeted through this activity is – can SCDs be built locally, are materials available and does the local workforce have the skills and capacity. To minimize SCD cost, the objective is that SCD materials will be sourced

and built locally. The design will be provided by Covestro, and local partners will locate materials and a professional to complete construction. Locally sourced and built SCDs will aid in the technology's ability to scale.

3. Utilization of SCDs: The goal is to test at least three agri-fishery commodities, in each country, using the SCDs to answer the research question of whether or not the technology can be properly used by smallholder farmers and/or small-scale rural agri-businesses in Cambodia and Laos. Through this activity the project will be able to understand the farmer's ability to use the technology, the quality of the construction, and effectiveness of the training.

4. SCD performance assessment: Finally, the project seeks to understand the performance of the SCDs. Specific performance parameters include volume, drying time, and a food quality analysis that compares traditional drying methods with SCD drying methods. This important data will help formulate viable market strategies and a return-on-investment for the technology.

3 Approach & Methodology

PIN will be the project lead and oversee implementation in both countries. The project will be implemented by in-country local partners in a rural area of both Cambodia and Laos. This project builds off of PIN's Green Energy program which actively leads the implementation and testing of solarized productive use technologies within Cambodia's agri-fishery sector. Currently, this includes the use of medium- to large-scale solar drying solutions. Until now, few if any, small-scale drying solutions have been implemented and tested in either country. Given the prevalence of open-air sun drying as a post-harvest technique, substantial opportunity exists to build and scale solar drying solutions which improve quality and enhance climate change impact resiliency. Upon successful demonstration, PIN will also leverage its experience in the agri-fishery sector to scale SCD solutions through is market systems development approach and partnership with solar technology providers.

Additionally, the project design incorporates elements of People in Need's Market Systems Development (MSD) approach which is used to more effectively develop local markets to meet the needs of poor women and men, in this case smallholder farmers. The ability to locally source SCD materials and components, and identify suitable and capable craft workers to build the technology will reduce costs and meet future demand, if the technology proves capable. Additionally, the results and objectives of this project center around the need to build a business case scenario which would incentivize smallholder farmers and a possible technology distributor. For widespread adoption, smallholder farmers need to see that the technology can increase revenue, and that the return-on-investment is reasonable. In turn, this data can be used to understand full market potential of the technology and increase the likelihood of the technology to be adopted by an existing agri-fishery supplier. For example, if successful, SCDs could be carried and distributed in Cambodia as a product by either or both of Harvest the Sun or Kasekor Chhalt. The solar market in Laos is not currently as mature as Cambodia, but SCDs could be promoted by SAEDA as a solution within their development portfolio.

Local project implementation will be carried out by two local partners, Agri House in Cambodia and the Sustainable Agriculture and Environment Development Association (SAEDA) in Laos. Agri House and SAEDA have a long history of working with rural, farming communities, and prioritizing programming that focuses on women. They will lean on this experience to ensure the most appropriate farmers are selected. SAEDA will focus on two districts located in the Champask province which were selected base on value chain fit and past experience working in the province. Similarly, Agri House will prioritize Siem Reap, Kampong Thom and Battambang provinces, where the company currently operates and has deep partnerships with farming communities. PIN will support smallholder farmer or agri-business selection through the development of a smallholder farmer data collection tool which will allow the project to develop a better understanding of the type of characteristics required for successful SCD implementation and uptake.

The SCD supply chain assessment, sourcing and construction will be overseen by the local partners. However, guidance will be provided by Covestro's Inclusive Business ASEAN. Covestro is a German company that specializes in the development of high-tech polymer materials. One such material is the polycarbonate sheets needed to produce SCDs. As part of the company's Sustainability Strategy, the Inclusive Business ASEAN supports the use of Covestro technologies within marginalize populations to increase revenue, product quality, and regional competitiveness. The Inclusive Business ASEAN unit is based in Hanoi, but has substantial experience in supporting projects in Cambodia and Laos. In addition to providing guidance on the design, procurement, and construction of the SCD units, Covestro will also provide the training materials for SCD based on the selected agri-fishery value chains. Through the local implementing partners and Covestro support, the project aims to understand the ability to locally source and build SCD and provide the necessary training farmers will need to effectively use the technology.

Lastly, data collection for the project will be managed by PIN's Monitoring, Evaluation, and Learning Department (MEAL). This includes the design of a farmer data collection tool and certain aspects of the SCD assessment tool. PIN's MEAL team will work with local partners to implement the data collection plan and analyze final results. PIN's MEAL team has significant experience working on similar projects and designing data collection tools and methods which align with the objectives and incorporate the capacity of local partners. Additionally, a local food quality test will be conducted with a laboratory in each country to assess the food quality improvements SCD can provide in comparison to traditional open-air drying methods. In Cambodia, PIN has identified the Institute of Technology of Cambodia as possessing the necessary equipment, technology and skilled technicians to deliver the testing and analysis. In Laos, SAEDA has identified a laboratory in Vientiane to conduct the testing and analysis.

4 Project Implementation Process – Stories, Successes and Challenges

Agri-Business Selection

The selection of agri-businesses to participate in the pilot projects was accomplished without any major challenges. Agri House was required to target a second location, but this was mainly driven by the need to aggregate agri-processors in one area to reduce travel related expenses. The selected agri-businesses were excited to participate, and generally recognized the need for technologies which allow drying to occur in a controlled and protected manner. An additional success was the ability to select the same value chains in both Cambodia and Laos. This presented an opportunity to compare results within similar value chains and assess the impact of differently designed SCDs on the same agricultural commodity. Lastly, through project cost-savings, SAEDA selected three additional agri-businesses to test the SCDs; this included a noodle maker and a larger-scale fish processor. This development has allowed the technology to be tested in a third value chain, and experiment with the drying of fish at bigger volumes.

Agri-Business Spotlight

Cambodia

Located in Battambang province of Cambodia, Mr. Man Yesin has been operating a fish drying business for approximately 10 years. Formerly he was a fisherman, but recognized the opportunity to make more money through processing and selling of dried fish. Initially, he was processing 10-20 KGs of fish per day; fortunately, he has seen his business grow to over 100 KGs of processed fish per day. Mr. Yesin operated his business 7-days week, unless overcast or rainy weather prevents him from drying this typically occurs during the rainy season from May to November. Fish is purchased each morning at a local market and transported back to his home where processing and drying takes place. Fish are dried, packaged and sold within the day. Weather events which limit sun exposure can greatly impact the drying schedule, and in extreme cases, prevent the products form reach market.

Figure 4: SCD in operation during a raining episode, fish on drying treys are covered with tarps.

As a result of drying under the sun, Mr. Man Yesin faces three main challenges. First, as described above, his product is exposed to the weather-related events which impact drying time and in prolonged cases, the ability to dry fish at all. During the rainy season, it is not uncommon for Mr. Man Yesin to go several days without processing fish. Second, the drying fish is exposed to insects, including common flies and Lesser Banded Hornets. The hornets in particular are harmful to the fish, and in extreme cases the hornets have contaminated entire treys of fish rendering them unsellable. The third challenge faced by Mr. Man Yesin is the need to cover the drying fish during rain episodes. This requires additional labor and if reaction is not quick enough the fish are rained on which prolongs the drying time.

