FINDINGS FROM TESTING THREE DRYING METHODS IN LAST MILE SETTINGS

KOPERNIK

TABLE OF CONTENTS

INTRODUCTION

As Indonesia seeks to increase the value of its agricultural industry, solar drying is one avenue in which the potential to add value is enormous. In 2017, Kopernik published an insight which estimated that inefficient drying caused losses amounting to almost US$3 billion a year across 10 commodities in Indonesia.

Although drying a commodity can increase its selling price significantly, the decision on whether to dry is complex. In the Unmet Needs Report, published in 2016, Kopernik stated: “Even if the economic benefit of drying is clear, farmers may still choose to sell their commodities raw because they need cash immediately, do not want to bother with the effort of drying, face challenging or uncertain weather conditions, and/or do not have access to buyers who would buy the crop in its dried form.”

Most smallholder farmers who do dry their harvest, as opposed to selling it raw, do so by laying the commodity out under the sun, which is a time-consuming and labor-intensive process and has the potential for contamination. While solar drying technology could alleviate these problems, there are essentially no commercial dryers available in Indonesia which are affordable and whose capacities make sense for smallholder farmers. In response to a clear need for locally available dryers with costs and capacities aligned with the need of farmers, Kopernik designed and built three solar dryers from materials found locally in Bali and East Nusa Tenggara.

These dryers were then tested with three commodities, cacao, cashews and copra, in a series of five experimentation projects. This report reviews the potential economic benefits of solar drying technology in order to better understand how these benefits might materialize on the micro level for an individual farmer.

While the benefits are specific to the situations of Kopernik’s local partners, benefits for other farmers can be calculated in the same manner. It is also important to note that this report focuses solely on an economic analysis. Further research is needed on behavioral change, barriers to dryer adoption and individual behavior in a cooperative setting in order to fully realize a solar dryer’s benefits.

COMMODITIES

» CACAO

Cacao Overview

Cacao beans, the seed of the cacao tree, are the main ingredient in chocolate and can also be used to create cacao butter (common in cosmetic products), cacao powder and animal feed. Indonesia produces more than seven hundred thousand tons of cacao beans a year from 1.7 million hectares of planted area[1], which places it third in the world for cacao production.[2] The majority of cacao in Indonesia is grown by smallholder farmers, many of whom participate in agricultural cooperatives called *Unit Pengolahan Hasil* (UPH), coordinating their work across each other's fields.

In Bali, demand for cacao beans is driven in part by the growth of the gourmet chocolate industry on the island. Globally, cacao prices have been volatile over the past few years due to concerns about excess supply and higher prices set for chocolate, which has in turn reduced the demand for cacao.[3] However, in Asia demand for chocolate is expected to outpace global growth.[4]

To dry cacao beans, farmers in Bali typically lay them flat on the ground outside until the moisture content reaches seven percent, a time-consuming process. Bali's weather is unpredictable and rain can cause problems even during the dry season.

Kopernik's research for its Unmet Needs Report found that Grainpro's Solar Bubble Dryer was one of the only dryers that claimed to be appropriate for drying cacao. Furthermore it was the only dryer whose capacity was reasonable for smallholder farmers. However, the Solar Bubble Dryer is extremely expensive for smallholders and as there are no distributors in Indonesia, its shipping cost from the Philippines is significant. Recognizing the need for a dryer to be available locally, Kopernik built a solar dryer, the "K Cacao Dryer" from locally available materials. Over a series of three experiments in Angkah Village, Tabanan Regency, the K Cacao Dryer's performance was tested against the Solar Bubble Dryer and the traditional method of ground drying.

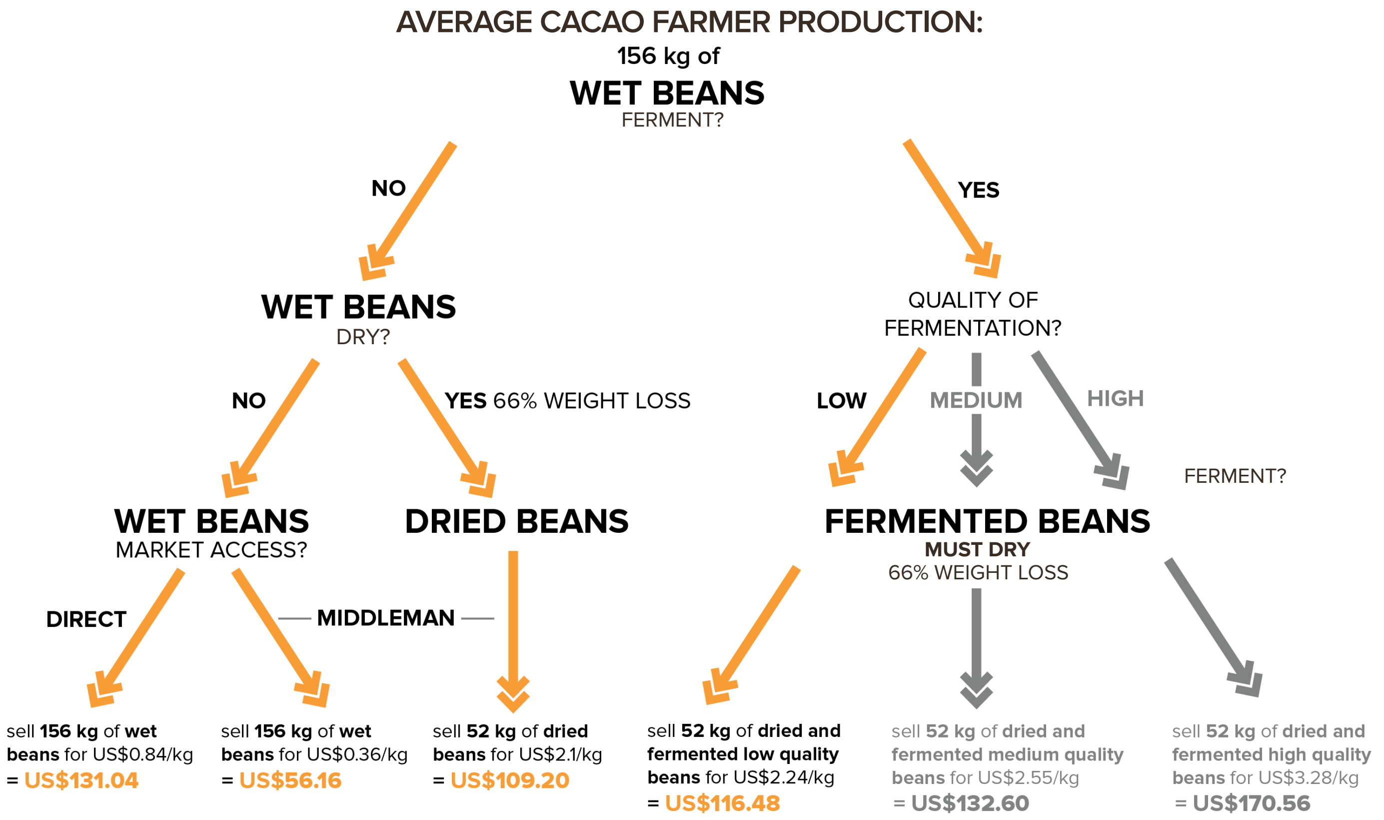
Key Findings

- **Market access is equally as important, if not more important than drying technology in determining cacao farmers' incomes.**
- **Kopernik was able to design and build a dryer that has the potential to increase cacao farmers' incomes by US$84.81 a year, which is more than double what they previously earned from selling their cacao.**

[1] Unmet Needs Report
[2] *Cocoa production by country 2016/2017. (n.d.).* Retrieved from https://www.statista.com/statistics/263855/cocoa-bean-production-worldwide-by-region/
[3] Terazono, E. (2017, October 04). *Asian chocolate demand set to outstrip global growth.* Retrieved from https://www.ft.com/content/3cb2e488-a8f8-11e7-ab55-27219df83c97
[4] *Ibid.*

Process

Drying is only one of several factors that affect a farmer's ultimate income from cacao beans. Fermenting beans can potentially increase the cacao bean's quality and the price it is sold at, but it requires agricultural training to ensure that the process is done correctly. Income is also affected by market access, as middlemen will typically offer prices lower than direct buyers. Additionally, drying entails weight loss which must be offset by a higher increase in price if farmers are to earn more money from drying. The factors, as they apply to farmers in Tabanan, are mapped below:



Based on the average production of a farmer in Angkah Village (156 kg), the most lucrative option is to reach high quality fermented and dried beans. However, most farmers in Tabanan do not have the agricultural knowledge needed to consistently obtain such quality in their beans, making this scenario extremely unlikely.

