D-Lab I Final Report:

Solar Dehydration Project in Ecuador

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Overview

Because of its geographical location, Ecuador benefits from some of the highest and most consistent levels of solar irradiation on the planet. As a result, there is an enormous potential to capture energy from the sun. The Ecuadorian government and a diverse number of companies have shown special interest in solar energy projects. Kiwa is one of these companies that want to make use of the abundant solar resource in Ecuador.

Currently, Kiwa produces and exports vegetable and plantain chips. They use a frying process to produce the chips. This process is very energy intensive and limits post-harvest life. Kiwa wants to explore ways to harvest solar energy to dehydrate fruit chips to address these problems in a cost-effective manner. In addition, Kiwa seeks to take advantage of its direct relationships with small-scale producers in the region to build a more secure future for the company and support these producers by introducing stable trade relationships.

UC Davis D-Lab has been working with Kiwa to find a solar drying system to produce a line of chips from dehydrated fruit - specifically mango, banana, naranjilla, coconut, and tomate de arbol. By using a drying system instead of frying, Kiwa will be able to increase the product quality and shelf-life. Financial and environmental cost savings also result from reduced fuel (propane gas) consumption.

We have also explored ways to strengthen Kiwa's relationship with small-scale producers in the region.

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Background

Ecuador

Kiwa is located in the province of Calderon, at the north of Quito, Ecuador.

Quito is the capital city of Ecuador. It has an elevation of 9,350 feet (2,800 meters above sea level) and it is located in north-central Ecuador, in the Guayllabamba river basin. With a population of 2,197,698, Quito is the second most populous city in Ecuador after Guayaquil.

Because of its elevation and its proximity to the equator, Quito has a fairly constant cool climate, with spring-like weather year-round. The city experiences only two seasons: dry and wet. The dry season, June through September (4 months) is referred to as summer; the wet season, October through May (8 months), is referred to as winter. Annual precipitation, depending on location, is approximately 1,010 mm (40 in). The solar irradiance in Quito is approximately 5-7 kWh/m2/day.

Over the past decade, Ecuador's national economy has witnessed a steady expansion. To mitigate an economic crisis in the year 2000, Ecuador generated better economic stability by adopting the US dollar as its official currency and creating bi-lateral trade agreements with several countries. Of Ecuador's exports, 37% of its goods are exported to the United States. This economic stability allows for an infrastructure that supports the implementation of innovative development strategies to bolster economic stability among small farmers.

Ecuador has an enormous photovoltaic potential because of its geographical location. However, up to 79% of Ecuador's energy comes from oil. This is one of the reasons why the Ecuadorian Government seeks to diversify the energy sector by implementing photovoltaic projects. It is important to mention that Ecuador is the only country in Latin America that has a Ministry of Renewable Energy. This entity has been dedicated to the support and implementation of ambitious solar power programs. The Ecuadorian Government, through the National Electrification Council (CONELEC), began the construction of 17 new photovoltaic projects in 2011. They are also installing a solar plant that would be considered as one of the largest producers of solar energy in the continent with a capacity of 50 MW. The plant would be installed in Calderon, Quito.

As we can see, there is an eco-friendly energy sector in Ecuador from which a lot of companies like Kiwa could benefit.

Background

Kiwa and Inalproces

Kiwa was launched in 2009 by Inalproces S.A., a snack company in Ecuador that produces and exports vegetable and plantain fried chips. Their production process is based on the following steps:

• Kiwa receives raw material from small farmers of the Pacific Coast and Andean Highlands
• Raw material is examined, weighted, peeled and washed
• Raw material is cooked/fried using propane gas as fuel
• Fat is drained and cooled by fan
• Selection process: only the best chips are selected, rejecting those that are raw, burned or too fatty.
• Storage: The best chips are stored in food grade plastic bags.
• Packaging process: Plastic bags are emptied in a hopper and the product is taken to the packaging machine.

Kiwa has identified several factors that limit the company's ability to expand production. These factors include:

• The company spends about $ 4,000 in propane gas consumption per month.
• Chip production is a labor-intensive process. For certain vegetables, like beetroot,4 full working days (day and night) are required.