Figure 5: Lesser Banded Hornet eating fish during the drying process.

<u>Laos</u>

Ms. Nok Thonekeoudon comes from an improvised family located in Don Som Village, Khong District, Champasak Province. Fishing aligned livelihoods dominate given the village's location adjacent to the Mekong River. Ms. Nok Thonekeoudon started producing dried fish to sell at local markets 7 years ago. Fish are procured from local fisherman or are caught by family members. Traditional open-air sun drying methods have been used to process the fish since the start of the business. This type of drying method was challenging during the rainy season (June – September) and the winter season (November – January) when temperatures are lower. Drying during these conditions could take between three to five days, and in many cases the fish would rot, or not dry properly. The rainy season was particularly difficult and required additional labour to move the fish during rain events. In the worst-case scenario the fish needed to be dried by fire. Poor drying conditions adversely impact the quality of the final product. This includes undesirable color from drying with fire and exposure to insects

Figure 6: Ms. Nok Thonekeoudon with dried fish from the SCD.

After completing the interview and assessment process, carried out by SAEDA and the District Agricultural and Forestry Office, Ms. Nok Thonekeoudon received a solar conduction dryer at the end of February 2024. After training provided by SAEDA, Ms. Nok Thonekeoudon began using the SCD and saw immediate results. Fish could be dried within one day, and the color and overall quality greatly improved. Total volume is also estimated to be increased as a result of reduced cycle times. Previously Ms. Nok Thonekeoudon was averaging 70 to 80 KG/month, but now estimate an increase to 110 to 120 KG/month. Based on this projection of volume increase and product quality enhancement, monthly revenue will double. The SCD has also generated interest from neighbours curious about the technology and how it works. On multiple occasions, Ms. Nok Thonekeoudon has allowed villagers to dry their fish in the dryer. Given the positive results, many villagers are interested in adopting the technology.

SCD Design, Construction & Delivery

To initiate the design process, Covestro Inclusive Business conducted a virtual training for Agri House and SAEDA and provided sample design templates. Each in-country local partner was then free to design the SCD based on local context and through input provided by the fabricator. The end result was two SCDs which possessed slightly different characteristics. This includes: 1) ventilation: Agri House chose solar power fans to move air through the unit, SAEDA added mesh vents on each side; 2) access: Agri House's SCD opens from the top and includes a stand to rest the door on to eliminate the need to hold the door open with accessing product, SAEDA chose a front door design with hydraulic hinges which the door can rest on to prevent continuous holding of the door when accessing product; 3) height: Agri House's is lower to the ground, while SAEDA is accessible without the need to bend down; and 4) trey material: Agri House chose a wire mesh to allow for more air flow, while SAEDA used polycarbonate to potentially increase temps from the bottom.

Generally, both in-country partners successfully designed and constructed SCD units which performed acceptable drying functions comparative to open environment sun drying. During optimal conditions internal SCD temperatures reached 42°C There were however, some challenges. First, sourcing polycarbonate was difficult – quality polycarbonate is not readily available in Cambodia, and it is even more difficult to locate in Laos. Moreover, sufficient quantities needed for scale up are only located in the capital city of both countries requiring additional costs and time for shipping. Cost of the units was also higher than the target of $500 per SCD. This was the result of several factors relating to prototyping and fabricators unfamiliarity with the material and design. Agri House's designed encountered a few construction issues, this included insufficient ventilation offered by solar power fans. In response, Agri House installed a 3rd fan, which did have positive impacts. However, users also commented on the lack of power for the fans during overcast days. Additionally, the Agri House unit leaked at the seams during a heavy rain event which allowed rainwater to enter into the unit which increased humidity and prolonged drying times. Additional information and details on each in-country's design and construction process is provided below.

<u>Agri House</u>

To design and construct the SCDs Agri House utilized their in-house fabrication team. The company designs and build solar cricket incubators as part of the core business strategy. The team possess the necessary skills and experience in fabrication to be fully capable in designing and building the units. Furthermore, the fabrication team's experience in designing and building small scale incubation technologies aided in the SCD design and construction because the team had a cursory understanding of airflow and managing internal climate conditions. However, it was noted that Agri House's workshop space is small for handling and cutting the polycarbonate which are sold in large sheets. Following an initial discussion with Covestro, and reviewing SCD schematics shared by Covestro, Agri House developed an initial prototype design with slight variations on Covestro's provided schematics. This included i) a slightly larger box size which facilitated an easier construction process by reducing the need to cut the polycarbonate and eliminate waste, ii) using an aluminum composite panel for the wall and base material as the material is easier to find and build with, iii) inclusion of two drying treys, and iv) a side outlet to increase airflow and internal temperatures. Upon conclusion, a test with chilis was conducted and results were positive. However, this prototype was quite large making it difficult to build in Agri House's workshop and presenting delivery challenges. It was also costlier due to the addition of the side air flow outlet, and construction took one week, with two fabricators which greatly increased labor costs. Based on these factors, Agri House decided to make design changes for the final product.

Figure 7: Agri House's First Prototype

The second prototype eliminated the side airflow extension and instead incorporated two solar power fans to maximize airflow and internal climate conditions. Additional design changes included a top lid with support to increase ease of access and the inclusion of only one drying trey which was easy to remove and clean. With these changes, the SCD unit was at a more reasonable price point ($668 USD), and it was much easier to fabricate – the new design could be built in two days with two fabricators. As with the SAEDA prototype, the price point is higher than what was envisioned. However, prototypes tend to be more expensive and through economies of scale and re-design process a less expensive model can be achieved. As with the first prototype, chilis were tested and the result was positive. The chilis were dried in three days using the SCD; under traditional sun drying methods it normally takes 6-7 days.

Figure 8: SCD in use by Agri-business Illustrating Design and Functionality

Sourcing materials for SCD construction in Phnom Penh was mostly an easy process, as main components such as steel, aluminum polycarbonate, screws, steel mesh, and fans are readily available. However, polycarbonate is more challenging to find due to a limited number of suppliers and price fluctuates. Additionally, it was a challenge to find single solar PV panels to accommodate the fans. Small PV panels are sold within solar household lighting sets, but not individually. Agri House also noted a few additional challenges this included transportation from Phnom Penh to Battambang, the units require large lorries and roads conditions were bumpy which could potentially damage the units. Additionally, there was little guidance from Covestro outside of providing schematics and emphasizing key design components such as sufficient airflow.