The next most lucrative scenario is to sell raw beans directly to a chocolate factory or other value-added cacao processor, which would make drying and fermentation technology redundant. Selling raw beans directly would ultimately earn a farmer more money than selling any kind of dried beans, outside of the highest quality, because the higher price for dried beans is completely offset by the weight lost in the drying process. This option too, however, is unlikely as most farmers lack direct connections to buyers from chocolate factories.[5]

The most likely situation therefore is for small-holder farmers to produce low-quality fermented beans which they are only able to sell to middle-men. Cacao farmers in Bali therefore face two decisions, whether to ferment and whether to dry as compared to selling raw beans to a middleman.

[5] However, Kopernik's conversations with a chocolate factory owner revealed that some factories would prefer to buy raw beans and complete the drying and fermenting processes themselves, as farmers are often unaware of the chocolate factory's standards for fermenting and drying.

Technology: Dryer

TRADITIONAL METHOD

CAPACITY N/A

DIMENSIONS N/A

MATERIALS concrete floor

COST N/A

K CACAO DRYER

CAPACITY 500 kg

DIMENSIONS 4 m x 2.5 m x 1 m

MATERIALS poly-carbonate plastic sheet, timber, concrete, wire mesh, exhaust fan

COST US$1,350

SOLAR BUBBLE DRYER[6]

CAPACITY 1000 kg

DIMENSIONS 26 m x 2 m

MATERIALS LPDE cover, PVC, exhaust fan

COST US$2,860

The K Cacao Dryer used in phase one of this project was originally designed by Kopernik's local partner in Tabanan. In the results for the first phase of testing, this dryer had problems with air circulation causing the humidity levels inside the dryer to be too high and the dryer to perform ineffectively. In phase two, Kopernik added an exhaust fan and changed the roof material to improve air circulation and performance. This report focuses on the dryer and results from the project's second phase.

[6] Manufactured by GrainPro; studied in Kopernik's previous Unmet Needs Report

Technology: Fermentation Box

For the cacao drying experiments, Kopernik built a three-tiered fermentation box. Fermenting beans, which occurs before drying, increases quality and price, but the exact mechanisms by which high quality beans can be obtained are often unknown to smallholder farmers. The farmer that Kopernik worked with fermented his beans, although most farmers in Tabanan do not.

All beans tested in the experiments were fermented for five days (120 hours) inside the box. Fermentation was not expected to be the focus of the experiments.

FERMENTATION BOX	
CAPACITY	150 kg
COST	US$263.15

Dryer Performance

Based on Kopernik's experiments, the following estimates were obtained for drying and fermenting time with the drying technologies[7]:

	DRYING METHOD		
	TRADITIONAL METHOD	K CACAO DRYER	SOLAR BUBBLE DRYER
Time - drying (days)	5.92	3.17	2.75
Time - fermenting (days)	5	5	5
Total time (days)	**10.92**	**8.17**	**7.75**

For all drying methods, Kopernik was only able to obtain low quality fermented and dried beans, which could be sold at a maximum price of US$2.36/kg. A farmer's production over one year can be modeled in the following tables, with annual production split between rainy and dry season:

CACAO PRODUCTION DURING DRY SEASON			
	TRADITIONAL METHOD	K CACAO DRYER	SOLAR BUBBLE DRYER
Weight (kg)	78	78	78
Weight after drying (kg)	26	26	26
Time - drying (days)	5.92	3.17	2.75
Price	US$2.36/kg	US$2.36/kg	US$2.36/kg
Revenue	US$61.36	US$61.36	US$61.36
Operating cost of drying[8]	US$10	US$0	US$0
Income	US$51.36	US$61.36	US$51.36

CACAO PRODUCTION DURING RAINY SEASON			
	TRADITIONAL METHOD	K CACAO DRYER	SOLAR BUBBLE DRYER
Weight (kg)	78	78	78
Weight after drying (kg)	N/A	26	26
Time - drying (days)[9]	N/A	3.17	2.75
Price	US$0.37/kg [10]	US$2.36/kg	US$2.36/kg
Revenue	US$28.55	US$61.36	US$61.36
Operating cost of drying	N/A	US$0	US$0
Income	US$28.55	US$61.36	US$61.36

[7] These times are estimated according to each drying technology's best possible performance. For more information on how they were calculated, please see Appendix A.
[8] This excludes labor. Less time working in and of itself will not result in more income for the farmer unless he completes other activities with his time, which will be discussed later in the report.
[9] Kopernik did not test the dryers during the rainy season, so this assumes that time to dry and ferment would be the same in the dry season as the rainy season.
[10] The price earned by raw cacao beans sold to middlemen.

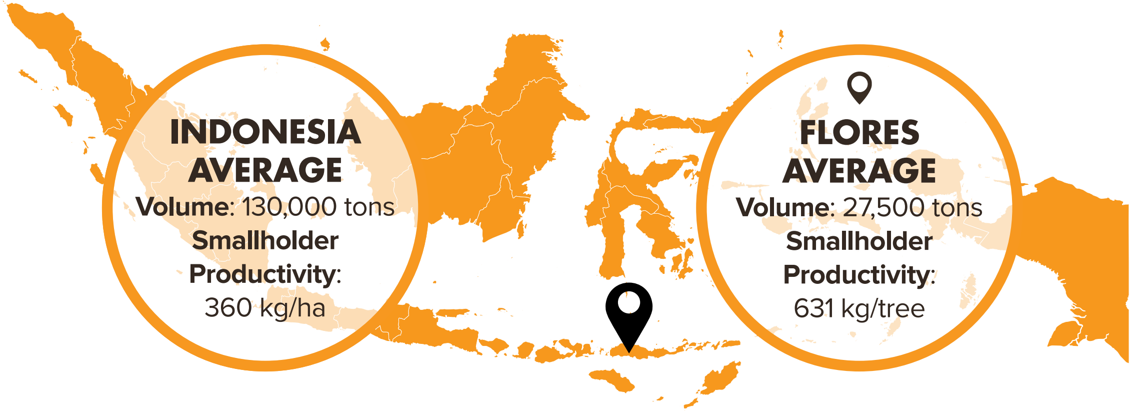
» CASHEW

Cashew Overview

Cashews are the nut or seed joined to cashew apples and grow easily on trees in tropical areas. While usually consumed on their own, cashews and their shells can also be processed into a wide variety of products, including cashew butter, cashew cheese, waterproofing materials and medical treatments. Indonesia is the world's ninth largest producer of cashews and second in Southeast Asia after Vietnam.[11] About 130,000 tons a year are cultivated in Indonesia, a volume which has essentially doubled in the last twenty years, with the majority grown by smallholder farmers.[12] The majority of production is concentrated in Sulawesi, but other islands in the eastern half of the country, where the dry season is long and rain is limited also produce significant amounts of cashews, including East Java, Bali and West and East Nusa Tenggara.[13]

Producing cashews as consumers know them (also termed white cashews) is a time and labor-intensive process. In addition to drying, there are several processing steps for removing the fruit, shell and skin from the cashew nut that must occur before the nut can be sold to consumers. Drying is divided into three stages, but only the first stage of drying can be accomplished using the traditional method of laying cashews out under the sun. Farmers who do not have access to other drying equipment must sell their cashews to a middleman/upstream processor after the first stage and miss out on the increased economic benefits from further processing.