Background

New Avenues for Production

Kiwa wants to diversify the brand by creating a new line of chips produced from dehydrated fruits and will be experimenting with mango, banano, naranjilla, coconut, and tomate de arbol. Kiwa would like to add value to the production and growing process by identifying a technology that will:

- Fortify the brand's reputation as an environmentally-conscious producer
- Increase product life via better moisture removal
- Reduce costs (especially in gas)
- Taste great and spur exports
- Strengthening their ability to purchase from small farmers and improve farmer livelihoods

In addition, KIWA wants to examine methods by which they can improve their relationship with small-scale producers to create lasting, transparent relationships that benefit all parties.

Background

Continuing Kiwa's Social Vision

Using KIWA's previous experiences in vegetable chip production as a model, we have identified several significant barriers to the company's goal of building consistent relationships with producers. First, KIWA can buy produce at market prices throughout most of the year without issue, but seasonal demand variations in Ecuador's export-driven fruit market will create difficulties in off seasons as prices rise. By investing in its farmers, Kiwa hopes to establish relationships that guarantee them access to fruit year-round.

Second, production of the identified fruits is located at a wide variety of distances and directions from Kiwa's processing installations. Potential for limited capture of economies of scale is available between a few locations, but sourcing and transport will be a challenge. Distances between the small-farmer production and Kiwa's installations are as follows:

- Mango, 400 km (Guayas)
- Banano, 133 km (Santo Domingo de los Tsachilas)
- Naranjilla, 20-200 km (Chimborazo, Pichincha, Imbabura)
- Tomate de arbol, 135 km (Tungurahua)

Finally, the farmers Kiwa work with inherently face a number of challenges that can generate risk. Most cultivate only a few acres or less and have little capital to invest in their land. Only half of Kiwa's farmers have access to irrigation and farmers seeking to rent tractors must pay the equivalent of 2 days of work for one rental-hour. All harvesting is done by hand. Moreover, farmers are subject to volatile prices for their goods throughout the year. According to a survey conducted by Kiwa, their farmers are interested in increasing production and have an interest in technical assistance services. If coupled with secure trading relationships, an investment form KIWA technologies and training to increase production could help meet the company goal of improving farmer livelihoods and allow significant room for company growth.

This approach has been tried before, but in an unsustainable manner. With funding from USAID, Kiwa launched a program to train and offer extension services to small farmers as a means of increasing productivity. By assisting farmers with methods of production, Kiwa intended to organize an established group of long-term suppliers. Farmers benefited greatly from the project and expressed their appreciation of work "with Kiwa" rather than "for Kiwa."

In the long run, however, Kiwa was unable to continue this program when funding was removed, and many farmers stopped working with the company. Kiwa is now looking for innovative approaches that both foster economic development among farmers and establish sustainable buyer/supplier relationships.

Project Goal

The goal of this project is to find a viable solar drying system to produce dehydrated fruit (mango, banana, naranjilla and tomate de arbol) in the subtropical climate of Ecuador. We seek to expand production capacity at KIWA, lower energy input costs, and increase product life and quality. The establishment of improved technologies will be leveraged by simultaneously advancing relationships with small-scale producers to create a more secure, sustainable future for the company and growers.

Project Objectives

1) Determine feasibility of a solar drying system for a new line of dehydrated fruit production.

2) Strengthen KIWA's relationship with small-scale producers in the region.