Material name	Qty	Unit	Unit price	Delivery fee	Total price
Square steel tube (L: 4m , Size: 20mm x 20mm, T: 1.2mm)	28	pcs	$ 3.55	$ 2.00	$ 101.40
Square steel tube (L: 4m , Size: 25mm x 25mm, T: 1.2mm)	2	pcs	$ 4.35	$ -	$ 8.70
Polycarbonate roof (L: 6m x W: 2.1m x T: 6 mm)	1	panel	$132.40	$ 15.00	$ 147.40
Silicone sealing	9	pcs	$ 2.50	$ -	$ 22.50
Silicone handle	1	pcs	$ 2.50	$ -	$ 2.50
Aluminum composite panel 3mm	3	panel	$ 18.00	$ 6.00	$ 60.00
V aluminum (L: 6.0m, Size: 25mm x 25mm)	16	pcs	$ 4.00	$ -	$ 64.00
U aluminum (L: 6.0m)	4	pcs	$ 4.20	$ 15.00	$ 31.80
Self-drilling screw 2cm	1	bag	$ 6.30	$ -	$ 6.30
Alunimium mesh	10	meter	$ 2.38	$ -	$ 23.75
Cutting grinding disc 1T	1	box	$ 7.50	$ -	$ 7.50
Grinding disk 1T	2	pcs	$ 0.85	$ -	$ 1.70
Drill bit	1	box	$ 5.00	$ -	$ 5.00
Cutter knife	1	pcs	$ 1.25	$ -	$ 1.25
Cover lock/door stopper connection	6	pcs	$ 0.60	$ -	$ 3.60
Door lock aluminium	10	pcs	$ 1.80	$ -	$ 18.00
Jigsaw knife	2	pcs	$ 0.75	$ -	$ 1.50
Steel pull handle	9	pcs	$ 0.85	$ -	$ 7.65
Small switch	3	pcs	$ 0.88	$ -	$ 2.63
Hinge	9	pcs	$ 0.30	$ -	$ 2.70
Angle meter	1	pcs	$ 2.00	$ -	$ 2.00
Yellow wheel 5 with brake	12	pcs	$ 1.00	$ -	$ 12.00
Metal paint U-90	1	pcs	$ 2.25	$ -	$ 2.25
Painting brush	1	pcs	$ 0.75	$ -	$ 0.75
Marker pen	2	pcs	$ 0.25	$ -	$ 0.50
Electrical conduit pipe	15	meter	$ 0.25	$ -	$ 3.75
Zip tie	1	bag	$ 0.75	$ -	$ 0.75
Electrial wire	3	roll	$ 1.50	$ -	$ 4.50
DC fan 12V	6	pcs	$ 3.50	$ -	$ 21.00
Solar panel 35W	3	pcs	$ 20.00	$ 2.50	$ 62.50
Protection gloves	1	set	$ 6.00	$ -	$ 6.00
Labor	3	Lump sum	$456.50	$ -	$1,369.50
				Total	$2,005.38

Figure 9: Cost Breakdown of Agri House's SCDs, cost per SCD is $668.46

Upon completion of the SCD construction the units were delivered to agri-processors in Battamabang the week of March 10th. Upon delivery Agri House provided a training on use and functionality, this was based on the virtual training provided by Covestro (described below) and also included pre-processing steps based on value chain. Agri House also provided training on the data collection process and use of the Kobo Tool (also described below). It was agreed with each agri-processor that data would be collected for three drying cycles and the sample for laboratory testing would be collected at the third cycle/test. This would allow the user time to become familiar with the technology and learn how to optimize the performance. In previous solar drying dome testing PIN has contributed to, it takes two to three cycles – sometime longer, for the agri-processor to understand the performance of the technology and how to achieve optimal results. Data will be collected for the next three to four weeks, this will be used to understand performance and financial impact on each agri-business.

SAEDA

SAEDA's SCD design and construction strategy was to conduct it in Khong district close to the agri-businesses that would be testing the technology. SAEDA does not possess in-house fabricators, nor does the organization have experience in designing these types of technologies. An immediate challenge was the location of polycarbonate in Vientiane. At the onset no polycarbonate could be located. Covestro then provided a list of suppliers in Thailand and Vietnam, and fortunately, one of the Thai suppliers had stock in Vientiane. However, SAEDA had to transport the polycarbonate sheets to

Khong district for construction, which added costs. The remaining materials were easily sourced in Khong district, this included steel, aluminum, and stainless-steel mesh. Additionally, SAEDA needed to find a competent fabricator in Khong district. They located three companies who submitted quotations, after vetting each company's experience and ability to work with polycarbonate, one was selected. A cost breakdown of one SCD can be found in figure 6, the total cost of $567.00 USD is slightly higher than the target indicated by Covestro, but this is largely a result of the polycarbonate transportation coats from Vientiane to Khong. A supplier of polycarbonate could drive down the cost by 20%, presenting a more affordable option for smallholder farmers or family owned agri-businesses.

Figure 10: Final Design of SCD in Khong District, Laos

The SCD design process was time-consuming and challenging for SAEDA due to a lack of experience with drying technology and no existing in-country examples in Laos, outside of large solar dryer domes, to draw inspiration from or advice from implementers. In the end, SAEDA based the design largely on the schematics provided by Covestro with a few structural changes. This included a taller overall SCD structure which allowed for easier commodity access by the agri-business, and the inclusion of multiple drying levels to increase capacity. The total fabrication time was 10 working days for three SCD units. SAEDA also faced logistical challenges in delivery due to the remoteness of the agri-businesses and lack of infrastructure. The SCD had to be transported by truck and boat across rough terrain. SCD delivery was completed to each agri-business during the week of February 26th.

Figure 11: SCD delivery in Khong District

As with Agri House, upon delivery a training was provided by SAEDA staff on SCD functionality and use, and the sample collection process for the food quality assessment (described below) which will be conducted in Vientiane. However, the Covestro provided training covering pre-processing based on value chain and SCD best practices did not occur until March 5th. This meant that SAEDA will need to conduct another site visit to perform this training. However, the technology is easy to use, and the agri-business began testing their product upon delivery. During the week of March 4th, samples were collected to deliver to the food quality assessment laboratory in Vientiane. The objective was to receive an initial assessment before the completion of this report. However, as of this writing an analysis has not been received. Furthermore, while the project team was rushing completion to meet this reporting deadline, in hindsight, samples should have been taken after agri-businesses became familiar with the technology and completed multiple drying cycles. As result, an additional round of lab testing may be conducted depending on the results of the first test.

At this point, the SCD units are being used by the agri-businesses and SAEDA is collecting data using the Kobo Tool. As with Agri House, the objective is to complete data collection across three drying cycles. These drying cycles to not have to be consecutive, but must occur over a three-week period.

Description	Unit	#	Unit cost (LAK)	Total Cost (LAK)	SDC Cost (US$)
Steel Box - 25x50	piece	7	135,000	945,000	$ 45.36
Steel Box - 25x25	piece	6	115,000	690,000	$ 33.12
Aluminum Frame	piece	8	250,000	2,000,000	$ 96.00
Steel Mesh	Per M	12	150,000	1,800,000	$ 86.40
Supplies (Screws, welding rods)	Lump Sum	1	250,000	250,000	$ 12.00
Labor	Lump sum	1	2,500,000	2,500,000	$ 120.00
Sending SDC to farmer	Farmer	1	500,000	500,000	$ 24.00
Polycarbonate	Sheet	3	2,480,000	7,440,000	$ 119.00
Polycarbonate Transport: VTE to Khong	Per Sheet	3	666,667	2,000,000	$ 32.00
				Total	**$ 567.00**