Kopernik experimented with cashews in two of its dryer designs. The K-Dryer 1 was tested on Adonara Island in Pajinian Village and the K Dryer 2 on Flores Island in Ile Padung Village. On Adonara Island, through Kopernik's Increasing Farmer Incomes: Solar Drying Solutions Phase One project, it was expected that the K Dryer 1 would reduce the drying time when compared to traditional drying processes and would potentially facilitate the later stages of drying. In Ile Padung, Kopernik conducted the Increasing Farmer Incomes: Solar Drying Solutions Phase Two project by working with the Punaliput Co-operative. This co-operative requested a Kopernik-designed solar dryer after seeing our model on Adonara Island. Kopernik improved the K Dryer 1's design to create the K Dryer 2 and wrote a User Manual so others could build a similar product. In this experiment, Kopernik also sought to collect more data on the effectiveness of the dryer, particularly when comparing it to another drying alternative, the electric oven.



Sources: FAOSTAT, Statistik Perkebunan Indonesia

Key Findings

- **The K Dryer 1 has the potential to increase cashew farmer incomes by up to US$266.08 per year, which is double the average annual income in East Nusa Tenggara.**

- **The K Dryer 2 can save a co-operative US$75.36 per year in electricity costs by providing an alternative to an electric oven for one stage of the drying process.**

[11] FAOSTAT
[12] *Ibid.*
[13] Daras, U. (n.d.). *Integrated production practices of cashews in Indonesia*. Retrieved from FAO

Process

The following cashew production description is based on the processes that Kopernik observed in East Nusa Tenggara. It may differ with cashew production in other locations.

STAGE ONE

PROCESSING STEP

Removing the cashew nut from the apple

INPUTS Labor (removal of cashew fruit is done by hand)

DRYING STEP

Drying to remove oil from the shell[14]

MOISTURE LEVEL REQUIRED 20%
TIME - DRYING 3-4 days (dry season)

WEIGHT LOSS: ≈70%[15]
END PRODUCT: shell cashew
TYPICAL ACTOR: smallholder farmers
PRICE: US$1.40/kg

STAGE TWO

PROCESSING STEP

Removing the cashew from the shell

INPUTS Labor (one person can remove shells from about 20 kg of nuts a day), *kacip* (traditional tool to open cashews, cost: US$20)

DRYING STEP

Drying to loosen the skin from the cashew

MOISTURE LEVEL REQUIRED 10-15%
TIME - DRYING 12 hours

WEIGHT LOSS: ≈80% (from stage 1)
END PRODUCT: soft skin cashew
TYPICAL ACTOR: cooperatives
PRICE: US$7/kg

STAGE THREE

PROCESSING STEP

Removing the skin from the cashew

INPUTS Labor (skin is removed by rubbing by hand or brush; one person can remove the skin from about 10-12 kg of white cashews a day)[16]

DRYING STEP

Drying to reduce the moisture level for consumption[17]

MOISTURE LEVEL REQUIRED <5%
TIME - DRYING 12 hours

WEIGHT LOSS: ≈8% (from stage 2)
END PRODUCT: white cashew
TYPICAL ACTOR: cooperatives
PRICE: US$13/kg

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[14] This shell oil is caustic so it must be dried to be able to safely remove the shell. Hand shelling is impossible if the oil has not been removed beforehand.
[15] Jain, S. M., & Priyadarshan, P. M. (Eds.). (2010). *Breeding plantation tree crops: Tropical species. New York, NY: Springer-Verlag New York.*
[16] Patil, P. J. (2017). *Indian Cashew Food. Integrative Food, Nutrition and Metabolism.* DOI: 10.15761/IFNM.1000173
[17] Mohod, A., Jain, S., & A.G., P. (2011). *Cashew Nut Processing: Sources of Environmental Pollution and Standards. BIOINFO Environment and Pollution*, 1(1), 5-11. Retrieved from http://www.environmentportal.in/files/file/cashew-nut.pdf

Process: Calendar of Harvest

Cashew harvest occurs continuously from August to December and prices for shell cashews vary throughout this time period. Prices are highest in the beginning of harvest season, at around US$1.75/kg (IDR25,000/kg) but drop significantly as the harvest season ends (and supply grows) to around US$0.55/kg (IDR7,500/kg).

Rainy season in East Nusa Tenggara starts around November meaning that any shell cashews harvested after this time or still undried at this time cannot be dried outside. Since there is no market for undried shell cashews, the remaining harvest must be dried indoors, which is a lengthy process taking 10 days or more to reach the necessary moisture level. The resulting dried shell cashews are usually of poor quality and command a low price, usually around US$0.37/kg (IDR5,000 /kg).[18] If, during the rainy season, farmers were able to dry cashews with the typical quality achieved during dry season, then the price earned per kilogram of normal quality cashews is US$1.27/kg (IDR 17,500/kg), due to the low supply of quality cashews dried during this time.

Kopernik estimates that a typical farmer in Pajinian Village, Adonara dries one quarter of his cashews in August and earns the highest price, another quarter in November which earns a lower price and the other half in the rainy season, which earns the lowest price.

	TIME OF DRYING & SALE		
	AUGUST	NOVEMBER	RAINY SEASON
VOLUME OF SHELL CASHEWS (BEFORE DRYING)	100 kg	100 kg	200 kg
PRICE FOR SHELL CASHEWS (AFTER DRYING)	US$1.75/kg	US$0.55/kg	US$0.37/kg (poor quality) US$1.27/kg (normal quality)

[18] Because prices for dried shell cashews go down throughout the dry season, the ability to dry more quickly means that farmers can sell earlier and probably earn a higher price. However, it is difficult to put a numerical amount on this benefit, but it is an added benefit of solar drying -- greater responsiveness to market changes.

Technology

TRADITIONAL METHOD

CAPACITY N/A

DIMENSIONS N/A

MATERIALS concrete floor

COST N/A

K DRYER 1

CAPACITY 1000 kg (for cashews)[19]

DIMENSIONS 6 m x 2 m x 2 m

MATERIALS polycarbonate plastic sheet, L beam, iron sheet, aluminum net, solar panels

COST US$2,580

K DRYER 2

CAPACITY 300 kg

DIMENSIONS 2 m x 2 m x 2 m

MATERIALS polycarbonate plastic sheet, timber , iron sheet, fish net, gravel

COST US$1,291.5

The K Dryer 1 was used in conjunction with a smallholder farmer to test its effectiveness on the first stage of drying in comparison to traditional methods, while the K Dryer 2 was used with a co-operative to test its effectiveness on the second stage of drying in comparison to an electric oven.

The major difference between the two dryer designs is the capacity. The K Dryer 1 is much larger than the K Dryer 2. Additionally, the K Dryer 2 did not use solar panels or a fan which significantly reduced its cost and made it more affordable for typical farmers in East Nusa Tenggara. Instead, the floor design was modified to increase air flow and gravel was added to its base to further trap heat and increase the temperature.

[19] The capacity is 700 kg for copra.

K Dryer 1: Performance

In phase one, Kopernik tested the K Dryer 1's performance on drying cashews through the first stage of drying and processing. The following results were obtained from this experiment:

DRYING METHOD		
	TRADITIONAL METHOD	K DRYER 1
Time - drying in dry season (days)	4	2
Time - drying in rainy season (days)	not possible	5

The following table models a farmer's cashew production year round:

	AUGUST		NOVEMBER		RAINY SEASON	
	TRADITIONAL METHOD	K DRYER 1	TRADITIONAL METHOD	K DRYER 1	TRADITIONAL METHOD	K DRYER 1
Weight (kg)	100	100	100	100	200	200
Weight after drying (kg)	93.5	93.5	93.5	93.5	187	187
Time - drying (days)	4	2	4	2	10	5
Price	US$1.75/kg	US$1.75/kg	US$0.55/kg	US$0.55/kg	US$.37/kg	US$1.27/kg[22]
Revenue	US$130.9	US$130.9	US$51.43	US$51.43	US$69.19	US$237.49
Operating cost of drying	US$10[20]	US$0	US$0[21]	US$0	US$0[23]	US$0
Income	US$120.9	US$130.9	US$51.43	US$51.43	US$69.19	US$237.49

[20] The US$10 cost comes from a fork-like tool to flip cashews to encourage even drying, which is not required by the K Dryer 1.
[21] Tool is still used, but is only purchased once (in August).
[22] The K Dryer 1 is likely to achieve a higher quality and thus earn a higher price for the cashews.
[23] Again, the tool to flip the cashews is still required but the cost is incurred just once.