Stakeholders

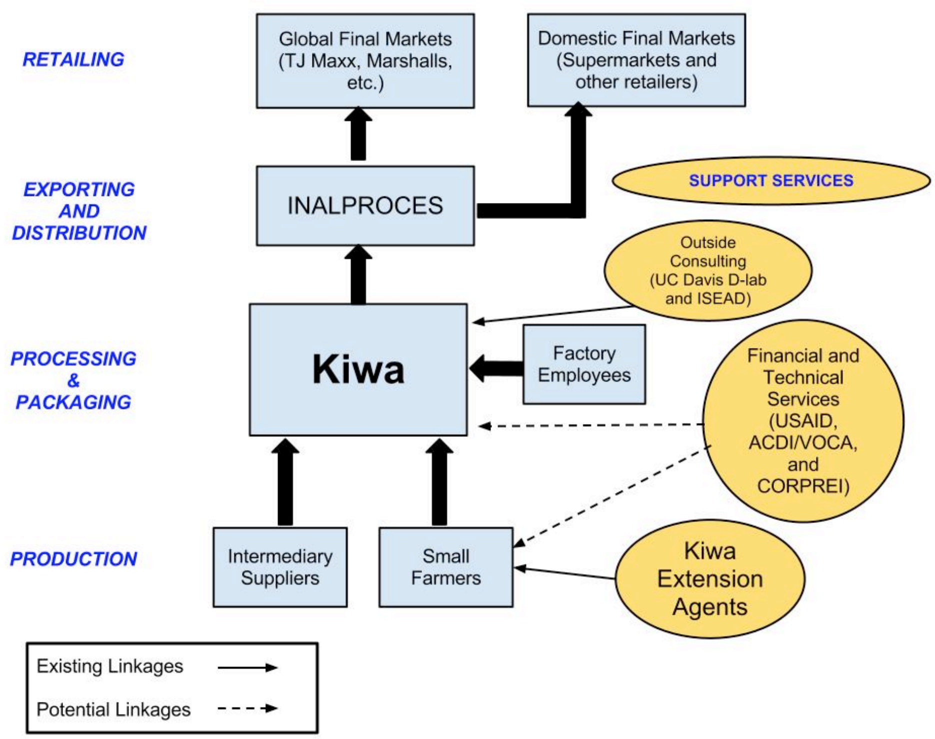
Overview

In researching the project, the team identified several direct and indirect stakeholders. These are groups or organizations that may be affected by the project or may have influence over its success. Stakeholders include:

Direct Stakeholders: Kiwa Company/Inalproces
Small Farmers that produce for Kiwa
UC Davis D-Lab

Indirect Stakeholders: Intermediary Suppliers
Donor and Financing Organizations
Retailers
Kiwa Factory Employees

Below is a table that highlights the current flow of goods and services between stakeholders and notes potential new linkages that may serve this project:



A second stakeholder map and supply-chain diagram can be found in the appendix of the report.

Objective 1

Determine feasibility of a solar drying system for a new line of dehydrated fruit production.

Solar Drying Overview

Normally, issues of solar dehydration are targeted for use by a farmer and his/her family in the developing world. This household is often extremely resource poor and looking to transition from either a total lack of preservation methods or from inefficient, natural sun practices. For cereals and pulses, the natural sun-drying method may be perfectly acceptable, but fruit preservation in this manner meets far higher losses. Over-drying, insufficient drying, contamination, discoloration, and outright loss due to pests are too prevalent in traditional sun drying to be ignored.

We will be devoting zero discussion to natural sun methodology, but some limited discussion to commonly cited, small-scale and off-grid systems. Pragmatically, Kiwa's marketing demands make the use of any low-density set-ups unfeasible. Even in the relatively dense arrangement of a cabinet drier (See Figure 2, below), throughput is not high enough to justify the investment costs. Second, sun-dried products generally don't meet the international quality standards and are therefore not allowed for sale in international markets (Esper and Muhlbauer, 1998). Finally, Kiwa has sufficient access to capital – both financial and social – to skip over this provisional process and implement a more reliable, efficient, and cost-effective technology.

Given these parameters of throughput *and* quality, it may seem unnecessary to discuss the merits and deficiencies of small-scale solar dehydration methods at all. However, we believe the wide-spread adoption rates of these technologies and their potential as illustrative tools justify a brief explanation.

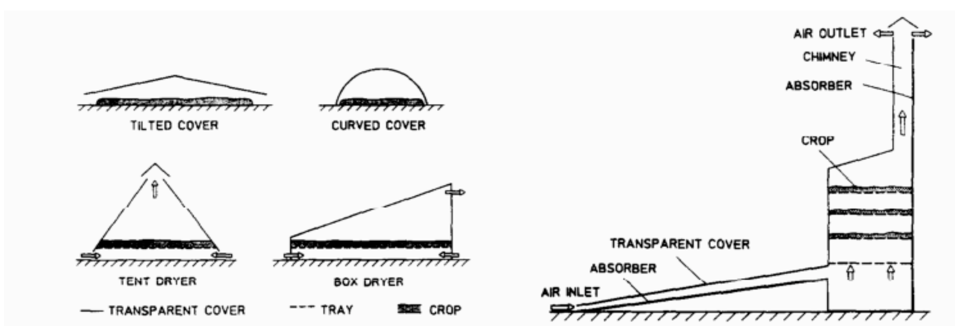


Figure 1. Simple natural convection type dryers **Figure 2.** Solar cabinet dryer

Figures from Esper and Muhlbauer, "Solar Drying – An Effective Means of Food Preservation" (pg 3).