Figure 12: Cost Breakdown of SAEDA's SCD Unit

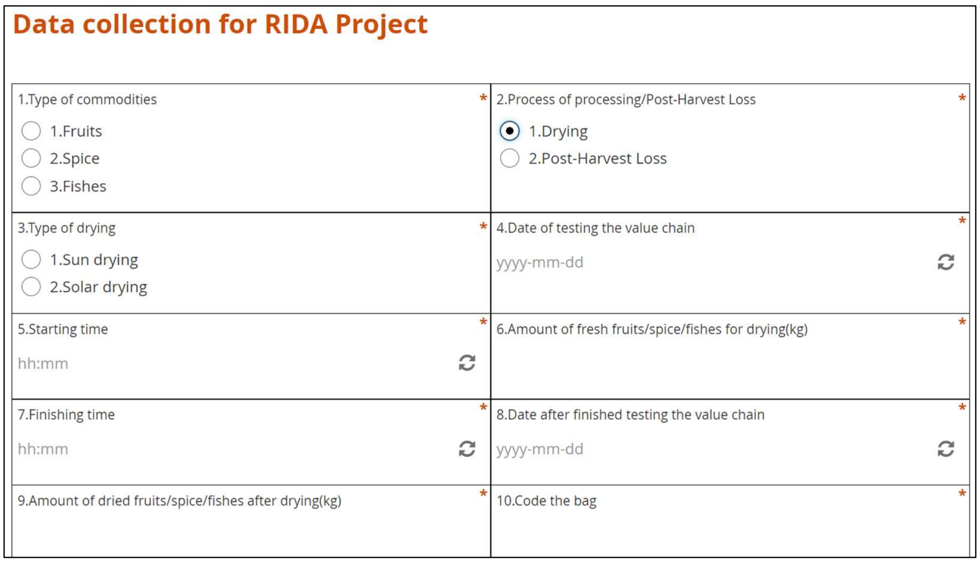
SCD Utilization

On March 5th, Covestro provided a 1.5-hour virtual training to both in-country partners. The objective of the training was to equip field staff with general understanding of SCD functionality and recommended pre-processing steps for each value chain to maximize end results. After the training Covestro provided step-by-step drying processing guides for banana and chili value chains. To date, Covestro does not have a guide for fish drying. This training provides the basis of the information delivered to the agri-processors by each in-country partner's field staff. Each in-country partner then provided basic training to each agri-business on the functionality of the SCD and proper drying techniques based on Covestro's recommendation. In truth, a significant amount of training was not required due to each agri-business's familiarity with drying practices and process. The only significant change was the introduction of the technology.

Figure 13: Screenshot of Training Presentation Delivered by Covestro

SCD Performance Data Collection

PIN's MEAL team developed a data collection tool to analyze the SCD performance. The tool measures key performance indicators of both drying methods (traditional vs solar) to make a comparative analysis; metrics include volume per cycle, drying time per cycle, and volume of waste reduction. Feedback was requested from both in-country partners and the tool was finalized at the end of February. The tool is simple to use for both in-country partners and agri-businesses which should facilitate timely and accurate data collection. For Cambodia a Khmer option exists, allowing for end-users to input the data. However, additional support will be provided by Agri House staff. This is especially needed for the banana processor who can neither read or write. A Laotian language version does not exist, instead SAEDA staff will transcribe data collection through phones calls and then upload results into Kobo. An additional qualitative survey was conducted to better understand agri-business SCD practice and perception of the technology and impact to processing operations. To facilitate data collection, Agri House and SAEDA conducted in-person visits to each agri-business during SCD operations, and PIN MEAL team participated on visits to Cambodian based agri-businesses.



Data collection for RIDA Project

1.Type of commodities * ◯ 1.Fruits ◯ 2.Spice ◯ 3.Fishes	2.Process of processing/Post-Harvest Loss * ◉ 1.Drying ◯ 2.Post-Harvest Loss
3.Type of drying * ◯ 1.Sun drying ◯ 2.Solar drying	4.Date of testing the value chain * yyyy-mm-dd
5.Starting time * hh:mm	6.Amount of fresh fruits/spice/fishes for drying(kg) *
7.Finishing time * hh:mm	8.Date after finished testing the value chain * yyyy-mm-dd
9.Amount of dried fruits/spice/fishes after drying(kg) *	10.Code the bag *

Figure 14: Screenshot of Kobo Data Collection Tool for SCD Performance

Data collection occurred without any major challenges or obstacles. It was easier to conduct oversight and monitoring in Cambodia because PIN's MEAL is located in the country and has vast experience in working within the agricultural sector. PIN has limited experience working in Laos, and SAEDA is a new partner. As a result, data collection was often delayed, additionally, it required more conversation and interaction with the SAEDA team to understand the results, challenges encountered, and any adjustments made.

Food Quality Assessments

Agri House and SAEDA took the necessary step to schedule food quality safety assessments with certified laboratories for each tested commodity. This also includes understanding the necessary collection steps needed to eliminate contamination during the delivery process. In Cambodia, the test was carried out by Institute of Technology of Cambodia located in Phnom Penh, and in Laos the test was performed by the Food Safety Laboratory is housed in the Ministry of Health. The tests provide data on basic physiochemical parameters, such as carbohydrates, sugar, fiber, fat protein and moisture, and basic microbial parameters, including e-coli, mold and yeast and total plate counts. In addition, the data provided on these parameters, a short narrative assessment will also be provided. The objective is to understand if there are food quality improvements associated with enclosed, drying environments. Traditional drying practices expose food to a variety of unhygienic factors including insects, rodents, and inclement weather.

5 Results (Including Clear Demonstration of a Proof of Concept, and (potential) Significance)

The results discussed below are related to the four research questions this project seeks to answer to better understand SCD scalability within small or family-owned agri-processing businesses.

Identification of Agri-Business Characteristics for Success SCD Utilization

The most important characteristic of the agri-businesses for SCD utilization is production cycle volume. Given the size of the intended SCDs, priority was given to agri-businesses with low-volume production cycles who could more appropriately take advantage of the technology. Of the three agri-businesses selected in Cambodia, two (fish & chili) identified volume as a utilization constraint based on the current design. Both processors commented that a larger size would be beneficial in the case of the fish processor his daily volume would necessitate a medium sized SCD, however, for the chili processors, he only requested a slightly larger model. It should also be noted that the Cambodian fish processor tested the SCD with smaller sized fished, which yielded significant results as he was able to double the amount of cycles within the same time frame. For this species of fish, the provided size was more appropriate. In Laos, the accommodation of product cycle size was less of an issue because the argi-processing businesses were generally small in scale than in Cambodia. Additionally, SAEDA's SCD design incorporated multiple drying shelves which allowed for the users to more easily expand or contract cycle size. The second key characteristic which would favour SCD scalability is user desire to improve food quality and hygienic conditions. The Cambodian banana agri-business's main clients are tourists visiting the city, as she is part of a multi-stop tourism package provide by tuk tuk drivers. And because tourist can visibly see the banana drying process, ensuring a hygienic product is critical to maintaining customers and good reviews. Additionally, similarly the Cambodian fish processor also recognized the value of the improved food quality and hygiene which could lead to a reduction of food loss. SCD users in Laos were also quick to point out the cosmetic and product quality improvements when drying in controlled environments. Fish processors noted the impact of insects and the effects of fire drying.