K Dryer 2: Performance

In phase two, Kopernik worked with a cooperative in Ile Padung which bought undried with skin on cashews (shell removed) and then completed stage two and three drying for them. For this experiment, Kopernik tested the K Dryer 2's performance on drying 40 kg cashews through the second stage of drying as compared to using an electric oven. The following results were obtained from this experiment:

	DRYING METHOD	
	ELECTRIC OVEN	K DRYER 2
Time - drying in dry season (hours)	12	5
Time - drying in rainy season (hours)	12	8[24]
Moisture level reached	10%	14.62%[25]

The cooperative processes approximately one ton (907 kg) of undried soft skin cashews from September to December. Rainy season begins in December, meaning about one quarter of drying and processing occurs then. The following tables model the cooperative's yearly cashew processing for the second stage during the dry and rainy seasons:

CASHEW PRODUCTION DURING DRY SEASON		
	ELECTRIC OVEN	K DRYER 2
Weight (kg)	680	680
Weight after drying (kg)[26]	637	637
Drying capacity (kg)	40	300
Time - drying (hours)	2040	15
Price	US$7/kg	US$7/kg
Revenue	US$4,460	US$4,460
Operating cost of drying[8]	US$56.52	US$0
Income	US$4,403.48	US$4,460

CASHEW PRODUCTION DURING RAINY SEASON		
	ELECTRIC OVEN	K DRYER 2
Weight (kg)	227	227
Weight after drying (kg)	194	194
Drying capacity (kg)	40	300
Time - drying (hours)	72	8
Price	US$7/kg	US$7/kg
Revenue	US$1,358	US$1,358
Operating cost of drying[8]	US$18.84	US$0
Income	US$1,339.16	US$1,358

[24] In the peak of rainy season, the K Dryer 2 can take up to four days to reach the stage two desired moisture level.
[25] Although the moisture level reached by the K Dryer 2 is different from that reached by the electric oven, it is still within the typical range needed for stage two drying (see page 14). While the higher moisture level for the K Dryer 2 means a smaller weight loss, this ultimately makes no difference to the cooperative because all soft skin cashews, regardless of stage two drying method, will be dried to the same ending moisture in the third stage of drying.
[26] For simplicity, these numbers assume that the K Dryer 2 reaches the same moisture level as the electric oven so that the weight loss is the same because, per the above footnote, minor differences in moisture level will not make a difference in the end when all cashews are dried to the same level in stage three.

Copra Overview

Copra is the term used for dried coconut meat or the kernel and is typically processed into coconut oil. It is also commonly used as animal feed. The price of coconut oil has more than doubled in the last five years in response to growing global demand within emerging markets for soft commodities.[27,28] Indonesia is the world's largest producer of copra with a planted area of 3,610,000 hectares that produces a yearly volume of more than three million tons.[29] Production is not limited to a particular area of the country and is spread from east to west with Riau, North Sulawesi and East Java provinces cultivating the largest amounts. The vast majority of coconut farmers are smallholder farmers.

Coconut oil production requires coconuts to be dried to a 6-7 percent moisture level, which farmers typically accomplish by laying the coconuts out on the ground to dry under the sun. However, this traditional method is lengthy and exposes the coconuts to pests and contamination. More importantly, traditional drying cannot be accomplished during the rainy season, which forces farmers to sell their coconuts undried at a much lower price than what copra commands. Coconut trees are harvested year round, so as much as half of a farmer's crop must be sold raw.

Unfortunately, very few commercial dryers are capable of drying coconuts into copra (in fact, Kopernik was only able to identify three such dryers available in Indonesia). Compounding this, the dryers that are commercially available are either too expensive, especially for smallholder farmers, or have too small a capacity to be relevant.

In response to this identified need for affordable dryers with sufficient capacity, Kopernik initiated an experiment where we built a solar dryer (referred to as K Dryer 1) from locally available materials and tested its performance on drying coconuts as compared to the traditional method of drying coconuts under the sun.

Sources: AusAID

Key Findings

- **The K Dryer 1 addressed the drying needs for smallholder farmers which have not yet been addressed by commercial manufacturers.**
- **The K Dryer 1 can potentially provide an extra economic benefit of up to US$97.65 a year (equivalent to more than a third of average annual income).**
- **Smallholder farmers should do the bare minimum of drying accepted by their buyer in order to maximize their income from copra.**

[27] McAloon, C. (2017, August 27). *Australians love coconuts, so has the time come for us to grow our own?* Retrieved from http://www.abc.net.au/news/rural/2017_08_26/australians-love-coconuts-so-should-we-grown-our-own/8834012
[28] Ribka, S. (2017, October 4). *Indonesia has opportunity to benefit from soft commodities: Jokowi*. Retrieved from http://www.thejakartapost.com/news/2017/10/04/indonesia-has-opportunity-to-benefit-from-soft-commodities-jokowi.html
[29] Unmet Needs Report

Process

Although the desired moisture level for processing copra is 6-7 percent, the smallholders that Kopernik worked with only dried their coconuts to a 40 percent moisture level (starting from 50-55% when harvested). The reason for this is the supply chain for copra which includes further actors upstream who complete their own drying processes:

Kopernik found that if smallholder farmers do not have direct market access to the final buyer (the factory that produces the coconut oil), which is the case on Adonara Island, they should only do the bare minimum of drying to maximize their income when selling to the “small” middleman. These farmers will need to dry to a level that the middleman classifies as dried copra but also maximizes the weight sold.

Quality of copra is determined by the evenness of drying and the level of contamination. Drying to a 40 percent moisture level results in a 6.5 percent weight loss, which is justified by the nearly 14 times higher price than selling undried coconut.

Technology

TRADITIONAL METHOD

CAPACITY 9.4 kg/m²

DIMENSIONS N/A

MATERIALS concrete floor

COST N/A

K DRYER 1

CAPACITY 700 kg (for cashews)[30]

DIMENSIONS 6 m x 2 m x 2 m

MATERIALS polycarbonate plastic sheet, L beam, iron sheet, aluminum net, solar panels

COST US$2,580

Kopernik designed the K Dryer 1 with the shortcomings of existing commercial dryers in mind, ie. creating a design that was easy-to-build from locally available materials. The materials used were chosen for their affordability (for a cooperative) and the ability to trap heat, while the dryer's capacity was built large enough to accommodate the average production of farmers in Angkah Village.

Although the capacity of the K Dryer 1 and the traditional method cannot be compared directly because the traditional method has no fixed amount of space, the K Dryer 1's increased efficiency with space can be illustrated with this comparison: a farmer would need about 75 m2 of space to match the capacity of the K Dryer 1. Thoroughly overseeing a drying space that large would be very difficult, whereas the K Dryer 1 requires no supervision as the dryer protects the coconuts from pests and poor weather and the commodity will not need to be flipped.

[30] The capacity is 1000 kg for cashews.

Dryer Performance

Based on an analysis of Kopernik's experiment results, it was determined that copra farmers should dry their coconuts to the 40 percent moisture level in order to maximize income. The time it takes both drying methods to reach this is modeled below[31]:

DRYING METHOD		
	TRADITIONAL METHOD	K DRYER 1
Time - drying in dry season (days)	4	1.5
Time - drying in rainy season (days)	not possible	2.2

Kopernik's local partner has an annual copra production of 300 kg, which is split between dry and rainy seasons. The farmer's annual production can be modeled by the following tables:

COPRA PRODUCTION DURING DRY SEASON	TRADITIONAL METHOD	K DRYER 1
Weight (kg)	150	150
Weight after drying (kg)	118.75	118.75
Time - drying (days)	4	1.5
Price	US$0.62/kg	US$0.65/kg
Revenue	US$73.23	US$77.19
Operating cost of drying	US$0[32]	US$0
Income	US$72.32	US$77.19

COPRA PRODUCTION DURING RAINY SEASON	TRADITIONAL METHOD	K DRYER 1
Weight (kg)	150	150
Weight after drying (kg)	N/A	118.75
Time - drying (days)	N/A	2.2
Price	US$0.05/kg[33]	US$0.65/kg
Revenue	US$7.5	US$77.19
Operating cost of drying	N/A	US$0
Income	US$7.5	US$77.19

[31] Please see Appendix B for the calculations.
[32] Copra does not require the same fork-like tool to flip the commodities.
[33] The price earned by raw copra.