The technologies outlined in Figures 1 and 2 are entirely reliant on environmental thermodynamics – which can be delineated to solar energy and natural convection. For small-scale purposes they can provide a level of production regularity that cannot be achieved by traditional sun-drying. To understand why this is the case requires consideration of the three most important independent variables of solar dehydration technologies (Thompson, 2013):

- Air temperature
- Relative Humidity
- Air Flow

In order to compete with consistent, established, and energy-intensive processing methods such as frying or baking, Kiwa's dehydration process must optimize the three variables above, while simultaneously adding value to the final product via improved flavor and quality.

Objective 1

Parameter 1: *Ideal drying temperatures for KIWA's desired products range from 49 – 60 degrees Celsius (120-140° F)*

Direct drying technologies improve reliability of processing primarily by elevating air temperature within a chamber. Note in Figure 1 that these chambers take many forms, but each has the same purpose of reaching a higher mean temperature within than that of the ambient air outside. They also function by maintaining high temperatures for longer periods over the course of a day.

To define practicable throughput strategies and choose an appropriate technology, we first need to define ideal temperatures for each fruit entering the system. Temperatures that are too high can "cook" the fruit, thereby altering the organoleptic properties (those appealing to senses of smell, taste, etc.), and temperatures that are too low slow processing time and allow for unfavorable enzymatic processes to occur ("rotting"). Table 1, below, outlines idealized temperatures for each product.

Table 1 – Ideal Drying Temperatures for Selected Fruits

	Banana	Tomato Naranjilla	Tomate de Arbol	Mango
Ideal Drying Temperature	60° C (140° F)	60° C (140° F)	60° C (140° F)	49° C (120° C)

Temperature variance in drying systems can be problematic. It is generally stated that a 20°F decline in desired drying temperature will approximately double required drying time for the product (Thompson, 2013). With this in mind, we can see that it will be potentially problematic to attempt to dry mangoes alongside our other products. Iterations of small-scale experimentation will be useful in determining a drying temperature that will optimize simultaneous drying of mangoes and other fruits closer to the norm.

Parameter 2: *Air Flow should be optimized according to energy costs and drying speed.*

Some systems, such as the cabinet depicted in Figure 2, also make use of natural convection to introduce a very low rate of air flow – another of our tell-tale variables for drying rate and reliability. The cabinet technology also provides opportunity to introduce another instructive term, *indirect dehydration* technologies. Indirect technologies operate by raising air temperature within an area adjacent to the chamber holding the produce and then using either natural or forced convection to move the warmed air across the product. Indirect dehydration technologies vary in scale from the cabinet shown in Figure 2 to those that can process 10 metric tons per day.

The generally cited range for air flow optimization is between 500 and 700 feet/min. To produce a speed in this range, electric ventilation fans will need to be introduced.

Objective 1

Parameter 3: *Kiwa wants a dehydration system that can process 1 metric ton/day*

We'll call this parameter *throughput* so as to avoid confusion with the separate parameters of drying rate and physical holding capacity. *Throughput* is a combination of capacity and rate and is therefore dependent on time as well as space. Providing reliable throughput is therefore one of the key parameters KIWA wants to maintain.

The requested rate of throughput in this project has been based on suggestions from Johanna that we use current vegetable chip exports as a target (20 metric tons/month or 800 kg/day) and allow for some scale-up of operations. Desired, marketable output has therefore been defined as 1 metric ton/day of dried fruit.

Objective 1

Parameter 4: *KIWA's dehydration facility will be connected to the electrical grid with steady, reliable access to energy at the industrial usage rate of $0.70/kWh*

Previously, Ecuador has offered preferential rates of $0.44/kWh to users of solar technology, but this policy has since been discontinued. Still, given KIWA's previously verified energy costs of $3,589 per month on natural gas used to heat cooking oil, we believe significant energy cost savings can be found through conversion to a hybrid system utilizing solar, natural gas, and electrical energy. To capture the magnitude of savings available, we can introduce a simple cost equation to our considerations.

