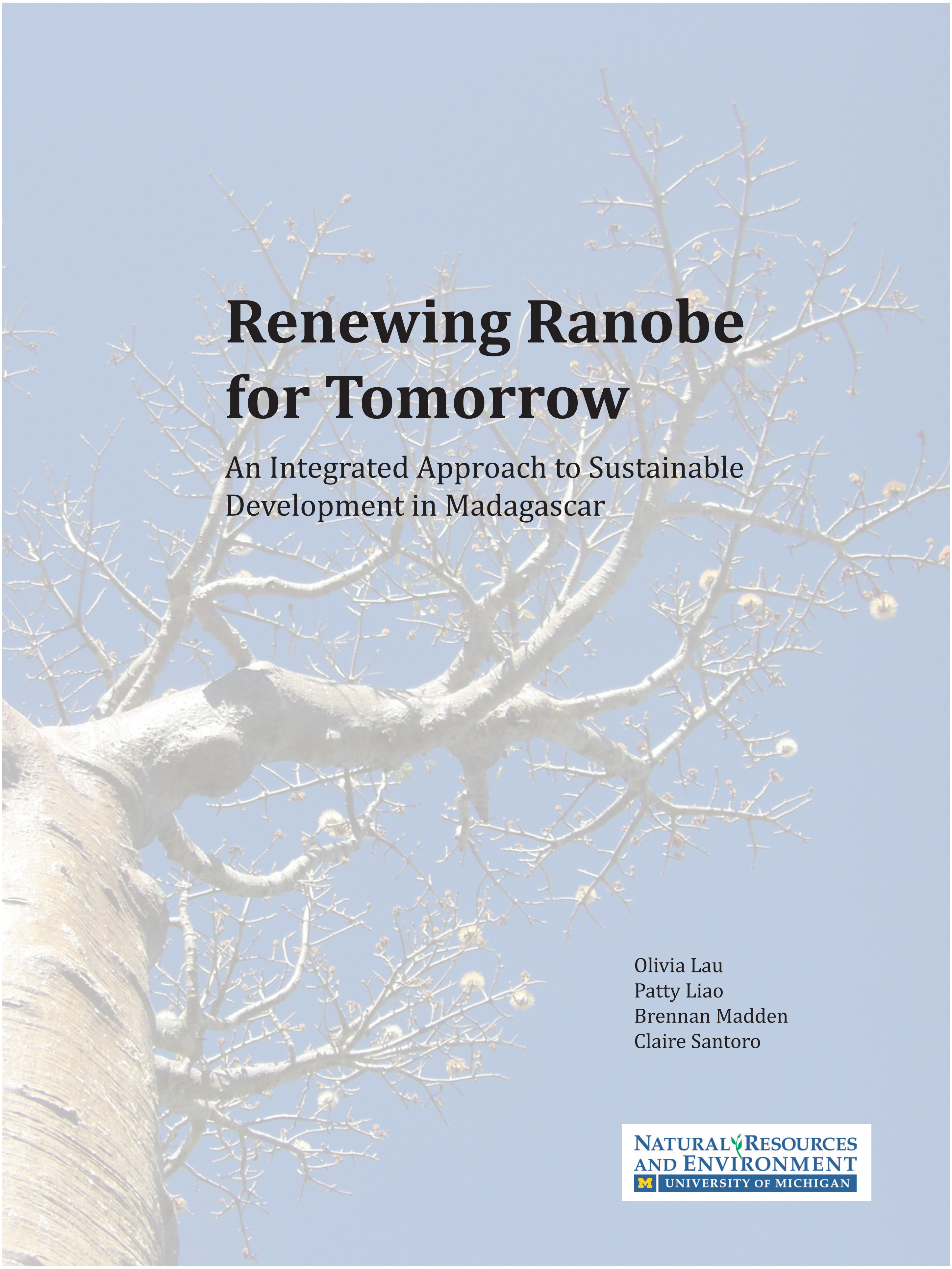

Renewing Ranobe for Tomorrow

An Integrated Approach to Sustainable Development in Madagascar

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Front cover. Soaring boabab. Photo credit: C. Santoro

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Contents

Abstract

The Spiny Forest in southwest Madagascar is home to a 90% endemic array of species and the village of Ranobe. Climate change and deforestation through charcoal production, agricultural use, and development, have degraded 43% of land cover in the last decade. This project collaborated with Ho Avy, a local nonprofit, to design a sustainable development plan for the community. The plan is based on five key perspectives: 1) land use/land cover change management, 2) energy potential, 3) water and health, 4) food security, and 5) economic growth. The plan recommends increased education, shifting incentives, and investment in renewable technologies to be implemented in Ranobe to improve the health of the region's population and unique environment.

Ranobe child pounding rice. Photo credit: P. Liao

Recommendations for *Renewing* Ranobe

1. Nonprofit Goal Prioritization

2. Enhanced Local Engagement

3. Education & Apprenticeship Program

Baobab in the forest. Photo credit: P. Liao

This landscape was cleared years ago, yet remnants of the forest remain: a few trees, puncturing through the red sandy soil. In the distance, now-healthy forest awaits its fate.

Photo credit: P. Liao

Introduction

Given the current state of the global environment and the impending challenges of climate change, the idea of 'sustainable development' becomes critical for less developed areas of the world. To paraphrase the words of the Brundtland Commission, sustainable development is economic development that allows the present generation to meet its needs without compromising the ability of future generations to meet their needs. Certainly, many areas of the world today are underdeveloped – 13.6% of the global population is undernourished (FAO, 2010), approximately 17% lives on less than $1 per day (World Bank, 2007), over 20% does not have access to electricity (IEA, 2011), and 13.2% does not have access to an improved water source (World Bank, 2011). Yet, at the same time, industrialized countries like the United States, which represents 4.5% of global population (US Census, 2011) and accounts for 22% of global CO_2 equivalent emissions (World Bank, 2009), continue to drive climate change along an unsafe trajectory.

Issues like these – the large-scale environmental injustice, the call for innovation and technological change, and the need to adapt to a changing world – represent much of the focus of the School of Natural Resources & Environment (SNRE) at the University of Michigan. Beyond that, these issues also serve as the motivation for this project. It was with these challenges in mind that four Master's students from SNRE travelled thousands of miles to a village in Madagascar in search of solutions to what had already become unsustainable development.

The small village of Ranobe sits on the edge of the Spiny Forest in southwest Madagascar, a sprawling community (population: 1,563 and growing (Ho Avy, 2011)) composed of a mixture of mud and grass huts, bordering a shallow lake of cattails and reeds and the true-to-name Spiny Forest. This forest is entirely unlike its northeastern neighbors in Madagascar, the tropical rainforests teeming with lemurs and tourists. This five million hectare (ha) forest (Wells, 2003) instead boasts baobabs and octopus trees, semi-arid shrubs, and a bounty of prickly trees and plants. And yet, just like the northern rainforests, this Madagascar ecosystem is home to valuable biodiversity: nearly 95% of Spiny Forest plants and animals are endemic to the region, constituting one of the highest endemism rates in the country (Philipson, 1996). Over the years, slash-and-burn agriculture, charcoal production, collection of wood for logging and fuel, and gathering of food and plants have steadily decimated the forest (Fenn, 2003).

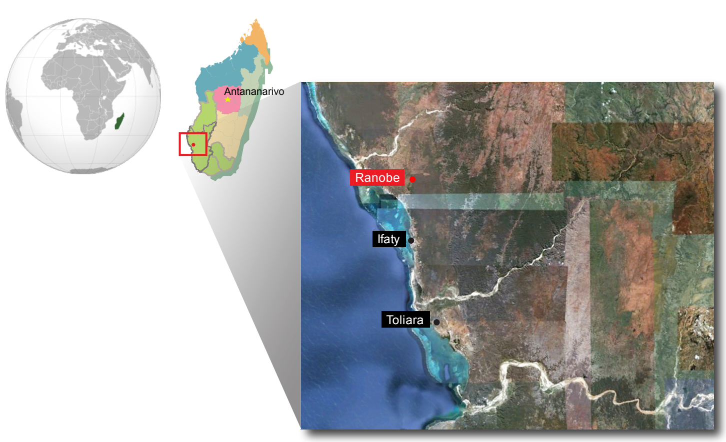


Figure 1. Ranobe is located in Toliara Province, in the southwestern region of Magadascar. Graphic credit: O. Lau

Figure 2. Winter view of the Spiny Forest in health. The multi-level canopy of plants and trees provides a rich environment for endemic species to flourish. Photo credit: B. Madden

Indeed, the residents of Ranobe, who tend to be extremely poor and isolated from urban areas, have had a hand in this destruction. Villagers have historically depended on agriculture and gathering of forest resources to earn their livings, and although the charcoal trade is legal through issued permits in Madagascar, the burn-pits dotting forest trails reveal that charcoal production is uncontrolled and that the market demand is strong. It is no secret that charcoal production happens—any villager can tell you where it is being made and how much a batch sells for in markets. After only a month or so of friendship, these same villagers revealed to us that they, too, have made charcoal, not to burn, but to pay for food for their families. When few households earn more than $0.50 per day (from village interviews that we conducted on the field site, the median annual household income was $100), supplemental income becomes critical, regardless of legality or environmental degradation.