SCD Local Material Sources and Construction

As described extensively above, both in-country partners successfully designed and constructed acceptable SCD units which achieve the desired results during field testing. Below is a description of the results from the process.

Polycarbonate Availability and Cost

Both in-country partners successfully sourced the needed polycarbonate to construct the SCDs, however, it did take considerable effort and supplies were limited. In fact, in Laos support was needed from Covestro to locate a vendor who was located in Vientiane. The polycarbonate had to be transported to Champasak for construction, adding additional costs. In Cambodia, the materials was more easily located; however, it was costly given the small amount purchased.

Availability of Design and Construction Skillset

It did not prove difficult to locate competent fabricators who could design and/or build the SDC units. The design templates and overview training from Covestro proved helpful, and despite polycarbonate being a new material for the fabricators, there were no identified issues encountered during the construction process. It is likely also that build-time will reduce once the fabricator become more familiar and comfortable building the units.

Quality Construction

The quality of construction was adequate, there were no major instances of failure or major testing disruptions as a result of poor construction. It was reported one of the Agri House SCD units experience internal leaking during a heavy rain event, but this is easily fixable with the addition of a different sealing component. There were no reports from Laos users on SCD failure or maintenance issues.

SCD Utilization

Once constructed and delivered. Both in-country partners deliver training on the proper use and functionality of the SCD, and some general guidance on drying process. Given the understand and past experience in drying practice and techniques the agri-businesses did not identify and issues in the use of SDCs or with their incorporation into their operational practices. Additional information regarding this research questions can be derived from the qualitative survey results. Most of the results are positive; however, a few responses were mixed which presents the need for further testing and training.

- All participating agri-businesses stated that the SCD reached the desired internal temperatures to sufficiently dry their commodity.
- All participating agri-businesses stated that there was no additional impact to taste or smell as a result of the use of new materials.
- All participating agri-businesses stated that they experienced no over-heating or malfunctioning in the use of SCDs.
- Half of the participating agri-businesses (all from Laos) noted a change in color or structure in the final product. This could be a result of the design of the Laos SCD unit and further testing and understanding will be necessary.
- All participating agri-businesses noted the reduction of labour required to monitor the drying process and prevent insects from interacting with the commodity.

SCD Performance

PIN's MEAL team collected data from each agri-business for three separate drying cycles. Data was collected across three categories: 1) weight before drying, 2) weight after drying, and 3) drying time for each drying technique open-air sun drying and SCD. Data was collected by the agri-business with in-field support provided by the in-country partner. To compare the SCD results to open sun drying the same volumes of the commodity were used during the testing. Tests were also conducted at the same time to ensure identical climate conditions. Data results were then uploaded to the Kobo tool for analysis. A fourth data point, food quality assessment, performed by a certified lab is also included.

Data Interpretation

Drying Time - Cambodia

Based on the results the open-air sun drying method was more efficient. Over the course of testing each commodity three times, for a total of nine tests the open-air drying method was faster in seven tests, in the other two tests, the drying times were identical. This is a surprising result given PIN's experience in working with medium to large scale solar driers, which typically reduce drying times by 20% – 50%. The main theory for these results is that the design of the SCD did not provide sufficient ventilation to control internal humidity. As a result, moisture levels remained higher for a longer period of time. In an effort to increase airflow, Agri House added a third fan, and based on verbal check-ins, this had a positive impact. However, the addition of the third solar powered fan also occurred during the time period with additional cloud cover and the solar panel was not sufficient to properly run the fan to optimize internal conditions.