Because we are advocating hybrid systems that utilize several types of technologies and energy inputs, our key variables will be:

- Energy costs for each technology involved
- Energy inputs
- Desired through-put
- Cost of fruit
- Cost of Pre-treatment
- Fixed Costs or Capital Costs of technology

This can be mathematically expressed as:

$$\frac{(Cost_{kWh} \times hrs_{dry})}{Weight} \times \frac{(Cost_{kg} \times kgs_{dry})}{Weight} \times \frac{Cost_{fruit} + Cost_{pretreat}}{Weight} = \frac{Cost}{Unit\ Weight}$$

In conjunction with the variable cost function listed above, a total cost function should be provided for each technology examined in D-Lab II. This will include fixed costs or capital costs of the technology. In the short-term, variable costs will be used for comparison against existing, frying technologies, and payback periods will be established for new, solar/hybrid technologies.

A case study utilizing a hybrid greenhouse drier with ample project specifications is outlined below:

$$\frac{(0.7_{kWh} \times 40_{dry})}{1\ mt} \times \frac{(0.114_{kg} \times 7.29_{dry})}{1\ mt} = \frac{Variable\ Energy\ Cost}{Unit\ Weight} = \frac{\$28.83}{1\ mt}$$

$$\frac{\$28.83}{1\ mt} \times \frac{20\ tons}{1\ month} = \frac{\$576.60}{month}$$

Clearly this provides significant savings compared to the frying technology utilized by KIWA and currently costing $3,589/month. The fixed cost for this technology is $20,000 to install. At a monthly energy cost savings of $3,012.40 ($3,589 - $576.60), this equates to a payback period of approximately 8 months at an annual discount rate of 8 percent.

Solar Irradiance in Ecuador

The technologies that D-Lab recommends for KIWA do not specifically utilize photovoltaic technologies to collect energy. Because of KIWA's peri-urban location and on-grid energy capabilities, we have not costed off-grid technologies, such as solar panels, for energy input. However, receiving adequate, consistent energy from the sun is still *the* key consideration for solar dehydration technologies. Therefore, our use of solar irradiance will pertain more specifically to the number and effectiveness of drying hours per day – a practical measure that allows for direct comparison of economic and energy efficiencies with KIWA's current processing system.

Solar irradiance is a measure of solar power on a given unit area. Solar insolation is a measure of how much power is provided at this location for a given time – it is a rate most often written as kWh/m²/day. Generally, KIWA's location on the equator provides great consistency in meteorological conditions including levels of solar irradiance and temperature. The low level of seasonal variance in these two variables, highlighted in Table 1 below, is derived from the low level of variance in day length (<10 minutes annually) and the consistent angle of incidence between the sun and the surface of the earth.

Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Insolation, kWh/m²/day[1]	**3.67**	**3.63**	**3.78**	**3.71**	**3.72**	**3.81**	**3.89**	**3.99**	**3.96**	**3.95**	**3.91**	**3.672**
Temperature, °C[1]	**18.1**	**18.3**	**18.5**	**18.2**	**18**	**17.4**	**17.5**	**18.5**	**19.5**	**19.7**	**18.8**	**18.2**
Relative Humidity (%)[1]	80	81	82	82	80	75	67	65	70	79	79	79
Precipitation, mm[2]	82	132	157	180	118	52	23	32	98	151	132	107
Solar Hours per Day[2]	5.4	5	4.3	4.5	5.3	6.3	7.1	7	6.2	5.4	5.6	5.6

[1]NASA Atmospheric Science Data Center
[2]Climatetemps.com

Objective 2
Strengthen KIWA's relationship with small-scale producers in the region

Farmer Relations Overview

As mentioned above, the second objective is to assist Kiwa in taking advantage of its direct relationship with farmers to implement a program that strengthens the company's relationship with its producers and improves farmer loyalty. Kiwa has made attempts to reach out to farmers in the past. With funding from USAID, Kiwa launched a program to train and offer extension services to small farmers as means of increasing productivity. By assisting farmers with methods of production, Kiwa intended to organize an established group of long-term suppliers. Farmers benefited greatly from the project and expressed their appreciation of work "with Kiwa" rather than "for Kiwa." Additionally, the quality of the goods produced increased. In the long run, however, Kiwa was unable to compete with market prices for raw vegetables during some parts of the year, and, when funding for the project ended, many farmers did not continue to work with the company.

There are two main barriers that inhibit solving this problem. First, Kiwa is unable to compete with intermediary buyers during seasons of the year when demand for produce is high and the costs skyrocket. Second, Kiwa is dealing with farmers of various sizes and socio-economic levels, which means they need an approach that works for all types of farmers, not only a few.