The spread of deforestation has taken its toll, however, on traditional income sources. Agricultural output has fallen throughout the region, leading to increased migrant traffic through the forest in search of food; on top of that, weather patterns are changing, making the future of livelihoods based on agriculture and forest resources unsustainable for the foreseeable future. With these pressing drivers in mind, our project team took on the challenge of pursuing sustainable development for Ranobe, in partnership with the nonprofit Ho Avy.

Five perspectives of sustainable development will be discussed in this paper: land use/land cover change management, energy potential, water and health, food security, and economic growth. The end product is a list of integrated sustainability recommendations, to be translated, refined, and implemented by Ho Avy in collaboration with the Ranobe villagers. It is our hope that the recommendations provided in this report may also reach a larger audience, and guide sustainable development in poor rural villages throughout southwest Madagascar or be adapted for the rural poor worldwide.

Figures 3 & 4. Leftover charcoal and the destruction that results from the charcoal production process. Photo credit: P. Liao (top), O. Lau (bottom)

About Ho Avy

This project aims to provide recommendations to Ho Avy to further their goals in the sustainable development of Ranobe. Ho Avy is a Ranobe-based nonprofit organization; their mission is in Spiny Forest protection and reforestation. The organization also has a fundraising arm in the United States under the name New Latitude, formed in 2008. In Ranobe, Ho Avy operates a small research center and two plant nurseries with the help of a community organization, FIMPAHARA. Although Ho Avy is a small organization led primarily by Mr. Anthony Arnold of the United States and Ms. Martina Petru of the Czech Republic, the organization brings in numerous experts on topics ranging from plant ecology to biogas digesters to aid their work in Ranobe. Our role was that of consultants to Ho Avy in the numerous projects and topics that we experimented with in the field.

Figure 5. Replenishing supplies at a quincaillerie, or hardware store, in Toliara. From left to right: Olivia, Brennan, Claire, and Patty. Photo credit: P. Liao

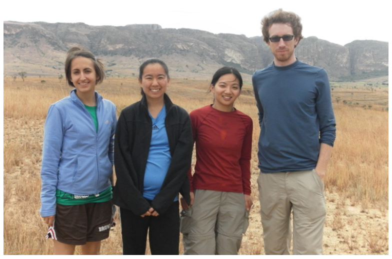


Figure 6. The project team at Isalo National Park. From left to right: Claire, Patty, Olivia, and Brennan. Photo credit: A&D EcoExplorers 2010

About the Team

The team formed at the beginning of 2010 in response to a call from Ho Avy for sustainable development projects in Ranobe. Project parameters were broad, and the team proposed an integrated assessment – bridging natural sciences, social sciences, and policy – based on our collective skills and experience, to be carried out between January 2010 and April 2011. This project serves as the capstone requirement for our M.S. degrees.

Olivia Lau is a dual MS/MUP student in Environmental Justice. Her interests are in the interaction between the built and natural environment, and she brings experience in GIS mapping to the project. Olivia's role in this assessment was focused primarily on assessing land use/land cover change and developing strategies to reduce deforestation.

Patty Liao is a dual MS/MSE student in Engineering Sustainable Systems. She studies sustainable energy systems and is interested in how to universalize concepts of sustainability and disseminate available technologies toward this end. Patty took a lead in this assessment on drafting designs and usage guidelines for the solar dryer.

Brennan Madden is an MS student in Sustainable Systems, focusing on sustainable energy systems and industrial ecology, who is interested in strategies to improve living standards while decreasing environmental impacts. Brennan brings biofuels experience to this assessment, and he took a primary role in assessing biofuel potential and designing appropriate photovoltaic systems.

Claire Santoro is an MS student in Sustainable Systems, and her focus is on energy and environmental economics. Claire brings skills in quantitative analysis as well as the social sciences, and she took a lead on conducting village interviews and analyzing the data collected in the field.

The team as a whole has experience conducting integrated assessments and working abroad with developing countries such as Jamaica and Botswana. The breadth of the analysis we were able to conduct was the direct result of the interdisciplinary and exploratory nature of our team.

Figure 7. Daily life in Ranobe village. Photo credit: C. Santoro

Project Implementation

In February 2010, the team offered an assessment proposal to Ho Avy in response to their call for a Master's project. After learning as much as we could about Ranobe from discussions with Ho Avy, we formulated preliminary sets of options in the energy and land conservation issue areas. We ambitiously planned to conduct a more comprehensive evaluation of the current state of development upon arrival in Madagascar, followed by recommendations, designs, and even early implementation of some of our options.

Our team packed our bags in early May to spend three months in the southwest corner of the fourth-largest island in the world. We had prepared well: we researched all that we could about Madagascar ecology and development, aware that internet was nonexistent in the village; we had brushed up on French for communication in the former French colony; we had even copied pages from the only Malagasy language textbook we could find. Over the months, we learned all that we could about local culture, development needs, and ecosystem health while collecting baseline data on land use and energy resources.

The team spent the summer along the southwest coast of Madagascar, with approximately one month in Ranobe and the majority of the remainder in Toliara, the nearest city and the major port city of the southwest region. Here, we continued our research and frequented local markets to purchase project supplies and provisions. Through fastidious note- and photo-taking, we were able to collect data to describe and understand the local economy, food security, water usage, climate and weather, and land use patterns in Ranobe and neighboring areas. These data, coupled with the experience of living in the village and observing the relationship between the villagers and Ho Avy, provide the basis for our report. Despite our best efforts, the majority of our communication with villagers still required a Malagasy translator.

Life in the Village

In May, the team transitioned from Ann Arbor, Michigan to the tiny village of Ranobe. Ranobe's residents occasionally make the four-hour trip by zebu (local cattle) cart to Toliara to buy or sell goods in the city market, but most days, villagers venture no farther than the nearby forest and cattle rangeland. There are other small villages in the area, but most of these – like Ranobe – lack electricity, running water, and markets selling goods other than staple crops.

Figure 8. Local women preparing food. Photo credit: C. Santoro

Thus, living in such a small and isolated village, we became intimately aware of the culture and daily life. Thatched huts house families of five or more. Our drinking water came from the same wells that the villagers used, although – aware that schistosomiasis is a pervasive problem in the region – we purchased chlorine to treat it. That was something most villagers could not be bothered to do, despite having been told multiple times of its health benefits. Even our daily routine fell into the same pattern as that of the village, with breakfast before sunrise and a siesta during the heat of the day. Gender roles, too, became extraordinarily prevalent. Claire, Olivia, and Patty found themselves responsible for helping the local women cook lunch and dinner and wash dishes afterwards, and the women were also not allowed to map the fields or forest without a teenage boy from the village to lead them. Safety in the forest, we learned, was a significant concern to Ranobe villagers, who frequently had zebu stolen by men from surrounding villages. Three months in Madagascar thus became not only a lesson in science but also in cultural adaptation.

Figure 9. Project team reviews data in the field. Photo credit: O. Lau

Our time in the village helped verify and quantify many of the trends that form the basis of this assessment. For example, our interview results show that 93% of residents rely directly on the earth's yield for livelihoods; indeed, this was apparent from the families we would see working the fields each day, or the freshly cut reeds drying before being sold in the market. Ranobe's economic dependence on the earth's productivity is even higher than the Malagasy national average of 82% in 2005 (World Bank, 2010). Interview responses decried the past four years of drought for wreaking havoc on household earnings, and although it rained often while we were there, the lake had dried up far beyond the edges of the cattails and empty wells were a common sight. Nevertheless, that lake was still frequently used for bathing (by humans and zebu alike), washing clothes, fishing, and playing. One of the most prevalent problems is that the children, oblivious or indifferent to the risk of schistosomiasis, loved to build rafts and go swimming. We had been warned before traveling to avoid standing water because of schistosomiasis, but to the villagers of Ranobe, such warnings meant little, and we saw evidence of the health impacts of these activities in the swollen bellies of village children. Our interviews determined that many residents were aware that the illnesses of which they complained were likely caused by "dirty" water, but overwhelmingly, households rejected the idea of waiting to boil, filter, or treat water before drinking. With that, a new facet of our project was born: the need to change habits and shift behaviors.

Project Motivation
The following assessment draws on our field experience in addition to data collection and literature review to make recommendations for development in Ranobe. Underlying our recommendations is a series of critical assumptions:


Figure 10. The Ho Avy Research Center serves as a base for ongoing research and initiatives. Photo credit: P. Liao

- The **Spiny Forest must be protected** as a unique and valuable ecosystem.
- Ecosystem health is **intrinsically tied** to village survival.
- Advancing the quality of life of Ranobe villagers depends on the improvement of a combination of **interwoven issues**, including the five perspectives we focus on.
- These developments must become **self-sustaining** such that the village can continue to develop with Ho Avy playing only an advisory role.
- **Education and training** are essential for the villagers to **take ownership** of their development.
- Successful solutions need to be **culturally sensitive** and draw on locally available resources.

The assessment presented here is not intended to be exhaustive, but given the lack of existing work on sustainability in southwest Madagascar, it is a preliminary examination of prominent issues and potential solutions. Recommendations are prioritized for short-term implementation and are projected into the long term. For optimal effectiveness, this analysis should be revisited by a future project team and/or when additional data becomes available.