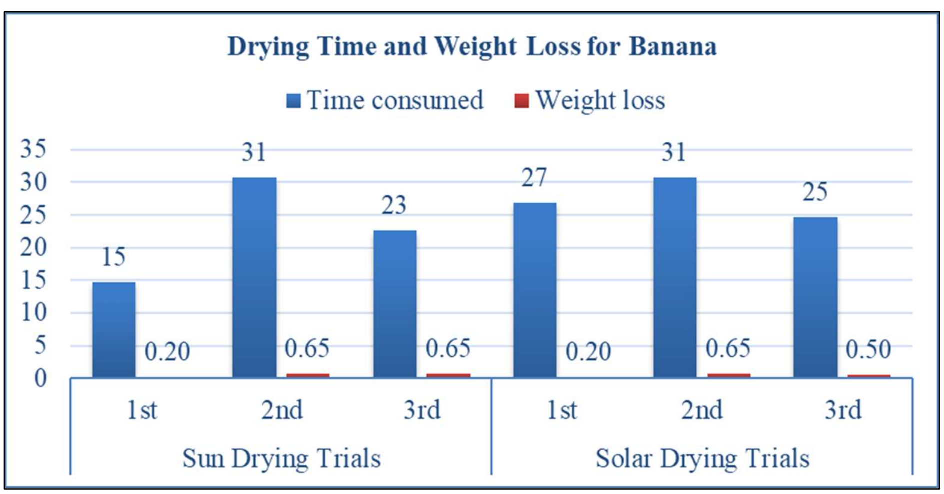


Figure 15: Banana Drying Comparison - Cambodia

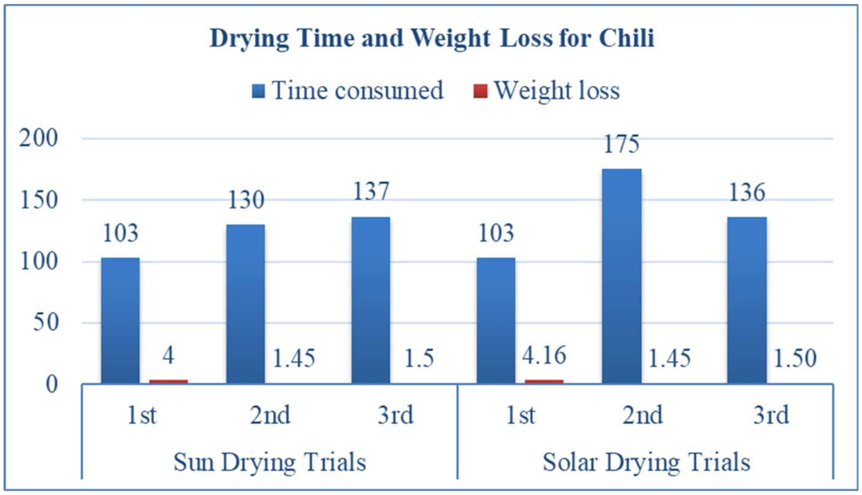


Figure 16: Chili Drying Comparison - Cambodia

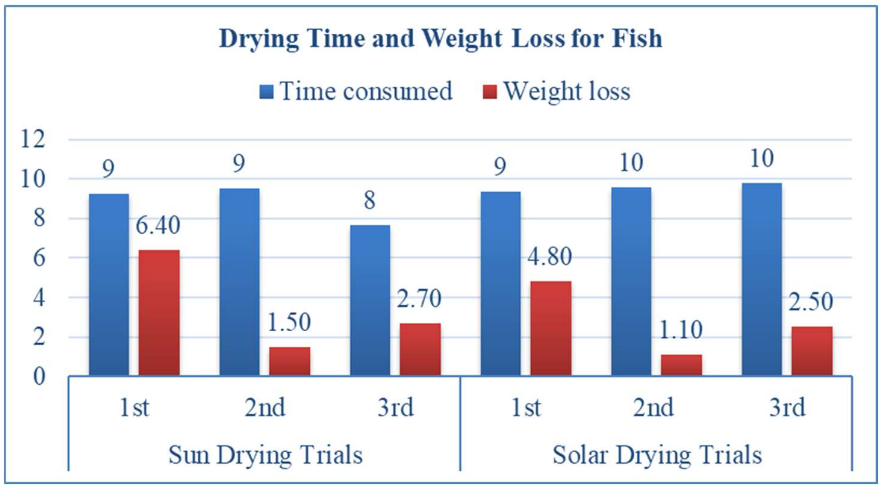


Figure 17: Fish Drying Comparison - Cambodia

*While not included as an official test, the fish processor experimented with smaller fish containing less pre-test moisture and communicated favourable results to PIN’s MEAL team. Typically, these fish also take a full day to dry under the sun, but the SCD was able to dry them in half the amount of time. This would mean the fish processor could double his daily production of this species, adding a significant increase in revenue.

<u>Drying Time – Laos</u>
Drying time results were more positive for the SCD, perhaps indicating that the design provided better airflow and more favourable internal climatic conditions. Of the nine tests of the initial three SCD units, the SCD outperformed the traditional sun-drying method each trial. In fact, significant results were recorded for fish, reducing overall drying time by 2/3rds. Commodity weight loss was also uniform across each trial, which also indicates the SCD unit was performing well and design was consistent with each agri-processor’s need. It’s difficult to know exactly why SAEDA’s design produced better results, but the two significant design differences in SAEDA’s model are the airflow vents and the polycarbonate treys.

SAEDA built an additional three SCD units which were not part of the original design. However, as a result of cost savings, the organization decided to build and test three additional units. These three additional units were delivered to two fish processors and one noodle manufacturer. The unit were installed in early May, and given time constraints, only one testing cycle was completed. Despite this, the result mirror the results of the first three units. Drying times were significantly improved, while the desired moisture content of the final product was reached.