The D-Lab team explored several different pathways for approaching this issue.

Objective 2

Solution 1: *Development of a Cooperative-Style Farmer Association*

The development of a farmers association consisting of agricultural workers that produce only for Kiwa is a method of locking in suppliers and guaranteeing farmers a buyer (Kiwa). Bulk purchasing of expensive inputs, such as seeds and fertilizer, and crop insurance can be centrally coordinated through the farmer association and Kiwa to reduce costs for affiliated members. Moreover, resumed extension service advising and trainings to farmers will increase productivity and farmer buy-in. In this way, when farmers are successful, so is Kiwa.

Farmers are incentivized to subscribe to the farmer association through reduced input costs, contracted purchaser agreements that include yield and quality bonuses, and access to extension services. Kiwa benefits from a guaranteed supply of raw materials for chip making with increased yield and quality associated with improved crop management due to increased access to inputs, reduced perceived risk from a guaranteed buyer, and access to extension services. The most import factor of this solution, however, is that Kiwa must be able to guarantee year-round, competitive prices to farmers. Kiwa will need to offer a price that is the average (or above average) market price for goods throughout the year to attract and maintain suppliers. That way, farmers receive the same (or better) price for their goods throughout the year. Affiliated farmers association benefits and production yield and quality bonuses will support grower recruitment and retention efforts.

Objective 2

Solution 2: *Development of a Kiwa Mobile Phone Advisory Service*

Another solution investigated by the D-Lab team involves developing a mobile phone advisory service infrastructure to enhance Kiwa's connections with its farmers. Due to advances made in information and communications technology, mobile phone services have been made available to people in even the most rural regions of Ecuador. Most of Kiwa's farmers have mobile phones. Utilizing this existing technology, Kiwa can communicate with producers and provide them technical assistance, pricing updates, and information on weather conditions.

If Kiwa were to take advantage of this technology by developing a mobile phone advisory service program, they could increase productivity among farmers and possibly help farmers save money. However, for these improvements to optimally benefit KIWA and the farmers, KIWA will need to take a significant role in system input. Investments of time and money into development of a system that further connects KIWA to its growers instead of supporting further alienation could be sizable. If KIWA is willing to invest in becoming an information and advisory hub this solution would merit further examination.

Recommendations

Objective 1

Due to the need of a large-scale system and the amount of power required to produce air speeds through a large space, electricity will need to be incorporated into dehydrator designs. D-Lab and KIWA will analyze the Ecuadorian energy sector in more detail to determine if electricity costs are anticipated to trend significantly in any direction. Because on-grid electricity is such a significant portion of variable energy costs in the prototypical hybrid system above and because of prior inconsistencies in pricing from the national supplier, we believe this area merits further attention and diligence. Prototyping in D-Lab II will further address needs of the technology regarding air flow.

Data for pricing of pre-treatment options was difficult to locate for a project of similar scale. Pre-treatment is the norm in industrial and domestic fruit-dehydration to promote flavor and induce preservation. We recommend that D-Lab work with KIWA on material sourcing and continue researching cost information for this stage of drying and experiment with options in the approaching 10 weeks.

Because variable energy costs of the solar/hybrid technology are quite low (providing a payback period of eight months), we recommend suspending examination of segregated or stage-by-stage drying at this time pending a closer examination of the supply chain from farm to processing. Instead, we will continue with prototyping of a hybrid technology drier that allows for significant scaling to through-put requirements of one metric ton/day. If upon further evaluation, significant delays or unpredictability within the supply chain become evident, D-Lab recommends that we return to examining segregated drying processes. A D-Lab site visit is required to properly complete this analysis.

Preliminary research outlines clear Returns on Investment (ROI) advantages over the current production system. D-Lab should prototype a hybrid dehydration system to evaluate variables and cost three additional systems in more detail.

Recommendations

Objective 2

To improve farmer relations and secure raw material supplies, the D-Lab team recommends Kiwa initiate the establishment of a contracted farmers' association/cooperative for the reasons listed in the Objective 2, Solution 2 section. Member farmers will be contracted to produce crops as specified by Kiwa, giving Kiwa increased stability and control over their supply chain and farmers increased stability and control over their revenue generation.