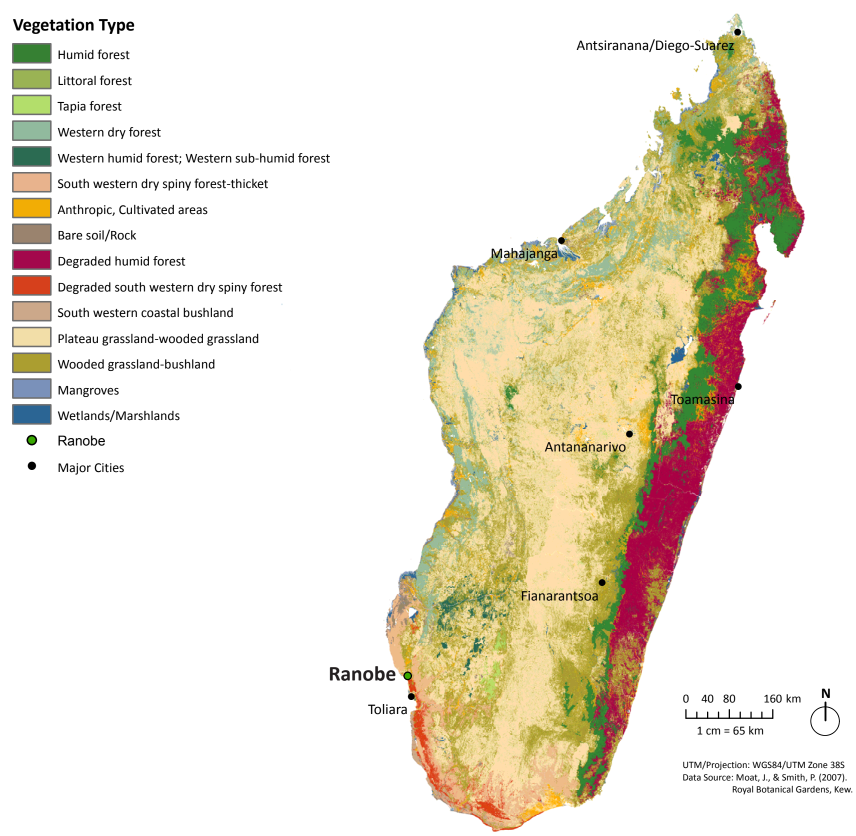
Literature Review

In the following five sections, we present a survey of the existing literature on sustainable development in our five chosen perspective areas.

LR 1: Land Use/Land Cover Change Management

Background
Madagascar's long isolation from the main continent has resulted in an exceptional array of unique life with over 10,000 plant species, 90% of which are found nowhere else in the world (Moat and Smith, 2007). This wonderland of biological diversity is supported by a wide range of ecosystems on the island country, including the Spiny Forest in the southwest (Figure 11). While the country boasts rich and unique biodiversity, increasing anthropogenic change has left only 10% of original forest cover and 18% of native vegetation intact, with one-third of this degradation occurring since 1970 (Moat & Smith, 2007; Myers et al., 2000). Specifically in western Madagascar, primary forest cover declined from 12.5% to 2.8% between 1950 and 1990 (Smith et al., 1997). The drivers of deforestation vary by ecoregion, but practices of agriculture cultivation and conversion, charcoal production, and wood production are significantly contributing to this trend.

Climate change is also further distressing the semi-arid regions of southern Madagascar. Temperatures have been steadily rising since the 1950s, to be 0.2ºC warmer in 2000, and drought has been more common in recent years. Drought may be attributed with some uncertainty to a combination of climate change and the rapid recent deforestation discussed above (Heath, 2010). Climate change impacts are expected to exacerbate problems in food security, economic livelihoods, and water quality and supply as a result of increasing soil erosion and deforestation.



Cover image. Euphorbia trees emerge from the thicket of the Spiny Forest. Photo credit: B. Madden

Figure 11 (right). Vegetation map of Madagascar illustrates the diverse range of ecosystems on the island country. Graphic credit: O. Lau

Figure 12 (left). A Euphorbia stenoclada grows with brilliance in the Spiny Forest. Photo credit: C. Santoro
Figure 13 (right). The 'Spiny Forest' gets its name from the diversity of spiny vegetation that are prevalent throughout the region such as this octopus tree (Alluaudia montagnacii). Photo credit: B. Madden

Spiny Forest
The Spiny Forest ecoregion spans an area of approximately 2.38 million ha in a north-south direction on the limestone plateau and sandstone ridges inland from the south and west coasts at altitudes ranging from sea-level to 300 m within Toliara Province (Moat & Smith, 2007). The climate is sub-arid and the region experiences low and variable rainfall of 330 to 540 mm per year (Leprun et al., 2009; Moat & Smith, 2007). The combination of abiotic and biotic conditions produces a landscape of desert and xeric shrublands, where 336 plants are documented and include species such as the spiny Didiereaceae, Euphorbiaceae and Adansonia. (Scott et al., 2005). Of these, between 90-95% are endemic (Gautier & Goodman, 2003). This biodiversity supports a wide range of unique wildlife and provides direct and indirect benefits to human and ecological systems.

A major threat to the Spiny Forest is rampant forest clearing. Between 1975 and 2000, the southwestern dry Spiny Forest experienced a dramatic 70.28% loss (Moat & Smith, 2007). While multiple factors such as agricultural conversion (see *Food Security* section) and construction contribute to deforestation, the primary driver is charcoal production, which is discussed in the following section. Harvesting of wood resources is selective based on use and demand. For example, lower density trees such as givotia are targeted for the fabrication of pirogues and hardwoods such as *Commiphora spp.* and *Cedrelopsis grevei* for construction material (Seddon et al., 2000). For charcoal, all trees species are prey for cutting, except those of low fiber density (Seddon et al., 2000). The current rate of extraction is unsustainable since the regenerative capacity and potential of these species to recover is extremely low, if existent at all. The low resilience of the forest system may be due to a combination of factors including increased intensity and duration of disturbance, agriculture conversion, environmental climate conditions (i.e., low rainfall, high temperature, and high evaporation), and poor quartz sand soil (Leprun et al., 2009). As of 2006, less than 5% of the Spiny Forest is protected (Moat & Smith, 2006).

Charcoal

A primary driver of forest clearing in Toliara Province is the production of charcoal, which is commonly used in the region for cooking. Approximately 69.2% of the island's population is rural and depends directly on ecosystem services and resources for daily survival, while the remaining 30.2% in urban areas also use forest resources (United Nations, 2008). The limited availability of agricultural land and profitability of agricultural activity has forced many to seek alternative sources of income. With much of the country dependent on wood-based charcoal for daily use, it is estimated that 1,067,880 tons were produced in 2009 (FAO, 2011). Hence, charcoal production provides a steady and reliable income for those with few options. Despite national regulations that determine who and how much charcoal can be harvested, the lack of government oversight allows people to easily participate in the charcoal economy. Logging for charcoal has proven especially devastating for the Spiny Forest and the species that thrive in this unique ecosystem.

Figure 14. Bags of charcoal in Ambolomailaka waiting to be trucked into Toliara. Photo credit: O. Lau

While clearing for charcoal is generally a small-scale, high-intensity activity, the aggregation of these individual acts create widespread deforestation. The Ministry of Water and Forest (MEF) legally handles licensing to manage unprotected government forests by issuing a limited number of permits so that harvesting is sustainable and monitored by local MEF representatives. However, corruption coupled with the lack of government resources for effective monitoring allows illegal production to flourish. Seddon et al. (2000) found that MEF officials not only issued more permits than allowed, exacerbating unsustainable harvesting, but were themselves engaged in charcoal production. According to a World Wildlife Fund (WWF) investigation in 2009, four trucks were observed journeying south twice a week on National Route (RN) 9 from the depths of the Spiny Forest into Toliara, each carrying a maximum of 250 bags (Figure 14 &15). Within a year, eight trucks were making the trip twice a week, carrying 400 bags each per trip (WWF, 2010). The increase in charcoal business has been attributed to several factors including drought and the limited availability of arable land, which has forced the regional rural

Figure 15. In Toliara, charcoal is sold in the urban market. Charcoal is commonly used for cooking and heating. Photo credit: O. Lau

population to seek alternative sources of income. In Mangily, a coastal village 27 km north from Toliara, approximately 40% of the people are employed in the production of charcoal, of which only 30% is used locally. The remainder is transported south on RN9 to Toliara (Seddon et al., 2000). Study results show that a large portion of the regional community and surrounding inhabitants rely on charcoal production for their staple income.