BENEFITS OF SOLAR DRYING

Through Kopernik's research on copra, cashews and cacao, we identified the following factors as potential benefits of solar drying. While these were the benefits identified in the context of Kopernik's local partner, they are by no means an exhaustive list of all economic benefits associated with solar drying. Each factor is discussed below as it applies to the three commodities in the locations that Kopernik worked in.

- Increasing processing capacity
- Drying in the rainy season
- Farmer completing other income earning activities with time saved
- Value-added processing
- Decreasing operating costs for drying
- Increasing quality

» INCREASING PROCESSING CAPACITY

- With the same amount of time, solar dryers allow farmers to process greater quantities of commodity
- Farmer income increases by the same percentage as processing capacity increases
- Assumes that farmer can expand planting or can buy raw commodity to meet expanded capacity

The copra, cacao and cashew farmers that Kopernik worked with were already drying the maximum yield of their land. Furthermore, all other same-commodity farmers nearby completed the same drying processes, therefore there was no raw product that could be bought to increase the drying volume. However, if for some reason someone else in the village needed to sell their commodity raw, the farmer could potentially purchase theirs, dry it and increase his income.

Kopernik's local partner for the second and third stages of cashew drying in Ile Padung, a cashew farming co-operative, buys soft skin cashews from the surrounding farmers and has bought all of the area's cashew supply. While the co-operative could potentially buy cashews outside of this area, the price for cashews is higher elsewhere and the transportation costs would eat into the already razor-thin profit margin. Given the extra effort and work required, it is unlikely that the co-operative would find increasing their production volume more profitable.

» DRYING IN RAINY SEASON

- The traditional method of sun drying on the ground cannot occur during rainy season, so farmers are typically forced to sell their commodities raw at a much lower price
- Solar dryers are able to facilitate rainy season drying, allowing farmers to earn higher incomes
- Assumes that the farmer will have a buyer for the dried product

CACAO IN RAINY SEASON

TRADITIONAL METHOD

Commodity sold: **wet beans**
Weight sold: **78 kg**
Price: **US$0.37/kg**
Income: **US$28.55**

K CACAO DRYER & SOLAR BUBBLE DRYER

Commodity sold: **dried beans**
Weight sold: **26 kg**
Price: **US$2.36/kg**
Income: **US$61.36**

Cacao is a seasonal crop harvested from September to December in Bali, which means that it coincides with the beginning of rainy season, making it difficult to dry the entire harvest. Assuming that half of the yearly crop must be sold raw, the solar dryer can increase the annual income of cacao farmers by more than 30 percent.

CASHEWS IN RAINY SEASON

STAGE ONE DRYING

Cashews are usually harvested from September to November in East Nusa Tenggara, which similarly leaves farmers with about half of their harvest unable to be dried outdoors. There is no demand for undried shell cashews, so farmers still dry their crops during the rainy season, but do so indoors. While the solar dryer does not enable anything new, there is a quality difference between the solar dryer and the traditional method.

STAGE TWO DRYING

The cashew co-operative in Ile Padung completes the second and third stages of drying for cashews but these stages are not weather dependent as they typically use an electric oven for drying.

COPRA IN RAINY SEASON

TRADITIONAL METHOD

Commodity sold: **coconuts**
Weight sold: **150 kg**
Price: **US$0.05/kg**
Income: **US$7.5**

K DRYER 1

Commodity sold: **copra**
Weight sold: **118.75 kg**
Price: **US$0.65/kg**
Income: **US$77.19**

Unlike most crops, copra is not seasonal as coconut trees produce fruit year-round and as such, are harvested year-round. Thus, usually half of a copra farmer's crop cannot be dried and must be sold raw at a much lower price. The ability to dry during the rainy season can almost double a copra farmer's total annual income.

» FARMER COMPLETING OTHER INCOME EARNING ACTIVITIES WITH TIME SAVED

- Unlike the traditional method of drying, which requires the farmer's attention throughout the day to flip the commodity and guard against pests, the solar dryer requires no supervision
- With a solar dryer, farmers can use time previously spent supervising traditional drying to work in other capacities and earn additional income
- Assumes that the farmer uses all time saved for work instead of leisure

LABOR ALTERNATIVES IN EAST NUSA TENGGARA

OJEK DRIVER (MOTORBIKE TAXI)
earns US$3.50 a day (IDR 50,000)

FARM DAY LABORER
earns US$7 a day (IDR 100,000)

FISHERMAN
earns US$21 a day (IDR 300,000)

CASHEWS (stage one) - 18[34] days saved
at minimum, if working with all days saved, a farmer can earn US$63

COPRA - 4[35] days saved
at minimum, if working with all days saved, a farmer can earn US$14

The cashew co-operative owner (stage two drying), on the other hand, does not have labor alternatives with the time saved because he must stay at his processing plant to supervise other activities.

LABOR ALTERNATIVES IN BALI

FARM DAY LABORER
earns US$7 a day (IDR 100,000)

CONSTRUCTION DAY LABORER
earns US$7 a day (IDR 100,000)

CACAO - 6[36] days saved
at minimum, if working with all days saved, a farmer can earn US$42

[34] Time saved from drying during rainy and dry seasons, both of which the farmer was engaged in before.
[35] Only timed saved from the dry season. Rainy season drying with the solar drying requires no supervision so it doesn't change the number of days available for labor.
[36] Only timed saved from the dry season for the same reason as the previous footnote.

» VALUE ADDED PROCESSING

- Drying for some crops is divided into several stages according to additional processing steps
- Solar dryers can enable value-added processes that traditional drying cannot accomplish, increasing the price of the commodity sold
- Assumes that farmers have access to buyers for the up-processed product

Cashews (Stage 1)

Drying for cashews is divided into three stages. The farmers that Kopernik worked with were unable to complete the second and third stages of drying because of contamination risks from open air drying once cashews are removed from their shell.

The solar dryer, can complete all stages of drying by protecting the shell-less cashews. Enabling the second stage of the drying process in Pajinian Village would result in the following:

Ending weight (kg)	74.8
Price	US$7/kg
Revenue	US$523.60
Cost	US$89[37]
Income	**US$434.60**

The total income from completing stage two drying is US$434.60, compared to US$241.52 for stage one drying according to traditional methods, for a total benefit of US$193.08.

Kopernik did not test solar dryers on the third stage of cashew drying, but a farmer's income could increase even more if the third stage of drying was enabled by the solar dryer.

Cashews (Stage 2)

As the cashew co-operative is already able to complete the second and third stages of cashew drying, the solar dryer does not enable further value-added steps.

Cacao & Copra

Value-added processes do not apply to copra or cacao drying. For cacao, farmers are able to complete the entire drying process themselves. For copra, the traditional drying method would technically be able to reach the industry standard moisture level, however farmers typically do not complete the entire drying process because of the way the supply chain works. Middlemen dry the copra further (but no further processing steps) in order to obtain a higher price from the next buyer up the chain, so it does not benefit the farmer to dry further.

[37] See Appendix C for an explanation of the labor and non-solar dryer capital costs of second stage drying.

» DECREASING OPERATING COSTS FOR DRYING

- The traditional method of drying often requires tools to flip the commodity to ensure even drying. Solar dryers remove the need for these tools
- Other drying equipment often requires energy costs, which are not required by solar dryers

Cacao & Cashews (Stage 1)

Both cacao and cashew stage one drying require a fork-like tool that costs US$10 to flip the commodity.
A one-time savings as the tool is a fixed cost.

Cashews (Stage 2)

For the co-operative cashew farmer, the operating cost of drying is reduced significantly because the solar dryer replaced an electric oven and the cost of electricity is replaced by the zero fuel costs of the solar dryer. The co-operative Kopernik worked with can save US$75.36 in electricity costs based on their current production volume.

Copra

No tools necessary other than the dryer, so this factor does not apply to copra.

» INCREASING QUALITY

- Solar dryers can increase the quality of commodities by protecting them from contamination
- The monetary benefit is the price differential between the quality differences multiplied by the volume of commodity dried

CACAO

DECREASED QUALITY

The cacao that Kopernik dried in fact had reduced quality because the buyer believed that the beans were dried too quickly in the solar dryer and the temperature/humidity was not controlled enough. Better control could be achieved by the solar dryer so there is still potential for the dryer to result in increased quality.