Terms will be negotiated and agreed upon prior to planting, with Kiwa guaranteeing to purchase a portion (or all) of the farmer's harvest. This secures raw material supplies for Kiwa and a purchaser for farmers at a previously agreed on price. Kiwa and community farmers will support the establishment of cooperative farmers' association with the provision of joint Kiwa and farmer-funded support services, including discounted inputs (ie. seeds, fertilizer), crop insurance, and technical assistance extension service. Increased farmer membership and buy-in will increase the efficacy of the cooperative. With more farmers involved, per farmer cost rates to fund support services will decrease. Due to the large smallholder farmer population, this arrangement provides the most optimized situation for both Kiwa and local farmers. Smallholder farmers are more vulnerable to risk and more likely to benefit from the described farmers' association benefits. The large number of smallholder farmers will support the viability of a farmers' association. Member-affiliated benefits will improve farmer livelihoods and support retention in the farmers' association, making them less likely to exit the association and leave the afforded opportunity and security provided by the farmers' association. Further resources regarding the establishment of a cooperative can be found in the annotated bibliography and should be examined in detail.

After piloting the technical assistance extension service programs, development of a mobile phone advisory service program could further bolster information access to Kiwa's growers across different regions in Ecuador specializing in production of different crops. D-Lab recommends a follow up feasibility study of the viability, community interest and stakeholders, and community capacity of launching and sustaining a relevant mobile phone program that could be capable of providing technical advice, weather projections, and market data via SMS and text messages. Along with the farmers' association, this service could increase information access relevant to profitable crop production, build local advising and farming capacity, increase Kiwa-farmer engagement and collaboration, and further support the farmers' association structure, network, and community.

Our team proposes to send two D-lab members to Quito to conduct further research on both farmers' association and mobile technology program. The team will develop surveys and interviews to be carried out with Kiwa farmers and identify key indirect stakeholders (representatives from related nonprofits, government agencies, and academic institutions) to meet with and discuss project goals. Additionally, the team would analyze the capacity of Kiwa to maintain a mobile phone advisory service program and work with Kiwa representatives to identify possible sources of funding for the project.

Improving Kiwa's relationship with farmers though these new services would be a long-term project. The first step of the project was researching alternative development schemes for improving farmer livelihoods in collaboration with Kiwa. Our next goal is to carry out our proposed feasibility study. The future of the project has several steps that include: communicating with potential funding organizations and financial service providers, continuing research in the UC Davis D-lab to develop appropriate mobile phone programs and apps, and designing a pilot project to be carried out in Ecuador in the near future.

Annotated Bibliography

Article	
Bal, Lalit M., Santosh Satya, S.N. Naik, and Venkatesh Meda. "Review of Solar Dryers with Latent Heat Storage Systems for Agricultural Products."*Renewable and Sustainable Energy Reviews* 15.1 (2011): 876-80. *ETDEWEB*. Web. 11 Feb. 2013.	*This article offers a review of different types of solar dryers with an emphasis on latent thermal heat. Moreover it has an emphasis on seeking fossil fuel alternatives for food producers in developing countries. The article offers a review of the more technical aspects related to drying system. It concludes that specifically latent thermal heat technology should be considered for its higher level of energy conservation.*
Dissa, A., J. Bathiebo, S. Kam, P. Savadogo, H. Desmorieux, and J. Koulidiati**.** "Modelling and Experimental Validation of Thin Layer Indirect Solar Drying of Mango Slices."*Renewable Energy* 34.4 (2009): 1000-008. *ETDEWEB*. Web. 11 Feb. 2013.	*The authors in this article explain the effectiveness of a specific solar drying model for removing moisture from mangoes. Though it describes the potential impact of increasing production of dried mangoes in Burkina Faso, it applies to the KIWA case since the company is interested in utilizing solar dehydration processes for mangos and tomatoes. The solar dehydrator system they use is similar to the cabinet system we are taking into account for KIWA. They note that with this system Mangos do not reach optimal dryness until after 3 days in the dehydrator.*
Janjai, Serm**.** "A Greenhouse Type Solar Dryer for Small-scale Dried Food Industries: Development and Dissemination." *International Journal of Energy and Environment* 3.3 (2012): 383-98. *ETDWEB*. Web. 11 Feb. 2013.	*This author offers an intensive review of solar drying technology through greenhouses, specifically with small-scale industry in developing countries in mind. The author explains the appropriateness of the greenhouse for the size of small developing businesses. A benefit of this type of system is the amount of fruit that can be dried at once. A drawback is the price of materials to construct it and its reliance on an additional "burner" to help regulate temperature. For KIWA, however, this system could be promising.*
Leon, M Agustus, S. Kumar, and S.C. Bhattacharya. "A Comprehensive Procedure for Performance Evaluation of Solar Food Dryers."*Renewable and Sustainable Energy Review* 6.4 (2002): 367-93. *ETDEWEB*. Web. 11 Feb. 2013.	*This article offers a detailed explanation of the differences between different food dryers that are widely used today. This includes direct, indirect, mixed, forced circulation, cabinet, and tunnel systems. It also proposes its own metrics for testing their effectiveness: time, density, product flavor, etc. With its in depth evaluations of existing systems, we will have a better idea of what type of system to suggest to KIWA – the benefits and the drawbacks.*
Murthy, M.V. Ramana. "A Review of New Technologies, Models and Experimental Investigations of Solar Driers." *Renewable and Sustainable Energy Reviews* 13.4 (2009): 835-44. *ETDEWEB*. Web. 11 Feb. 2013.	*In this article, the authors discuss the costs and benefits associated with cabinet, greenhouse, and forced convection systems. It also places an emphasis on making these systems available to businesses in developing countries. They explain an "Evaporative Capacity" concept that is related to each system's ability to efficiently dry a given fruit, vegetable, or grain in a given climate. They conclude that the type of product being dried should be the driver in choosing a system. This article should help us identify when system is better for KIWA's specific needs.*