Land Management

National Policies

An environmental policy-making framework was developed in the late 1980's to address concerns of deforestation and threats to biodiversity. Two major factors contributed to this, the nation's economic debt crisis and increasing pressure from the international community and conservation non-governmental organizations (NGOs). The framework led to the development of new transnational environmental management policies with global institutions such as the World Bank and WWF beginning with the National Environmental Action Plan (NEAP) and the Charter for the Environment in 1990. Then in 1996, former President Marc Ravalomanana proposed the Durban Vision Initiative, which committed Madagascar to tripling the amount of protected lands within six years to create a 6 million ha network of terrestrial and marine reserves. During this time, the government shifted toward decentralization to adopt two measures that recognize and integrate traditional rights into governance. The Malagasy government in 1996 legislated the contractual transfer of management of renewable resources to local communities with Law 96025, and in 1999, enacted Decree 99-952, which allows for two or more neighboring communes to cooperate and defend their common interests, e.g., managing natural resources through the structure of the Public Organization for Inter-Communal Cooperation (OPCI) (Rakotoson & Tanner, 2006). This marked a significant step forward toward integration of *dina* (local rule-making processes) into official state management and recognition of local rights. Additionally, the government established the National Land Program (PNF) in 2005 as part of the national tenure security reforms. Land titles called *certificate foncier* are issued at the lowest level of local government, the commune (Programme National Foncier, 2011). A commission at the commune level keeps all records of rights and transactions and now handles all proceedings of sales, inheritances, long-term leases, and mortgages. As of 2007, 39 commune offices have logged over 12,000 requests for land certificate, with 2,400 land certificates issued covering 2,900 ha (Teyssier et al., 2008).

Despite the enactment of national environmental policies, follow-through by the Malagasy government has proven ineffective and been set back further by the military coup in 2009. Little progress has been made to implement the reforms in statutory law and many places remain unprotected and untitled. In some cases, areas demarcated for protection are seen as mere 'paper parks' with little or no change in management (Kunzig, 2008). In the meantime, rampant clearing continues due to the lack of enforcement and sufficient resources to manage the unique forests.

Land Ownership

The landscape of land ownership is a quagmire with multiple claims for control. By law, the Malagasy government owns all untitled or uncultivated land and most natural forest areas are designated as classified forests or protected areas. Though the government stakes ownership of these areas, the lack of funding and resources limits their ability to protect large areas of forest despite the adoption of environmental policies. Permanent crop fields are privately owned through official titles or *dina*. Traditionally, land is passed to descendants of those who originally cleared the plots. The government recognizes this traditional practice, but the land must be in permanent cultivation for the official title to be applicable.

Protection Areas

To ensure long-term protection of irreplaceable ecosystems, several courses of action are historically seen as the most effective. These approaches span the spectrum of institutional control and community engagement to ensure conservation and management of natural resources.

Figure 16. Natural treasures such as Isalo National Park receive funding, tourists, and protection. An official park guide leads students through the Park. Photo credit: O. Lau

Establishment of formally protected areas

Precedents of formally protected areas in Madagascar are Parc National de Mananara-Nord and Parc National de Masoala (Seddon et al., 2000). This includes categorization as either a national or provincial park. Provincial parks allow for greater autonomy for officials to protect an area, but resource channels differ from national parks. This option also attracts tourists that bring in additional revenue needed to manage such parks.

Community-based conservation initiatives

A wholly community-based conservation method would involve the local community voluntarily staking out and protecting their surrounding area. Community-based forest management is touted because local communities would most immediately feel adverse effects of deforestation. There are few (if any) instances available in the literature where this has occurred independently. Main reasons are that the Malagasy often find immediate and tangible benefits in living off the land, either by harvesting wood for charcoal production or to sell, or converting forests into crop fields to feed their families. Community-based initiatives may also fail because of centralized and non-transparent management by an elite member of the community and/or lack of accountability to the community by the designated manager (Raik, 2007).

Géstion Locale Sécurisée (GELOSE)

GELOSE is a relatively new approach to conservation implemented by the national government. As part of the broader decentralization strategy, resource use and management are negotiated between local communities and the national government - a middle ground taking the benefits of the two previous arrangements. The arrangement enables locals to legally defend against illegal exploitation of resources. In the Toliara province, this approach has been implemented in other parts of the Spiny Forest. In the Mikea Forest region in 1999, L'Association pour Seuvegarde de l'Environment established a GELOSE, and a similar program was initiated near Lake Andranobe (Seddon et al., 2000). The long-term impacts on protecting these forests are still unknown.

LR 2: Energy Potential

Background
The island of Madagascar is geographically about the size of California and Oregon combined, with a population of 21.28 million (CIA, 2011). However, the population growth rate is among the highest in the world, at nearly 3% (CIA, 2011), and, being an island, resources are limited and often have to be imported. Energy provision is especially problematic given the very low GNP per capita of $1060 and lack of fossil fuel resources (World Bank, 2009). The average energy use per capita was 40.0 kg of oil equivalent in 2007 (UN Statistics Division, 2010), which is already low compared to OPEC countries, and yet many urban and rural Malagasy still do not have access even to this level of energy resource.

Conditions in Ranobe, Madagascar
From our household surveys, the median household income is $202 per year but almost half of the households interviewed make less than $100 per year. Ranobe currently operates without electricity, though a few higher income households use battery-powered radios for entertainment. Other exceptions include Ho Avy and a few employees from outside Ranobe who own cell phones. A majority of the energy budget for the Ranobe community comes from biomass for cooking.

Current energy needs in Ranobe, outside from Ho Avy's use of a solar photovoltaic system to power their research center, are met through a small biodigester and Spiny Forest biomass. Sufficient biomass is currently not hard to find in the area. However, with a forest protection area in the process of being established, Ho Avy may need to find ways for the villagers to meet their energy demands with significantly less biomass. Otherwise villagers may simply travel farther to obtain biomass for cooking. Observations in the village suggest that women play the major, though not sole, role in obtaining biomass. Unfortunately, literature suggests that as these activities become more time consuming, "it may reduce woman's metabolic energy level, limit the time available for agricultural and non-agricultural (e.g., entrepreneurial) economic activities, and/or detract from children's play and study time" (Murphy, 2001; Skutsch, 1998; Parikh, 1995). Exposure to smoke from burning biomass can also result in health problems like conjunctivitis and acute respiratory infection (ARI) (WHO, 1991; Kammen, 1995a). Compounding these health effects is open-fire cooking that takes place indoors, which was observed in Ranobe.

Burning wood also emits carbon dioxide, the most significant contributor to climate change (Davidson, 1993). Although emissions in Madagascar are much lower than in industrialized nations, we still recommend considering strategies to reduce emissions. As of 2006, Madagascar emitted 2.83 million metric tons, or 0.2 metric tons per capita, compared to the United States' 5.74 billion metric tons of carbon dioxide, or 18.4 metric tons per capita (UN Statistics Division, 2010). However, the people of Madagascar and specifically Ranobe remain extremely poor, and future economic development can be expected to increase these emissions given traditional biomass and fossil-based energy sources.

Sunset in Ranobe. Photo credit: P. Liao

Figure 17 (left). Migrants transporting bags of charcoal from the Spiny Forest. Photo credit: P. Liao
Figure 18 (right). These bags of charcoal are then sold along RN9. Each bag holds approximately 30 medium sized trees and sells for only one US dollar (Seddon et al., 2000). Photo credit: O. Lau

Energy Poverty Definitions
For this section of the report, certain common definitions are important to understand the energy context of developing countries and Madagascar:

Energy access: access to a sufficient quantity of energy to fulfill basic services and provide for development opportunities. The energy required to meet the needs of the many people currently living without sufficient access is very small compared to total world demand; likewise, investments to improve energy access are small compared to investments for global energy security.

Energy poverty: Energy access is important for reducing economic poverty, improving education, and improving health, among other factors, and insufficient access is generally referred to as energy poverty. Although a standardized global definition of energy poverty does not exist, the classification depends on both physical access and household expenditure required to meet energy needs (Mizra & Szirmai, 2010).

Biomass Implications for Energy Poverty
The most significant causes of deforestation around the world seem to be agricultural land expansion, lumbering, and road building. It is important to note that fuelwood collection may not actively contribute to deforestation because tree trunks may not be harmed (Casse et al., 2004). However, all deforestation does contribute to energy poverty, which often manifests itself as a shortage of fuelwood in areas without electricity. (See *Appendix C* for Ranobe survey results concerning fuelwood use.)

As the *Land Use/Land Cover Change Management* section of this report describes, charcoal collection remains another category of energy use that could be considered an energy export from rural areas to urban areas with little economic payoff (also see the *Economic Growth* section). Charcoal, like fossil fuels, is a high-density, easily-transported fuel that can be trucked long distances at a profit. Hence, the market for charcoal along major roadways remains prevalent in developing nations. Like man-made watersheds of wood - or 'wood sheds'- impromptu charcoal markets, similar to those in Figure 17 & 18, can extend great distances from a large city. These 'wood sheds' can then contribute to rural areas' energy poverty by depleting their fuelwood resources (Holdren & Smith, 2000).

Leapfrogging Energy Technologies

Sustainable development in Ranobe, or in any developing area, needs to carefully consider using leapfrogging technologies to effect a rapid switch from fuelwood and charcoal to modern energy sources like electricity (Karekezi, 1997; World Bank, 1996). Systems such as biodigesters and photovoltaics are often viewed as more sustainable ways of providing electricity than connecting to the grid. (World Bank, 1996; van der Plas, 1998; Hankins & Bess, 1996). However, various studies and projects suggest that rapid implementation of these types of technologies do not immediately carry down to the household level. Household adoption remains an incremental process that coincides with the technological capabilities of these households (Murphy, 2001).