CASHEWS (STAGE ONE)

INCREASED QUALITY - DRY SEASON

During dry season, shell cashews dried under the sun are more likely to split than shell cashews dried inside the solar dryer and shell cashews command a price 17 percent higher than split cashews.

INCREASED QUALITY - RAINY SEASON

During rainy season, the quality of cashews dried indoors is poor. As normal quality cashews, which the solar dryer can obtain, are in short supply during the rainy season, the price earned is much higher.

US$0.90 price increase x 187 kg = US$168.3

COPRA

INCREASED QUALITY

The higher quality of the copra dried by the solar dryer because of less mold and a stronger rubbery quality earned it a slightly higher price.

US$0.03 price increase x 118.75 kg[38] = US$3.56

[38] Only includes the production volume from dry season as the rainy season copra dried with the solar dryer is not directly comparable in quality with selling undried coconuts.

» SUMMARY OF SOLAR DRYING BENEFITS

Does the dryer create additional economic benefits through...

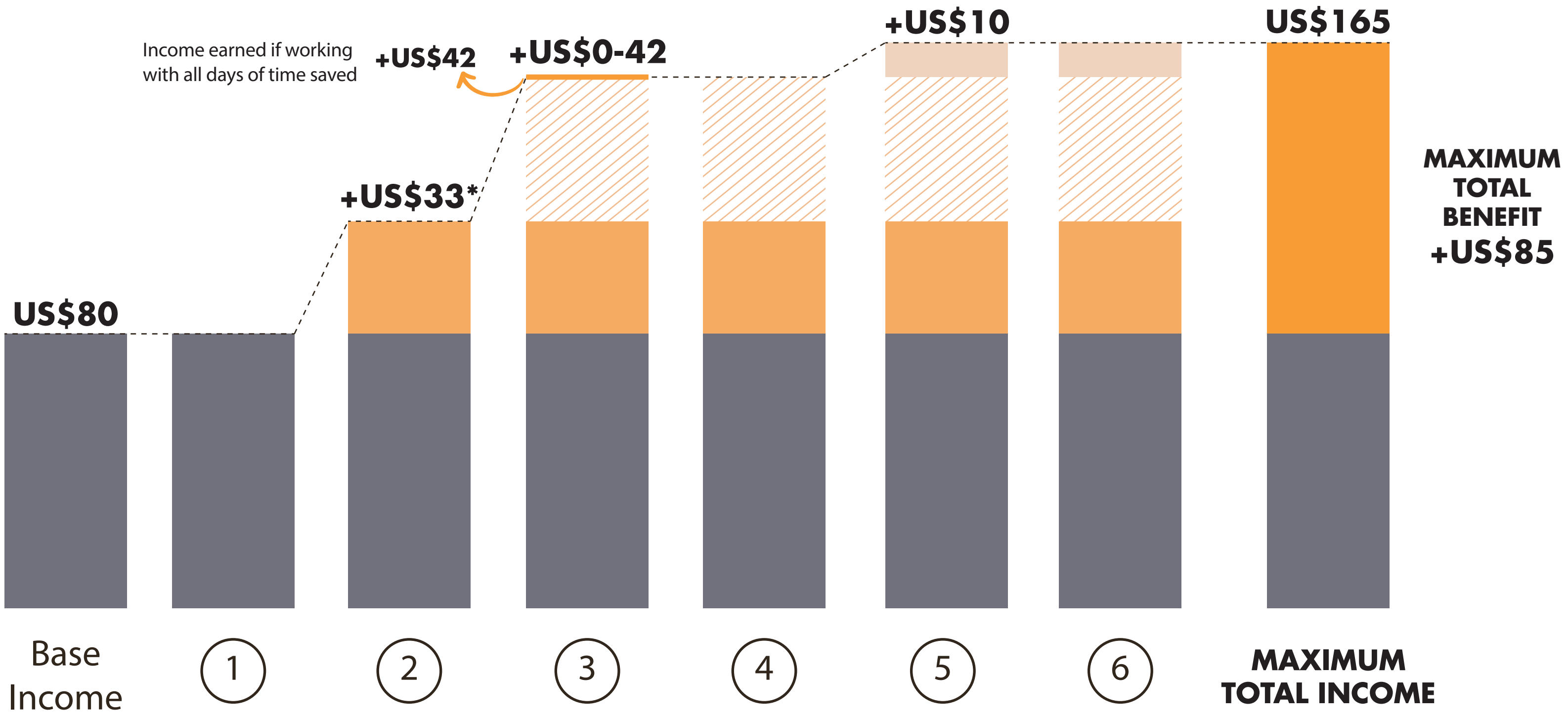
	CACAO (K Cacao Dryer)	CASHEWS 1 (K Dryer 1)	CASHEWS 2 (K Dryer 2)	COPRA (K Dryer 1)
an increase in processing capacity?	✗	✗	✗	✗
drying in rainy season?	✓ US$32.81	✗	✗	✓ US$69.69
the farmer completing other income earning activities with time saved?	✓ US$42	✓ US$63	✗	✓ US$14
value-added processes?	✗	✓ US$193.08[39]	✗	✗
a decrease in operating costs for drying?	✓ US$10	✓ US$10	✓ US$75.36	✗
an increase in quality?	✗	✓ US$168.30	✗	✓ US$3.56
TOTAL ADDITIONAL BENEFIT PER YEAR	US$84.81	US$266.08 if up-processing US$241.30 if selling after stage one	US$75.36	US$87.25
INCOME FROM TRADITIONAL DRYING METHOD	US$79.91	US$241.52	US$5,742	US$79.82
COST OF DRYER	US$1,350	US$2,580	US$1,291.50	US$2,580

For cacao, the benefits of the K Cacao Dryer and the Solar Bubble Dryer are essentially the same but the Solar Bubble Dryer is double the cost, so Kopernik concluded that it was not a better alternative.[40] For stages two and three of cashew drying, the current drying method is an electric oven.

[39] The monetary benefit from value-added processes and an increase in quality are mutually exclusive as a farmer who chooses to up-process his cashews will no longer benefit from an increase in quality when selling them after stage one.

[40] The only difference between the Solar Bubble Dryer and the K Cacao Dryer in terms of benefits is that the Solar Bubble Dryer takes less time to dry. Because neither the K Cacao Dryer nor the Solar Bubble Dryer require supervision, the Solar Bubble Dryer's drying time advantage does not materialize economic benefits.

Cacao: Solar Drying Benefits



COST OF DRYER: US$1350

1. Increase in processing capacity
2. Drying in rainy season
3. Labor alternatives with time saved
4. Value-added processes
5. Decrease in operating costs of drying
6. Increase in quality

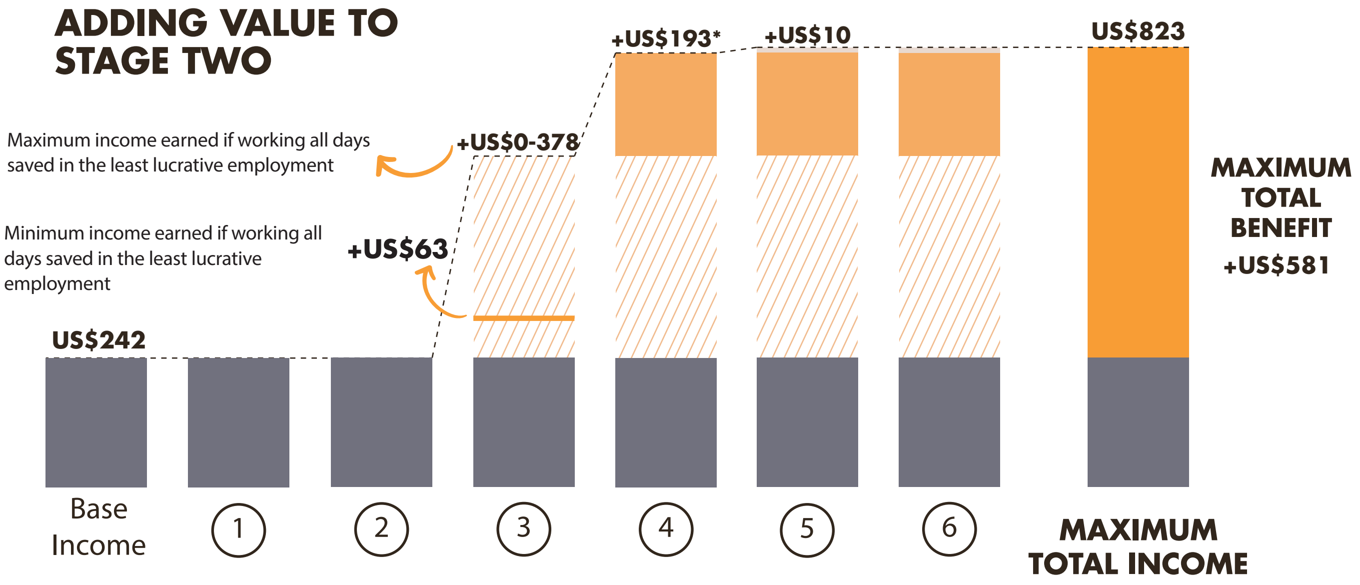
(hatched pattern) indicates range of benefits