Esper, A., and W. Mühlbauer. "Solar drying-An effective means of food preservation." *Renewable Energy* 15.1 (1998): 95-100.

As the title indicates, the focus of this article is on the economic and biophysical justifications for the introduction of solar drying technologies for the purpose of preservation. The authors contend that dehydration and preservation are vital components of mitigating post-harvest losses – an essential third front in the battle for food security, after increased production of goods and limitation of population growth.

Delgado, E., Peralta, J., Barriga, A. "Secadores solares-térmicos para granos y frutas para utilizarlo en zonas remotas." ESPOL Ciencia 2007. 12 Mar.2009

This article is based on worked realized by Ecuadorian researchers, which are part of the Escuela Superior Politécnica del Litoral (ESPOL), located in Guayaquil-Ecuador. The main objectives of this article are to show the advantages of using solar energy in food dehydrators systems; and to expose a solar dryer prototype that could be use in areas of Ecuador to dehydrated fruits and grains.

Gamaliel, Moreno M. "Manual de construcción y operación de una secadora solar." 7 Feb. 2013 <http://www.actuar-acd.org/.../manual_secadora_solar.pdf>.

This article explains the general characteristics of some of the most common types of dehydrators. It describes the components of a solar dehydrator, the air circulation methods that can be used (forced circulation, circulation natural convection), as well as the different types of solar dehydrators that exist (direct, indirect and mixed). It also explains how to operate these dehydrators (drying in batches, continuous drying) according to production capacity. It is important to understand this distinction to know what type of solar dehydrator is more suited for a specific production capacity.

United States Department of Agriculture. "How to Start a Cooperative." 1996. <http://www.rurdev.usda.gov/supportdocuments/cir7.pdf>.

A manual provided by the United States Department of Agriculture on starting cooperatives. This resource is highly recommended for KIWA's further evaluation.

Other Sources

Interview with Jim S. Thompson
March 7, 2013
Interview addressing general dehydration technologies and assessing feasibility of proposed models for KIWA.

http://www.saecsasolar.com/deshidratador/
This is a Mexican solar energy company that designs industrial scale solar ovens and dehydrators. Their system was utilized in a similar case study in Guatemala, mentioned below.

http://www.cona.at/index.php?id=17&L=2
CONA is an Austrian nonprofit that connects developing regions with sustainable technologies. We are using their case study in Guatemala as an example since its situation is comparable to that of KIWA.

"Technical manual on small-scale processing of fruits and vegetables." FAO Regional Office for Latin America and the Caribbean. http://www.fao.org/docrep/x0209e/x0209e06.htm
This FAO handbook will offer additional insight on drying methods and requirements of different fruits and vegetables.

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Appendix

Stakeholder Map