Given these circumstances, Murphy (2001) suggests three guidelines for energy analysis and implementation in East Africa. First, technical and economic analysis are not sufficient for technological adoption; environmentally sustainable technologies become socially sustainable when additional social, cultural or political drivers influence the decisions of targeted populations. Secondly, technological diffusion occurs in parallel to economic development and social change. Finally, the most effective projects intend to improve quality of life and not simply 'disseminate a particular technology or mitigate an environmental problem.'

Figure 19. Ranobe lacks access to energy infrastructures. Photo credit: C. Santoro

In other African countries, PV adoption has been limited by low power capacity in simple systems, high capital investment, and the ability of people to maintain and use the systems within their budget (Murphy, 2001). Integral to the durability of PV systems is a charging regulator, which protects batteries from overcharge and deep discharge, extending their lifetimes and lowering lifetime operation cost of the PV system. In Kenya, regulators have been often overlooked to lower the initial capital cost of the system, but such oversight may increase lifetime costs (van der Plas, 1998; Karekezi, 1997).

Access to grid electricity around Ranobe and in other rural areas remains limited to settlements along major roads or near cities, although some wealthier tourist areas do acquire a grid connection or some means to produce electricity – usually photovoltaics or a generator. Many major producers of off-the-grid electricity are foreign-owned or -operated organizations. Additionally, other renewable energy projects such as biogas, wind power and micro-hydropower stations remain limited in purpose and in scale in these areas, particularly in comparison to the demand for electricity services (Karekezi, 1997).

Adoption/Planning Limitations

With the exception of improved cookstoves, the majority of energy technologies must be imported. The result is a top-down, technology-focused approach to energy system design. Although some of these technologies have been successful elsewhere in the world, they are often quite difficult to adapt to the economic and social conditions in rural Africa (Goldemberg, 1998). Understanding changes to local energy systems will become most important to rural people (especially the women, who are responsible for cooking and managing their homes), and ascertaining how energy improvements rank in comparison with advances in agriculture, health care, housing, and education is paramount to any energy plan (Murphy, 2001). Dissemination into rural villages will require significant training to introduce economically viable and practical skills in these technologies. Often such training requires collaboration with villagers to determine their energy needs before considering technology options.

The information needed to determine the success of an adoption program is not the number of stoves or PV systems distributed. Technologies adopted will only be sustainable if they match people's daily patterns of behavior (Scott, 1995). Adoption of most new energy technology is heavily dependent on outside funding and expertise; however, without profitable participation by indigenous people in producing, marketing, and servicing electricity connections, appliances, and household systems, it will remain a top-down mechanism with less potential for sustained adoption. Implementation must be viewed in terms of adoption. Currently, if the support created by Ho Avy's efforts and existence is removed, the spread and use of these technologies becomes endangered.

LR 3: Water and Health

Background

According to the World Health Organization (WHO) and UNICEF (2010), health in Madagascar has been steadily improving since 1990. Between 1990 and 2008, mortality rates of children under-five have fallen from 167 to 106 deaths per 1000 live births as shown in Figure 20. However, health issues remained a major cause of under-five deaths in 2008, with diarrhea as the single greatest cause followed by malaria (see Figure 21). Even with prevalence this high, treatment occurs in less than half of cases (Figure 22) and did not increase between 2000 and 2004, highlighting the need for further health education and resources.

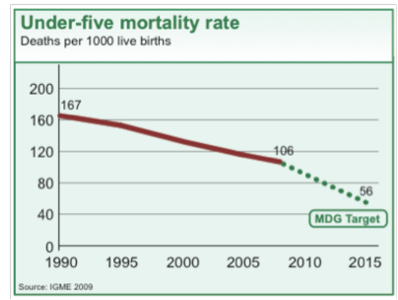


Figure 20. Under-five mortality rates in Madagascar from 1990 to 2008 (WHO & UNICEF, 2010).

Furthermore, water and sanitation issues, especially in rural areas, could be significantly improved. According to the WHO and UNICEF (2010), Malagasy rural populations get 71% of their drinking water from unimproved sources, i.e., open wells, lakes or rivers (Figure 23), that commonly spread communal and other types of diseases. Sanitation is also a major issue in public health. Malagasy rural populations experience open defecation and unimproved facilities on a regular basis (73%, Figure 24).

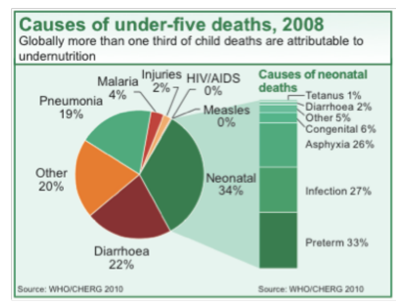


Figure 21. Cause of under-five death in Madagascar in 2008 (WHO & UNICEF, 2010).

Several programs in other developing nations show progress in dealing with these health concerns with relatively simply solutions. These solutions are outlined in the following sub-sections.

Prevalent Diseases

Diarrhea

Diarrhea usually stems from gastrointestinal infection from bacterial, viral, or parasitic organisms and is dispersed via contaminated food, drinking water or poor hygiene. Water contaminated with human or animal feces contains microorganisms that cause diarrhea through direct consumption or indirectly through crops irrigated with or fish harvested from contaminated water. Children, malnourished people, and people with weakened immune systems can experience severe diarrhea

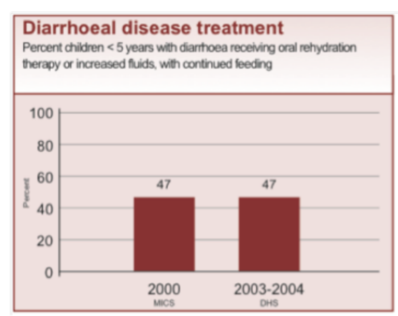


Figure 22. Percent of children under-five with diarrhea receiving oral rehydration therapy or increased fluids (WHO & UNICEF, 2010).

Cover image. Going home after a hard days work, Ranobe villagers walk through the flooded road and rice fields to get back to their families. Photo credit: O. Lau

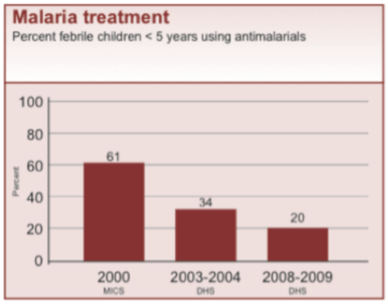


Figure 23. Percent of febrile children under-five using antimalarials (WHO & UNICEF, 2010).

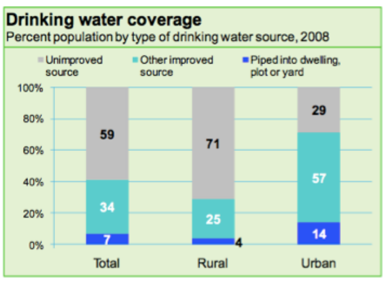


Figure 24. Percent of the population by type of drinking water source in 2008 (WHO & UNICEF, 2010).

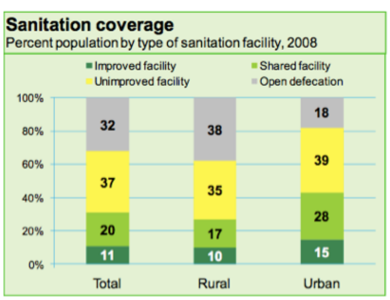


Figure 25. Percent of the Malagasy population by type of sanitation facility in 2008 (WHO & UNICEF, 2010).

resulting in fluid loss and dehydration that can be life-threatening (WHO, 2011). According to the WHO (2009a), key measures to prevent diarrhea include:

- access to safe drinking-water
- improved sanitation
- exclusive breastfeeding for the first six months of life
- good personal and food hygiene
- health education about how infections spread, and
- rotavirus vaccination.

Incentive-based education to teach oral rehydration therapy
In 1980, the Bangladesh Rural Advancement Committee (BRAC) innovated a health education program to reduce complications from diarrhea-related illnesses and deaths. They used a simple solution - oral rehydration salts, or ORS - of water, salt, and sugar. BRAC then trained locals as health workers to disseminate instructions on making and using the solution from local ingredients. BRAC estimates the cost of teaching each household at $0.75 for the 10-year program (Chowdbury, 2001).

As a regional initiative, the program covered much of Bangladesh. Health teams worked in small villages, and each worker spoke with mothers in 10 households each day. BRAC verified the effectiveness of the training by orally quizzing the mother before having her make the solution twice, or until the approval of the health worker. Each session took 20 to 30 minutes.

The program used random, supervisory checks of the quizzes from 10% of the households taught by each health worker every month to monitor success. The health worker's pay depended on the mothers' performance, which was graded from A to D. Grades of D gave no returns. The minimum salary for health workers was set at 250 Taka (Bangladesh's currency), with an average of 600 Taka per month after including performance rewards, or about $113 in 2010 dollars. Monitoring showed that 90% of mothers initially scored at the level of A or B, but two years later only 65% still did. Therefore follow-up education was introduced in schools. Mortality rates did fall over the study period, although isolating the effects of the ORS program from other influences was difficult.

As of May 2009, Madagascar had a national policy to promote the use of ORS for treating childhood diarrhea (UNICEF & WHO, 2009).