* assumes that smallholder farmer will have a buyer who will fairly appraise price

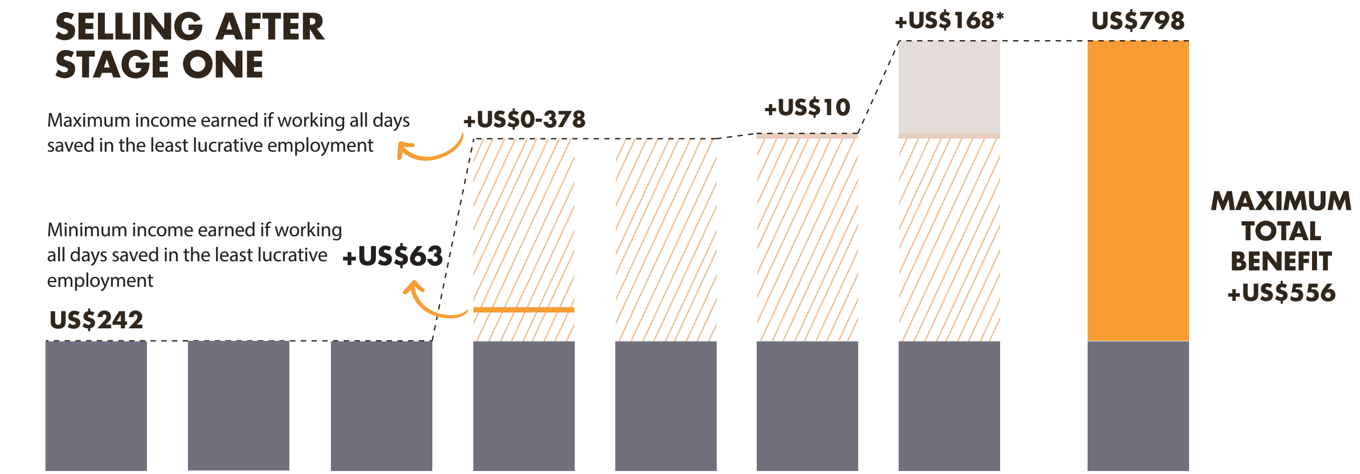
The above chart illustrates the potential individual and cumulative benefits of solar drying for cacao. The entire range of possible labor alternatives is shown, ranging from US$0 if a farmer chooses not to work at all in the days freed up by the solar dryer, up to US$42 if the farmer works with all days freed up. Other benefits such as drying in rainy season depend on the degree of market access; assuming that a farmer can find a buyer for the dried product in rainy season.

The K Cacao Dryer, in the best case scenario, can more than double the farmer's income (an increase of 106 percent).

Cashews: Solar Drying Benefits - Stage One[41]



1 Increase in processing capacity
2 Drying in rainy season
3 Labor alternatives with time saved
4 Value-added processes
5 Decrease in operating costs of drying
6 Increase in quality



COST OF DRYER: US$2580

The chart to the left illustrates the potential individual and cumulative benefits of solar drying for a smallholder cashew farmer.

The range of extra income from labor alternatives is massive because a farmer could earn up to US$21 a day if he worked as a fisherman with his time freed up by the solar dryer (the table on page 24 only illustrates the minimum extra income the farmer could earn if he chose to be employed with all days saved). Admittedly, it is rather unlikely that a farmer would choose to spend all freed days fishing.

For both scenarios, the K Dryer 1 has the best case scenario potential to more than triple farmer income (241% increase for adding value to stage two, 230% increase for selling after stage one).

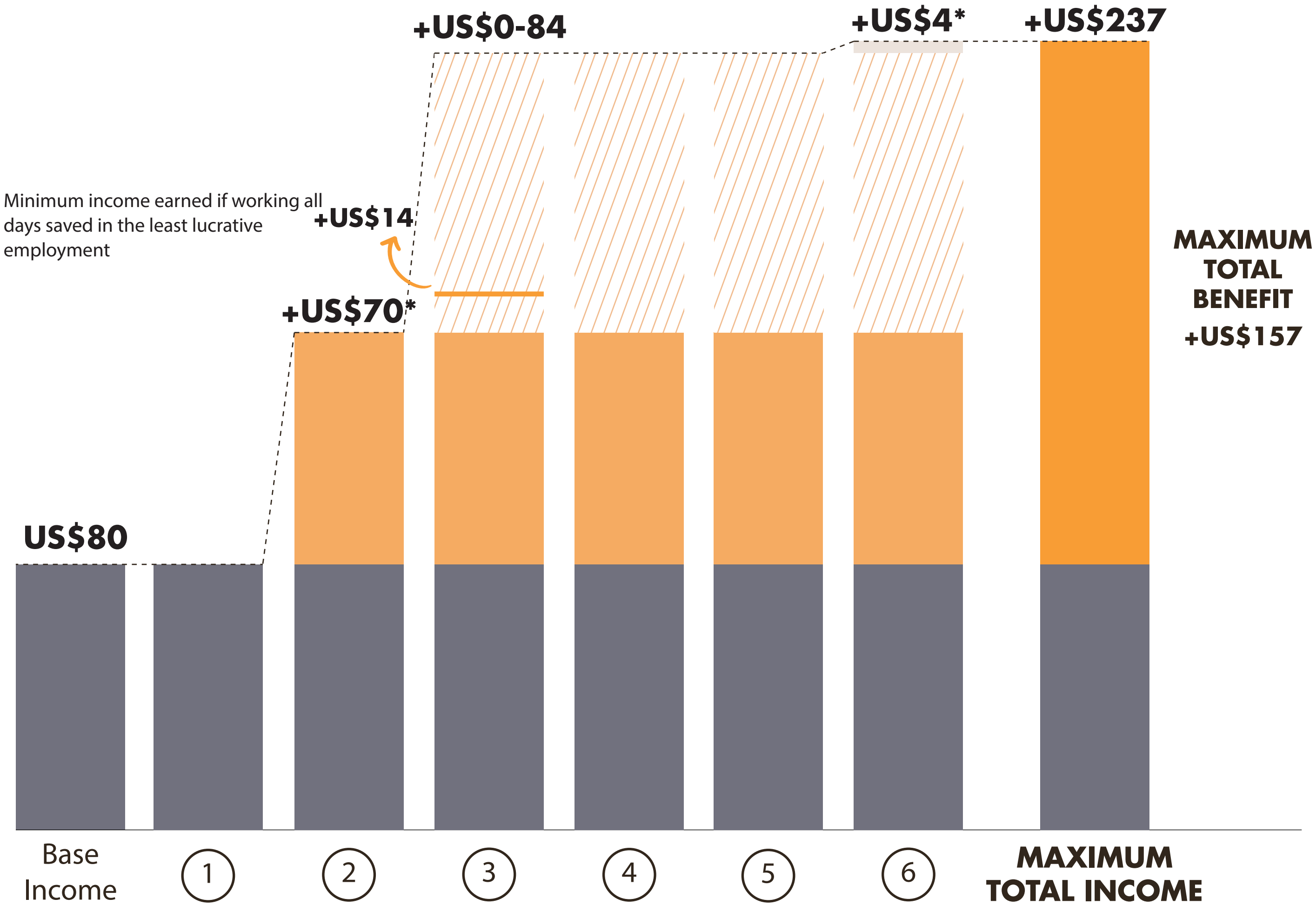
When only considering the minimum income earned if the farmer chooses to work with all days saved, but in the least lucrative employment, the solar dryer still has the potential to double previous income.

indicates range of benefits

* assumes that smallholder farmer will have a buyer who will fairly appraise price

[41] A similar graph is not shown for cashews stage two as the benefit from the solar dryer (US$75.36) is miniscule in comparison to the baseline income (US$5,742).