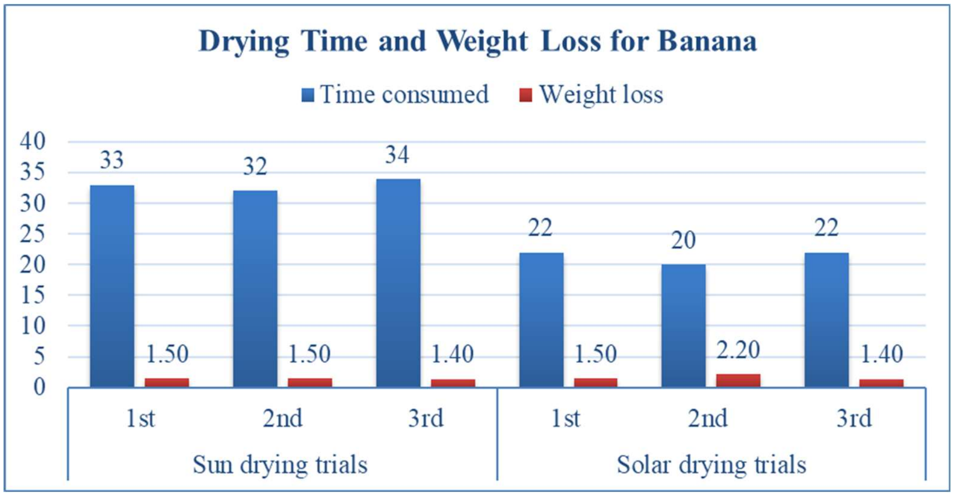


Figure 18: Banana Drying Comparison - Laos

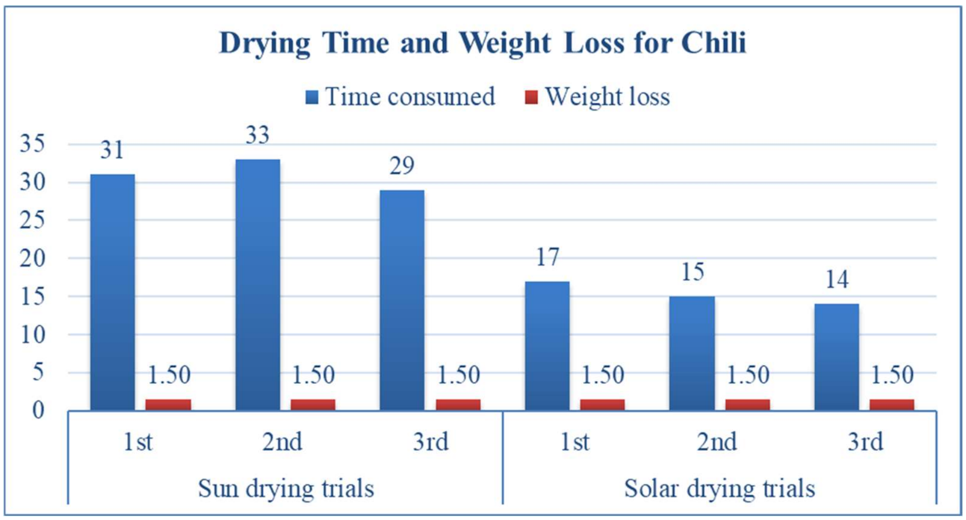


Figure 19: Chili Drying Comparison - Laos

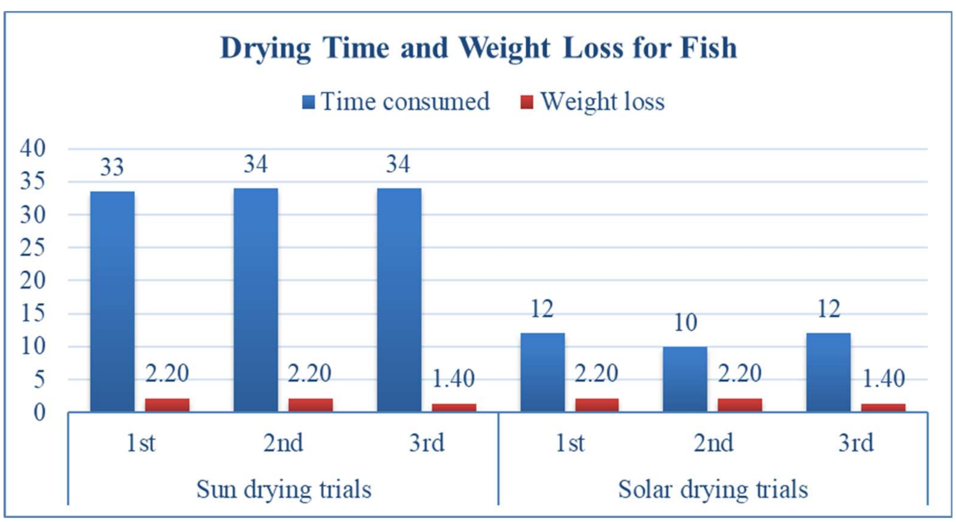


Figure 20: Fish Drying Comparison - Laos

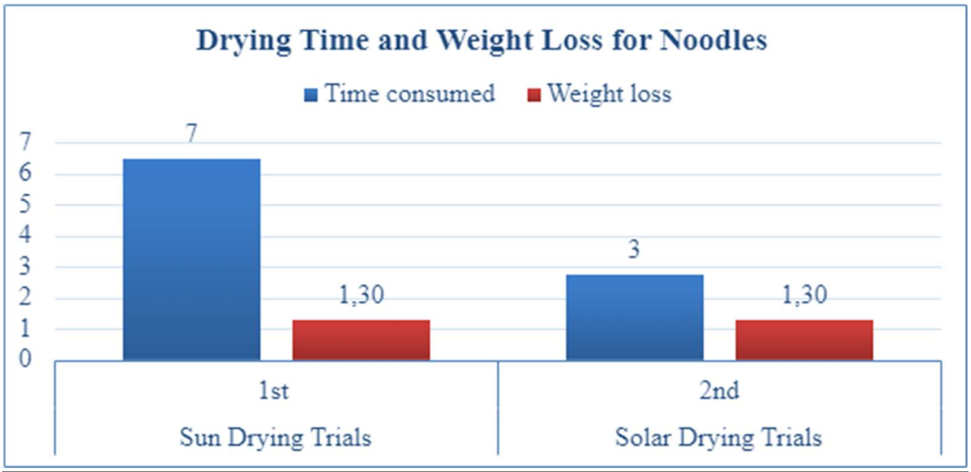


Figure 21: Noodle Drying Comparison - Laos

Commodity Weight Loss – Cambodia & Laos
Generally, SDCs were equivalent with open-air sun drying in achieving the necessary weight loss for each commodity. The only commodity where there was a noticeable difference was with the Cambodian fish processor. There are two reasons for this: 1) the large size of fish pieces which are dried and 2) the lack of airflow which contributed to higher internal humidity rates.

Food Quality Assessments – Cambodia
The laboratory analyses were used to understand SCD impact on food nutrition and microbial contamination. (Testing results are included as additional attachments). More specifically, the nutritional testing parameters include: moisture, protein, total fat, total carbohydrate, total sugar and fiber. The microbial testing parameters include: total bacteria, mold & yeast and coliform.

There were only minor fluctuations within the nutritional testing of all three products which indicates there are no significant impacts, good or bad, on the nutritional composition of the agricultural commodities. There were significant microbial improvements when using the SCD for all three agriculture commodities. This illustrates a significant food quality and hygiene improvement when drying in control, unexposed environments.

Sample Name	Sample Code	Testing Parameter	Result
Dried Slice Banana	Sun Dry	Moisture (1)	6.83%
		Protein (2)	3.35%
		Total Fat (3)	0.50%
		Total Carbohydrate	83.54%
		Total Sugar (4)	14.70%
		Fiber (5)	5.65%
	Solar Dry	Moisture (1)	7.41%
		Protein (2)	3.30%
		Total Fat (3)	0.56%
		Total Carbohydrate	83.50%
		Total Sugar (4)	15.00%
		Fiber (5)	5.63%
Note for Testing Method: (1) Oven; (2) Kjedahl; (3) Soxhlet Extraction; (4) Titration; (5) Extraction.			

Figure 22: Nutritional Testing Results for Banana - Cambodia

Sample Name	Sample Code	Testing Parameter	Result
Dried Slice Banana	Sun Dry	Bacteria (1)	5.1 x 10^5 CFU/g
		Mold and Yeast (1)	2.8 x 10^4 CFU/g
		Total Coliform (1)	3.6 x 10^4 CFU/g
	Solar Dry	Bacteria (1)	7.0 x 10^3 CFU/g
		Mold and Yeast (1)	4.0 x 10^3 CFU/g
		Total Coliform (1)	Not Detected
Note for Testing Method: (1) Standard Spread Method.			

Figure 23: Microbial Results for Banana - Cambodia

Food Quality Assessments – Laos

The testing parameters in Laos were slightly different than in Cambodia, but the same principals were tested. As in Cambodia, the nutritional level testing did not yield significant statistical differences. But, as with Cambodia, there were significant improvements in the microbial levels for products which were dried using the SCDs. Samples for the lab tests for the 2nd set of three SCD units have been delivered to the laboratory but results are not expected until mid-June.

Sample Name	Sample Code	Testing Parameter	Result
Dried Slice Banana	Sun Dry	Moisture	7.63%
		Protein	1.13%
		Total Sugar	33.0 mg/kg
		Total Fat and Oil	4.48%
	Solar Dry	Moisture	6.68%
		Protein	0.06%
		Total Sugar	62.2 mg/kg
		Total Fat and Oil	3.78%

Figure 24: Nutritional Testing Results for Banana - Laos

Sample Name	Sample Code	Testing Parameter	Result
Dried Slice Banana	Sun Dry	Bacteria	9.6 x 10^6 CFU/g
		E.Coli	Not Found
		Yeast and Mold	4.4 x 10^2 CFU/g
	Solar Dry	Bacteria (1)	6.1 x 10^4 CFU/g
		E.Coli	Not Found
		Yeast and Mold	7.0 x 10 CFU/g

Figure 25: Figure 15: Microbial Results for Banana - Laos

6 Scalability and implications at Southeast Asia / ASEAN level

Significant potential exists to scale solar dryers across Cambodia and Laos, and other ASEAN countries where open air drying is a common practice. When interviewing the participants of this project, they quickly identify the challenges faced with this technique – significant waste loss or inability to dry at all during the rainy season or as a result of insect infestation, poor hygienic practices results in reduction of quality, and an increase in drying time during the rainy season and inclement weather. Based on the results of this project, interaction with in-country partners, and interviews with the agri-businesses, the following components are key to achieve scalability for SCDs.

Cost

At project onset, based on information provided by Covestro obtained through similar SCD projects, the price point objective was approximately $500 USD. Agri House's SCD unit cost $668 and SAEDA unit cost was $567. There were three factors that contributed to higher costs, which are largely a result of prototyping through a pilot project, this includes i) lack of bulk purchases, ii) unfamiliar fabrication practices results in an increase in labor costs, iii) availability of polycarbonate in capital cities required additional transportation costs. Reducing unit cost to ensure affordability in rural communities will be necessary to achieve high technology rates. To reduce costs potential distributors will want to purchase polycarbonate in bulk and located a preferred fabricator to optimize build efficiency.

Construction Quality

Generally, construction quality was sufficient as there were no major flaws. However, it was reported that leaking occurred with the Agri House SCD unit during a heavy rain event, and it must also be noted that given the short nature of the pilot project, the long-term durability is unable to be assessed. Quality construction coupled with simple design features which are easily repaired will enable long-term use by agri-businesses. SAEDA's target agri-businesses are located in the Khong district of southern Laos. It is a remote area with little access to advanced technology. Rural agri-processors are a key potential customer segment for SCDs, therefore it is imperative maintenance issues can easily be troubleshooted with locally available resources.