Schistosomiasis

Schistosomiasis is a chronic parasitic disease that is caused by a trematode flatworm parasite. Two types of schistosomiasis are predominantly found in Africa, *Schistosoma haematobium*, which causes urinary schistosomiasis and *Schistosoma mansoni*, which causes intestinal schistosomiasis. Transmission of schistosome parasites to humans occurs through skin contact with freshwater habitats where the parasite is present. Schistomes requires a molluscan intermediate host to develop and undergo the lifecycle of schistosomiasis (Brooker, 2007; Figure 26). The most likely carriers in Madagascar are snails of the *Bulinus africanus* group (Rollinson, 1987).

Schistosoma haematobium causes severe inflammation and deformation of the urinary bladder, ureters and kidneys. It infects over 90 million worldwide and is found along Madagascar's western coast, including areas around Ranobe and Toliara, and in the north (WHO, 1987; Farid, 1993). People living in these areas are at risk for recurrent exposure. "Long term infection can include scarring and deformity of the ureters and bladder, chronic bacterial superinfection and kidney dysfunction or failure…[hence,] in some endemic areas, *S haematobium*-infected populations are significantly predisposed to develop bladder cancer"(King, 2001). This type is unlikely to be directly lethal, except in endemic areas like the areas around Toliara. Blood in the urine is one of the first signs of a mature worm infection, occurring 10-12 weeks after exposure, along with painful urination and frequent urination (Harries et al., 1986). After years of infection, dysfunction of affected organs can occur (King, 2001).

Schistosoma mansoni is found in Madagascar's eastern and southern areas (WHO, 1987), extending close to Toliara and Ranobe. Early infection signs include cercarial dermatitis or 'schistosome dermatitis,' also called 'swimmers itch', which consists of an itchy, patchy red pinpoint skin rash (Hoeffler, 1974; Amer, 1982). Unfortunately, the rash is often mistaken for scabies, impetigo, or insect bites but can be distinguished by severe itching 12 to 24 hours after exposure on areas that

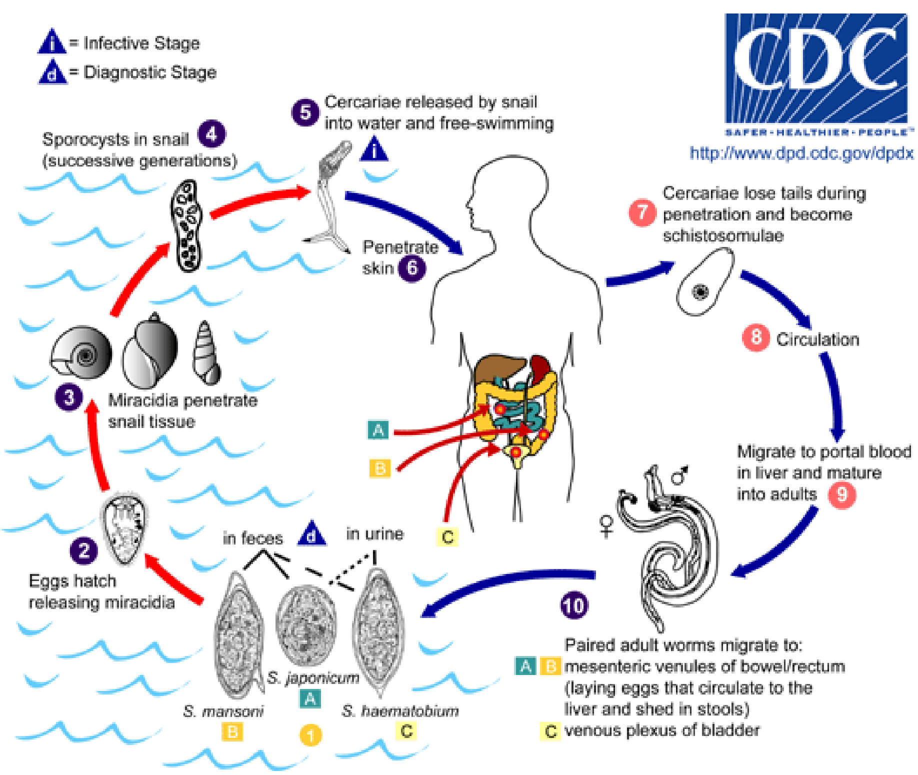


Figure 26. Schistosoma life cycle. Transmission to humans occurs when skin comes into contact with contaminated water (2010a).

were immersed in the water (Appleton, 1984). Common symptoms include fever, cough, infiltrates, muscle pain, and abdominal pain (Pedroso, 1984). More severe and long term symptoms include diarrhea, inflammation of the colon and small intestine, high fever, and heptosplenomegaly (enlarged spleen and liver), which is characterized by an enlarged belly. However, some people may show less defined symptoms such as low fever and few bowel movements, making the disease difficult to diagnose (Lambertucci, 1993; Evans, 1991).

Schistosomiasis Health Education

Health education can be critical to encourage a shift in habits that increase the risk of schistosomiasis; for example, "children cannot be expected to stop swimming and playing in water but they should be taught to urinate before doing so" (Webbe, 1993). To be successful, any health education program must be culturally sensitive and not undermine the authority of the local people.

Health education is an integral component of addressing schistosomiasis, in that knowledge can prevent infection and allow for treatment before the onset of serious complications. Ideally, children of school age will take part in all treatment programs and health education as part of the curriculum. As with the BRAC program described in the previous section, formal teaching is best accomplished through local teachers, and courses should cover the problems, risk, transmission methods, and control strategies. Similar programs have also used school authorities to lead by example and have provided adequate sanitation facilities as part of the lessons. Children can be taught to use and maintain these facilities with lessons in basic hygiene. In turn, older children should be encouraged to teach younger children and their parents (Hubley, 1987).

Additionally, in these programs, adults were made aware of the health education their children were receiving and the importance of encouraging their children to follow it. Adults receiving treatment were given extra attention in health education, with particular emphasis on women, who are exposed more frequently through clothes washing. These women were encouraged to use soap and wash clothes in an area away from the main body of water (Webbe, 1993).

Schistosomiasis Prevention Infrastructure
Studies suggest that to effectively prevent contact with schistosomes-infested water, the water supply for domestic purposes must be (Webbe, 1993):

1. Schistosome-free and of good quality;
2. Adequate for all domestic water needs of the community at all times of the year;
3. Available at sites convenient to users and more convenient than the nearest source of infected water;
4. Available at facilities acceptable to the user for bathing and clothes washing, with approved washing tubs or washing slabs, at approved height;
5. In a delivery system that is easily maintained and readily repaired.

In a comprehensive study on the effect of water in the control of schistosomiasis in St. Lucia, the effects of individual household's water supply and communal laundry, shower, and children's pool facilities were evaluated. Health education played a significant role in improving community health by reducing contact by 92% (Figure 27). Child infections decreased by 75% compared to nearby villages, and the prevalence and intensity of infections decreased in all age groups (Figure 27) (Jordan, 1985; Webb, 1993). Health education persuaded villages to use laundry and shower units in the village instead of the rivers. Furthermore, villages without laundry units began to desire their own units (Webbe, 1993).

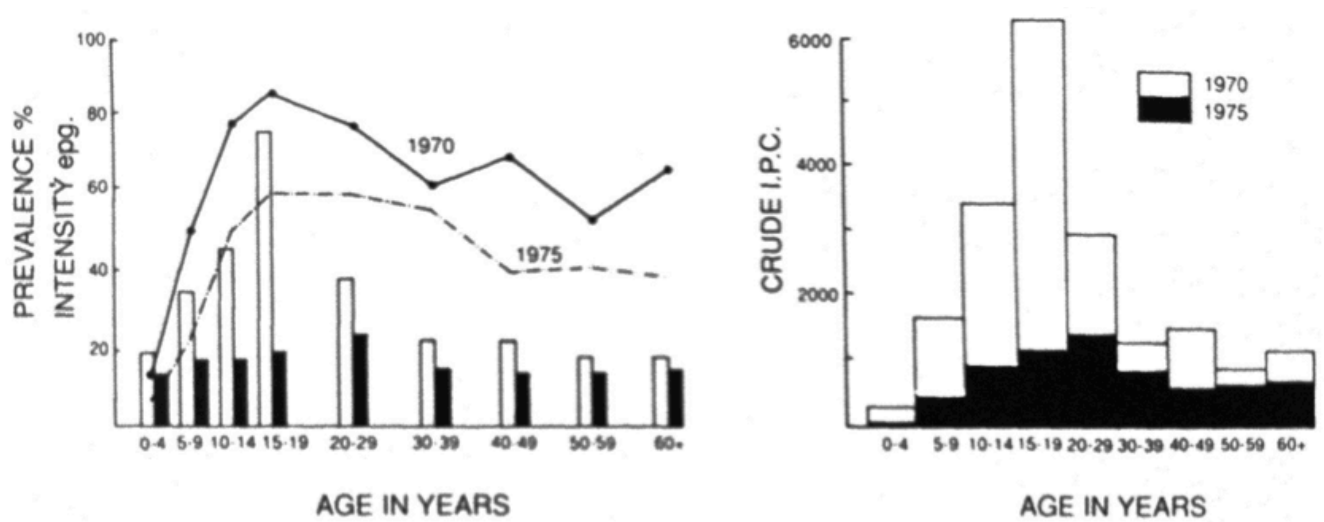


Figure 27. Prevalence (left) and intensity (right) of S. mansoni infections in 1970 before domestic water became available and five years later. Also shown is the resulting change in crude index of potential contamination (Webbe, 1993).