Copra: Solar Drying Benefits



1. Increase in processing capacity
2. Drying in rainy season
3. Labor alternatives with time saved
4. Value-added processes
5. Decrease in operating costs of drying
6. Increase in quality

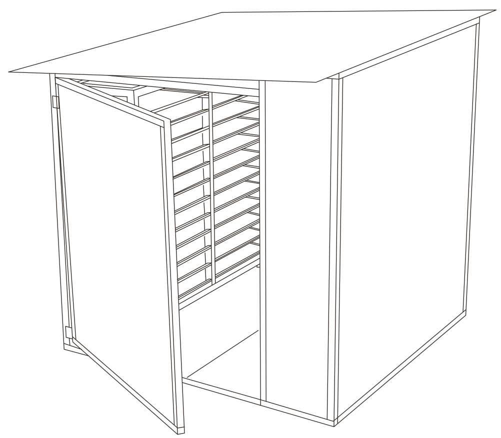
(hatched) indicates range of benefits

* assumes that smallholder farmer will have a buyer who will fairly appraise price

COST OF DRYER: US$2580

This chart illustrates the potential individual and cumulative benefits of solar drying for copra. The entire range of possible labor alternatives is shown, ranging from US$0 if a farmer chooses not to work at all in the days freed up by the solar dryer, up to US$84 if the farmer works with all days freed up in the most lucrative alternative, fishing. Other benefits such as drying in rainy season and increase in quality depend on degree of market access; assuming that a farmer can find a buyer for the dried product in rainy season.

The maximum total benefit of solar drying is enough to almost triple a smallholder copra farmer's income (an increase of 197%). When only considering the minimum income earned if the farmer chooses to work with all days saved, but in the least lucrative employment, the solar dryer still has the potential to double previous income.



» AFFORDABILITY OF DRYERS

While the benefits of Kopernik's solar dryers are significant when compared to the average annual income earned from harvesting commodities, they are small when compared to the cost of the dryer. Therefore, cooperatives or other group arrangements would be needed to make the dryers affordable. The optimal group size to maximize the dryer's benefits depend on the capacity of the dryer and the harvest volume per commodity.

CACAO

K Cacao Dryer capacity: 500 kg

Average annual harvest volume per farmer in Tabanan: 156 kg

OPTIMAL GROUP SIZE

12 FARMERS

YEARS TO PAY OFF: 2

With all additional profits going towards paying for the cost of the dryer, it would take two years of harvest to pay off the dryer.[42] If only 75 percent of additional profits went towards paying for the dryer, it would still take two years to pay off the dryer.

CASHEWS (STAGE 1)

K Dryer 1 capacity: 1000 kg

Average annual harvest volume per farmer in Pajinian Village: 400 kg

OPTIMAL GROUP SIZE

5 FARMERS

YEARS TO PAY OFF: 2

With all additional profits going towards paying for the cost of the dryer, it would take two years of harvest to pay off the dryer.[43] If only 75 percent of additional profits went towards paying for the dryer, it would take three years to pay off the dryer.

COPRA

K Dryer 1 capacity: 700 kg

Average annual harvest volume per farmer in Adonara: 300 kg

OPTIMAL GROUP SIZE

14 FARMERS

YEARS TO PAY OFF: 3

With all additional profits going towards paying for the cost of the dryer, it would take three years of harvest to pay off the dryer. If only 75 percent of additional profits went towards paying for the dryer, it would still take three years to pay off the dryer.

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[42] This and all following affordability calculations uses the total benefit in the table on page 24, taking the minimum extra income from employment with all days saved.
[43] For up-processing. For selling after stage one, it would take three years to pay off the dryer if all additional income went towards the dryer's cost.

CASHEWS (STAGE 2)

K Dryer 2 capacity: 300 kg

Annual processing volume for the cooperative in Ile Padung: 907 kg

OPTIMAL GROUP SIZE

As the local partner is already a cooperative, it cannot band together with other cooperatives to make a solar dryer more affordable.

YEARS TO PAY OFF 18

With all additional profits going towards paying for the cost of the dryer, it would take the cooperative 18 years to pay off the cost of the dryer. If only 75% of additional profits went towards paying for the dryer, it would take 23 years to pay off the dryer.

In this case, the K Dryer 2 would not make economic sense for the cooperative as it would take too long for the benefits to be realized. The K Dryer 2 is a fully functional solar dryer, but the unique situation of the local partner -- the cooperative was already completing stages two and three drying and had an electric oven, which it received for free -- means that the electricity cost savings are not enough to make the solar dryer economically viable for the cooperative. If this cooperative did not already have an electric oven (capacity: 40 kg, price: US$509) and was choosing between buying an oven or building a solar dryer, it would take 11 years for the current level of the solar dryer's electricity cost savings to be worth its added cost.

Electricity cost savings to the order of US$300 a year (achievable through larger production volumes) would make the solar dryer more affordable and more appealing when choosing between it and an electric oven for stage two processing. Additionally, for a farmer or cooperative that does not already have an electric oven and would like to start stage two drying, the added value of further processing is likely to make the K Dryer 2 affordable.

» LIFESPAN OF DRYERS

The lifespan of the K Dryers depends on the frequency of use and the quality of materials used to build it. There are two main components that Kopernik anticipates will need replacement: the outer layer of black paint and the inside nets used to hold the commodity. If a thin layer of paint is used, Kopernik estimates it will have a five year lifespan before a new coat is needed. If a thick layer of paint is used, Kopernik estimate it will have a ten year lifespan. The cost of repainting is US$12.34.[44]

Additionally, with heavy use (i.e. a cooperative's collective use), Kopernik believes the net will need to be replaced approximately every two years, at a cost of US$20.

Thus, the average yearly up keep cost for the K Dryers is about US$12.50. This cost is minor in comparison to a cooperative's total benefits and the cost of the dryer, and would not significantly change the years it takes to pay off the dryer's cost.

[44] Labor: IDR 50,000, tools: IDR 20,000, paint: IDR 100,000

CONCLUSION

The dryers that Kopernik built have the potential to provide monetary benefits that were usually large when compared to average income. However, the ultimate realization of economic benefits relies on access to buyers who are willing to buy the dried product, who recognize higher quality commodities and who pay farmers higher prices for higher quality.

In its solar drying experiments, Kopernik successfully addressed the drying needs of smallholder farmers which have not yet been addressed by commercial manufacturers. The K Cacao Dryer had the potential to increase Tabanan cacao farmers' incomes by US$84.81 a year; the K Dryer 1 had the potential to increase Flores copra farmers' incomes by US$97.65 and Adonora cashew farmers' incomes by US$537.78; and the K Dryer 2 had the potential to increase the Ile Padung cooperative's income by US$75.36. For all dryers, save for the K Dryer 2 for a cashew cooperative, these benefits were enough to make the dryer's cost reasonable for the local partner. While the affordability calculations of the dryers apply to the farmers that Kopernik worked with, the affordability of the Kopernik-designed solar dryers as it applies to the situation of other farmers can be calculated according to the methods described in this report.

However, the economic adoption of solar dryers does not have to rely on self-financing. Utilizing government funds for agricultural cooperatives is another possibility that should be explored to determine the best method of financing the solar dryers (i.e. a subsidy).

Kopernik's expertise lies in data collection, analysis and reporting and we still have a lot to learn in relation to improving agricultural efficiencies and income generation. While this report focuses on economic benefits, further research is needed on behavioral change, barriers to dryer adoption and individual behavior in a cooperative setting in order to fully realize a solar dryer's benefits.