Figure 26: SCD Delivery in Khong District, a rural area in Southern Laos along the Mekong

Unit Modularity

The SCD units prototyped and tested through this pilot project were only fabricated in one size, although the total volume capacities differed between Agri House and SAEDA's final SDC unit. Nor were the units built to accommodate the volume size of the agri-businesses. To increase rates of adoption, a potential future distributor will be best served by offering multiple sized models and/or the ability to customize designed based on agri-business cycle volumes. It was noted by multiple agri-businesses that bigger models would be more desirable.

Food Safety Standards

A clear benefit of SCD technology is the ability to improve food safety, hygiene, and quality. Lab tests across all value chains illustrated microbial improvements. Additionally, all agri-businesses noted the benefits of drying in controlled and closed environments. However, food safety standards and regulations in both Cambodia and Laos are non-existent, particularly in rural area. A significant development to push SCD technology would be the adoption and enforcement of food safety regulations. Furthermore, SCDs can also be instrumental in the ability of agri-exporters to meet food safety standards required from new, high value markets.

Continuation of Climate Change Impacts

Across SE Asia a predicted climate change impact is the increase in prevalence of unpredictable rain events and less predictable wet and dry seasons. The result is more difficult climatic conditions for rural farmers and community or family owned agri-processors to conduct traditional, sun drying methods. Solar conduction dryers are a proven and reliable technology which can mitigate the impacts of climate change impacts on rural farmers and agri-processors. Drying within controlled environments significantly reduces the risk of post-harvest loss through exposure to intense rain events. Additionally, these technologies reduce labor needed to constantly monitor drying product or protect post-harvest product during rain events.

Three key aspects need to be better understood to more fully access the market – which value chains can best utilize solar dryer given characteristics of each commodity, can SCDs be built to meet agri-processor's volume needs, and what is the economic benefit to the agri-processors. This project will provide insight to the first question once additional data is collected. The second question was a concern voiced by the agri-processors at the time of SCD delivery. In the case of the chili and banana processors, a unit only slight bigger will meet their daily drying needs. However, the fish processor would need a commercial collar dryer to accommodate his 100 KG/day volume. The SCD could be built in a manner that maximizes the internal space – for example SAEDA's prototype includes multiple levels of treys, thereby increasing cycle volume. The last question also will be more fully understood once data is collected. Ideally, the SCDs will reduce drying time and increase number of cycles/production, improve quality leading to better prices, and provide storage options through drying which can prevent waste and allow agri-processors to diversify products when prices drop.

The innovation of this product is quite simple which can aid in the technology's scalability, and given that other ASEAN countries may already have more reliable access to polycarbonate, unit costs could be less expensive. Additionally, the technology can be designed in a variety of ways, and through an iterative process that considers each agri-processors' individual needs and target value chain. This can allow for a wide range of variety and customized to address local conditions and agri-processor needs, making the technology easy to replicate across multiple ASEAN countries which rely on open air-drying techniques. Knowledge on how to control airflow and humidity levels can easily be learned and adjusted during the design process.

7 Limitations and Next Steps

The biggest current limitation in Cambodia and Laos is the lack of private sector actors operating as clean energy technology distributors within the agri-fishery sector. In Cambodia, as mentioned above, PIN is working with two start-ups, Harvest the Sun and Kasekor Chhalt, that design, fabricate and sell solar drying technologies to farmers, agri-processors and agriculture cooperatives. Currently these two companies have focused their sales strategies and business development activities on medium- and large-scale solar dryers. Harvest the Sun, during the course of this project, developed a prototype for small-scale agri-processors, but have not embarked on concrete plans to develop a marketing and sales strategy for the unit. Kasekor Chhalt currently has no plan to pursue this segment of the agri-processing market. Given PIN's close relationship with both companies, support will continue to be provided to both start-ups to ensure long-term viability, including the results of this study.

In Laos, the market of clean energy technologies in the agri-fishery sector is considerably less developed. PIN has spent time and resources on the mapping of private sector clean energy entities operating within the country's agri-fishery sector, and no well-established companies could be located, and only a few start-ups and pilot projects could be located. And even for these, limited resources and support were available, nor was any serviceable data available on technology performance or market sizing. Significant effort will be needed to develop Laos' clean energy private sector, including for the development and dissemination of green productive use technologies. In lieu of private sector solutions, the Laotian government and the local and international NGO sector will need to fill the gap.

A second current limitation with SCD dissemination is the lack of knowledge on the technology amongst target end-users and agricultural extension agents within provincial government entities. Additional steps will need to be take to inform and educate key stakeholders who are responsible for driving technologies within agricultural value chains to increase production, reduce operating costs, and enhance climate resiliency. PIN has successful implemented technology awareness raising campaigns with smallholder farmers and agricultural extension agents. These types of events have proven vital to increase knowledge and technology demand, and ultimately support the development of private sector driven approaches to sustainable technology adoption.

An additional project limitation was the inability to develop an evidence-backed Return-on-Investment (RoI) for the SCDs as a result of an insufficient data collection period. More production cycles would be required to accurately develop a trustworthy RoI. In the case of Agri House, significant improvements in their SCD performance would be necessary before attempting an RoI analysis. Potential buyers need to understand the payback period before purchasing the technology. In PIN's experience in promoting productive use technologies to smallholder farmers, a key influence which drives purchases is money saved and long-term economic gains. Furthermore, MFI and rural commercial banks require this information as the basis for the development of appropriate financing products. End-user financing has traditionally been a challenge in supporting technology adoption among rural, smallholder farming communities. While MFIs and commercial banks typically have agri-focused loan products, many smallholder farmers find them inaccessible due to unfavorable terms and requirements. To support broad technology adoption, steps will need to be taken with financial intermediaries to educate them on SCD technologies and their economic impact on agri-businesses. Additional support could be provided to financial intermediaries to develop appropriate loan conditions more favorable to smallholder farmers or family-owned and operated agri-businesses.

Lastly, the short project implementation duration was a limitation on achieving the project objectives. The design and construction of the SCDs was a lengthier process than what was first envisioned. Fabricators lack of experience with the polycarbonate material and design necessitated a longer prototyping process which could enable more SCD unit reiterations. A longer implementation period would have allowed Agri House to conduct a second design capable moderating internal humidity conditions. Additionally, a longer implementation period would have allowed for more drying cycles to collect data to assess SCD performance. Agri-processors completed three drying cycles during which data was collected. A fuller understanding of SCD performance and impact would have been possible if more drying cycles could have been conducted. The additional cycles would also have allowed the agri-businesses to perfect their use and understanding of the technology. While SCDs are simple to use, PIN has found that additional experience allows agri-processors to optimize impact.

In Cambodia, PIN will continue to support Harvest the Sun and Kasekor Chhalt to pursue small-scale SCD technologies as a business line. The results of this project will be shared with both companies as well as agricultural extension agents from the Ministry of Agriculture, Forestry and Fisheries. Additionally, PIN will continue to work within the donor and development communities to promote small-scale SCD technologies as climate resiliency strategies. In Laos, SAEDA will continue to partner with the provincial representatives of the Ministry of Agriculture to promote the technologies. Government partnership is currently the best strategy to support technology adoption within the agriculture sector given the lack of private sector engagement. And, as with Cambodia, SAEDA and PIN will continue to pursue donor funding to further develop SCD technology and private sector entities to support SCD development.