LR 4: Food Security

Background
Since the FAO initiated the "Freedom from Hunger" Campaign in 1960, the world has come a long way in alleviating issues related to poverty and hunger (Jackson, 2007). While many regions of the world have had success in combating hunger, Sub-Saharan Africa has not seen the same gains. According to the FAO, in 2009 there were an estimated 1.02 billion undernourished people in the world, of which 265 million were in Sub-Saharan Africa. Additionally, one in three Africans is chronically undernourished. On average, the FAO and WHO recommend 2250 calories a day to sustain "light activity" (Paarlberg, 2010). In Madagascar, more than two-thirds of the population, urban and rural alike, falls below this threshold (Dostie et al., 2002).

Climate and Environment Drivers
Seasonal climate changes already account for increased poverty rates in Madagascar. The average lean period stretches from November to February (Minten & Barrett, 2008). In rural areas, rice prices can fluctuate up to 45% between the lowest (May-June) and highest prices of the year (December-January). Since the rural poor feel the impacts of price changes in staple crops more acutely, they also become more susceptible to not having sufficient food to eat. The average Malagasy spends 70% of their income on food; the poor may expend an even higher proportion of their income for nourishment (Rasambainarivo & Ranaivoarivelo, 2003). In fact, an additional 8% of Malagasy rural poor drop below the poverty line during the lean season, compared to 3% of the country's urban poor. Additionally, seasonal switching between net sales of agricultural products and net purchases is more common among poorer farming households (Minten & Barrett, 2008). Seasonal changes in diet are also reflected in infant mortality rates, which can more than triple between times of low versus high food prices (Dostie et al., 2002). The heavy reliance of the country on domestic agricultural productivity as well as the already dramatic impacts of seasonal climate shifts clearly demonstrate that climate change will have a serious impact on future Malagasy agriculture.

Looking ahead, temperature increases are expected to be greatest in the south of Madagascar, although coastal areas, such as the areas surrounding Ranobe, may see less warming. Estimates suggest Ranobe may see anywhere from 1.3-2.4ºC increase in temperature over the next 50 years (Heath, 2010). Drought will stretch on and levels of rainfall will continue to decrease. This is corroborated by the results of our Ranobe interviews, in which most respondents cited the droughts of the last four years as the primary obstacle to providing for their families. For example, water for irrigated agriculture, 98% of which is used for rice and rice intensification methods, may become insufficient, and raising livestock also becomes more difficult with less available water (Heath, 2010). Declines in water supply and water quality increase vulnerability to malnutrition and water-borne illness, as well as to poverty, as the already arid South becomes increasingly dry. Decreased rainfall also threatens non-irrigated crops, such as cassava (USAID, 2008). Soil fertility is expected

Men at work in the sweet potato fields. Photo credit: O. Lau

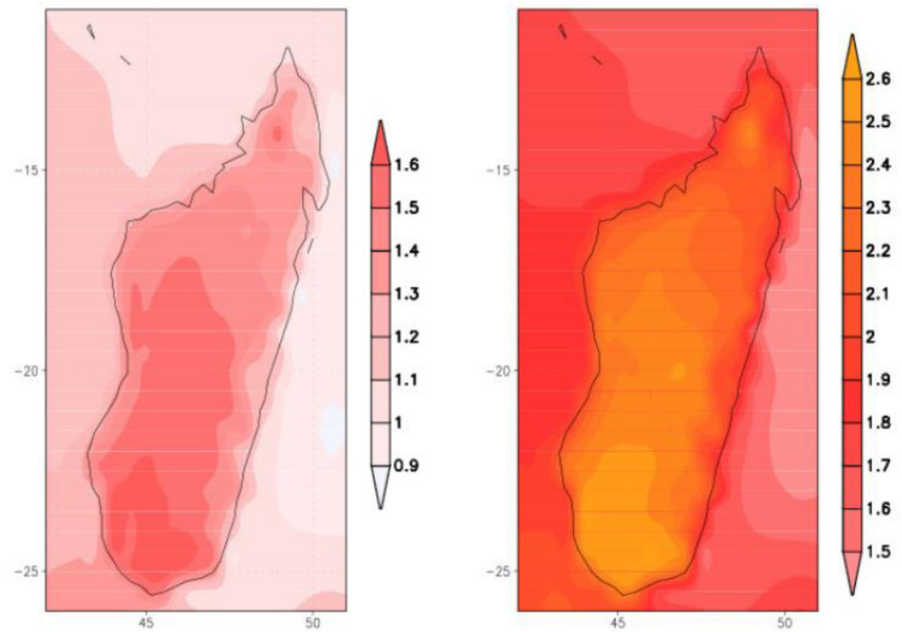


Figure 28. Minimum and maximum temperature increases to Madagascar as result of climate change (Heath, 2010).

to decrease and growing seasons to change. Locust swarms, several of which we witnessed while in Madagascar, and fire will become more frequent with increasing drought (Heath, 2010). Furthermore, severe winds from increasing cyclone frequency will cause destruction of crops and livestock mortality (USAID, 2008).

Given the inevitable climate impacts to agricultural productivity, USAID has identified several adaptation strategies. The first, economic diversification, is already happening in many areas as farmers switch to fishing or diversify their crops, including increases to counter-seasonal cropping. Other adaptations include adopting new technology, such as water pumps and robust varieties of seeds, and supplementary livelihoods, such as charcoal and handicraft production. Reforestation is also suggested by USAID, though it has had limited adoption so far by communities in Madagascar. Critical barriers to many of these adaptation strategies include the need for training and capacity-building, capital investment, population pressures, and isolation of rural communities (USAID, 2008).

Health Effects of Undernourishment
In many poor economies, a primary cause of undernourishment is that available food consists primarily of one staple grain or root, which is often deficient in essential nutrients (Pond et al., 2009). In Madagascar, rice is the primary staple crop and provides over 50% of the country's average calorie consumption. In the more drought-prone south, however, secondary crops such as maize, cassava, and other roots and tubers account for over 40% of caloric consumption (Dostie et al., 2002). Poorer households tend to rely more heavily on these secondary crops for their food sources. Hence, the rice share of caloric intake in the south is less than half of the national average (Dostie et al., 2002).

A monotonous diet that consists mostly of a single type of food will almost certainly leave the population more vulnerable to infections and malnutrition (Pond et al., 2009). Of the two billion people in the world who are anemic from iron deficiencies, 90% of them are from the developing world and also suffer from iodine and other nutrient deficiencies (Southgate et al., 2007). Iron, vitamin B12, vitamin A, and folic acid deficiencies can also lead to anemia in young children. Monotonous plant-based diets are often low in zinc and high in phytate, which can stunt growth in children (Pond et al., 2009). The list goes on. Without an appropriate diet that has sufficient caloric intake and a variety of vital nutrients, the health impacts, especially on children, can be severe. Because Madagascar relies primarily on domestic food production – food accounted for only 10.6% of 2008 imports (FAO, 2010b), and in 2000, these imports represented only about 5.7% of total food consumption (WRI, 2003) – reducing the number of undernourished people is inextricably tied to overall land productivity.

Solving Food Insecurity
Food insecurity often stems not from an overall shortage of food, but instead in a lack of access to food. The severity of this problem varies by location and demographic. For example, women and children tend to be more vulnerable to food insecurity, even though they need fewer calories by FAO standards to be considered food secure (Southgate et al., 2007). Beyond that, preschool

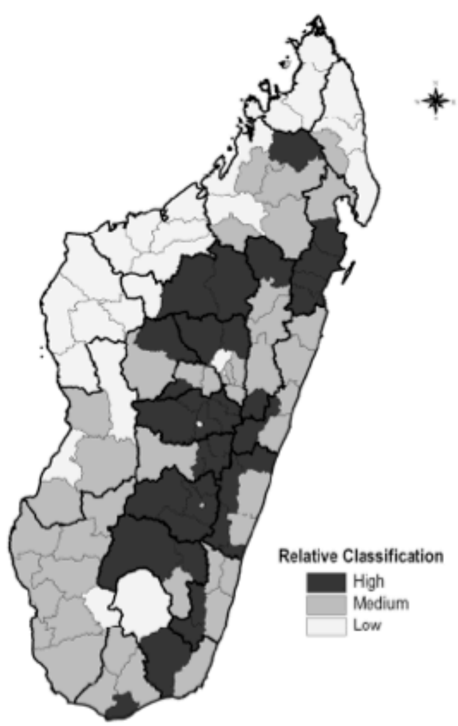


Figure 29. Food insecurity index. The southwest region where Ranobe is located experiences relatively medium levels of food insecurity (USAID, 2008a).

children and pregnant or nursing women are at the worst risk of chronic undernutrition (Paarlberg, 2010). It is also ironic that although women are more vulnerable for food insecurity and undernutrition, they tend to be the ones responsible for farming in African countries. This vulnerability may stem from preferential treatment (e.g., easier access to food) of males in Malagasy society. It is also counterintuitive that food shortages generally occur in regions that do the farming rather than in cities (Southgate et al., 2007). One likely explanation is that poorer rural households are more economically vulnerable and cannot afford to purchase supplemental food when yields are low as urban households can.

Improving Agricultural Yield

Arable land in Madagascar increased by 3.6% from 1980-1999 to 3,108 thousand ha, but food production per capita decreased consistently over the period of 1975-1999 by a total of at least 1.5% (Southgate et al., 2007). Though 70% of the Malagasy rural population grows rice, 66% are still net buyers of rice, implying that yields should be improved (Minten & Barrett, 2008). As of 2008, Madagascar was importing between 20-30% of rice consumed annually (USAID, 2008). The percentage of irrigated cropland in Madagascar is high, at 35.1% (Southgate et al., 2007), compared to the 4.1% average for Africa (Paarlberg, 2010). However, Madagascar has also suffered soil nutrient (nitrogen, phosphorous, potassium) losses exceeding 60 kg/year, from a combination of crop uptake, soil erosion, leaching, and other processes (Southgate et al., 2007). Malagasy use of fertilizer and agricultural machinery also ranks low even compared to other African countries (Southgate et al., 2007).

Suggested methods to improve overall productivity and robustness against climate change range from basic adaptation techniques, such as early planting schedules, long-season cultivars, and changing planting density, to more advanced adaptations, such as using cultivars with improved radiation-use efficiency or stress tolerance (Pond et al., 2009). Another way of categorizing farming strategies is to compare agroecology techniques, which promote learning from and imitating nature's successes, to green revolution approaches, which use new seeds that could be hardier, more productive, more drought-resistant, more nutritious, etc (Paarlberg, 2010). Dostie et al. (2002) recommends focusing on improving the yield of secondary crops, such as cassava, maize, and roots, to alleviate seasonal poverty, since these complex carbohydrates are cheaper and thus easier to access during the lean season.

A major problem in rural areas is that farmers often cannot afford to experiment with new seeds or new technologies. Successful technologies will consider more than just potential for improving agricultural yield. The System of Rice Intensification (SRI), for instance, was presumed to be appropriate for poor areas in Madagascar because it required minimal external inputs and could significantly improve rice yields. However, SRI requires a great deal of labor at a time when farmers already work harder in the fields. Because of this, it has not been well adopted in Madagascar despite its potential to increase crop yields; indeed, the disadoption rate was 40% (Moser & Barrett, 2003).

Figure 30. Ranobe villagers rely on the yield from their agricultural fields for their daily food. Photo credit: O. Lau

Figure 31. Villagers drying rice in open air. Rice is susceptible to theft, wind, etc. and may also lose nutritional value due to ultraviolet exposure. Photo credit: P. Liao

As mentioned earlier, seasonal changes are also responsible for significant food security concerns. One way to rectify this is to improve storage of harvested crops. The traditional method to store food in tropical climates is to dry it in the open air; however, this technique is extremely weather-dependent (Gregoire, 1984). The food can also be contaminated, infested by microorganisms or stolen by animals. Drying time is also unpredictable, and long drying times can result in further post-harvest losses from theft (Forson, 2007). Finally, drying food in the open air where it is exposed to the sun degrades much of the nutritional value of the food.

Using a solar food dryer can protect the nutritional value and quality of the food being dried while speeding up the drying process (Gregoire, 1984). There are multiple types of solar food dryers differing in size, material, portability, airflow pattern, construction cost, and time required to dry food.


BILOMALAZA
FORCE ONE
Orange

LR 5: Economic Growth

Development through Improved Agriculture
Economic development is critical for reducing food insecurity, improving health and sanitation, and addressing poverty. To empower economic development, a framework for economic growth is needed, defined by an honest government providing: security, stability, order, property rights, competition, a stable infrastructure, agricultural research and development, education, public sanitation and health, protection of natural resources, and food and income safety nets. Without these, it will be difficult for economic development to sustainably and continuously occur (Southgate et al., 2007).

Even without these frameworks currently in place, though, economic development is happening. For instance, poor households tend to spend proportionally more of their income on food for survival. As a result, those who are poorer are more incentivized to improve economically since they can see the direct benefits of having greater income (Pond et al., 2009). However, this is only true to a certain extent, since the poorest households live day-to-day on their income and cannot afford to use different techniques, such as SRI, to improve agricultural yields. In the SRI example, only farmers who had at least one stable and non-rice related source of income put their money and effort into trying SRI (Moser & Barrett, 2003).

Private sector partnerships also have the freedom to develop diverse aspects of rural economies. These may be best exemplified with case studies of farmer's group partnerships. In one such case, Starling Resources in Indonesia assisted with the creation of farmer networks and training that allowed farmers to purchase greenhouses and expand their agricultural base (Starling Resources, 2010). In another, the Pakngao Maize Farmer Group Enterprise in Laos dramatically raised incomes for 120 corn farmers involved in a cost- and labor-sharing cooperative (Ling, 2010), and in a third, Swift Company Limited in Thailand remains the sole buyer of certain farmers' certified organic asparagus in exchange for fixed prices and training in organic farming (Cadilhon, 2010).

Local residents rush to sell goods to taxi-brousse passengers in Ambolomailaka, a bustling coastal town just over 4 km from Ranobe. Photo credit: O. Lau

In these cases, education proved vital to creating business structure. Additionally, promoting alternative means of income outside of rice or staple crops that do not require upfront labor or capital costs or that allow flexibility in scheduling are more likely to be adopted and sustainable. These techniques allow those who face constant or more severe liquidity constraints the opportunity to improve their own economic status (Moser & Barrett, 2003).

To move beyond current economic advances, however, the government must play a key role in spurring economic and agricultural development. This is particularly true since the two types of development are so closely tied in Madagascar. African governments typically spend only 5% of their budget on agricultural investments, even though 60% of their citizens depend on the farming sector for income and employment (Paarlberg, 2010). In Madagascar, this percentage is higher, with over 85% of the population in 2008 leading rural subsistence-based lives (USAID, 2008). More funding needs to be directed toward this primary component of Malagasy livelihoods.

Economic development strategies for the rural poor have long been explored and debated. Smallholder agriculture in particular poses both a challenge and opportunity for development. Minten and Barrett (2008) find a strong link between adoption of improved agricultural technologies in rural areas of Madagascar and development indicators, such as higher crop yields, lower food prices, and higher wages for unskilled workers. They also encourage land-intensification, improved equipment, and utilization of irrigation to increase crop yields (Minten & Barrett, 2008). Moreover, discussion of the “preconditions for an African green revolution” focuses primarily on commercialization of smallholder agriculture to increase productivity and competitiveness (Rukuni, 2002).

Although Ranobe and Ho Avy may not be able to tackle large-scale policy or institutions, the recommendations for improved technology and infrastructure, as well as increasing commercialization, can be achieved. The role of Ho Avy in the economic development of Ranobe becomes more significant as one considers case studies such the Dryland Applied Research and Extension Project (DAREP) in Eastern Kenya. This project emphasized the need for external support from NGOs or the public sector to adopt strategies such as earlier-maturing crop varieties, shifting agriculture to more profitable crops such as fruit trees, and organization of a farmers' self-help group. Another key conclusion from DAREP was the importance of providing cash flows for rural poor in addition to subsistence food security (Sutherland et al., 1999). A different study also acknowledged that shifting "livelihood diversification away from dependence on food crop production appears to be a key to reducing poverty" (Pender & Gebremedhin, 2007). In each of these cases, assistance from external organizations such as Ho Avy is integral to the initial diversification of the economy.

Creating a Handicrafts and Exports Industry

For many rural villages in developing countries, utilizing natural resources to create products and crafts for sale to developed-world markets has proven a viable strategy. One such example in Madagascar is a rural women's organization selling essential oils at Chez Nanou le Savoyard, a boutique in Ambatolampy. Additionally, the handicraft market in Madagascar is a strong part of the tourist trade.

Figure 32. Tourists stop along the roadside to purchase locally-made handicrafts. Photo credit: B. Madden

South Africa has realized the potential for economic development through handicrafts and created the Department of Arts, Culture, Science and Technology (DACST) to enhance economic and social benefits of arts and culture. According to Cultural Industries Growth Strategies (CIGS) (1998), the industries supported by DACST tend to be:

- highly skilled
- labor intensive, to create a large number of jobs
- differentiated, to support development of small enterprises, and
- linked with strong but flexible networks of production and service systems.

To ensure the success and sustainability of craft sectors, DACST recommends reserving them for the benefit of economically disadvantaged and vulnerable peoples, but approaching the programs as the development of a small business and not as a welfare program. Commitment from local governments and municipalities in planning informal trading areas is also essential to ensure adequate markets. For rural craft enterprises, the key challenge is in identifying markets, information and communication networks, and distribution networks (CIGS, 1998).

Figure 33. Seed press to determine oil yield for biofuel potential. Photo credit: B. Madden

Potential for Biofuels Production

The majority of the literature on the feasibility of biofuels production is summarized in the *Energy Potential* section. However, small-scale production and processing of bioenergy can effectively target development at the more than half-billion Africans currently relying on biomass for energy, while realizing health benefits from reduced pollution (Ejigu, 2008). Ejigu (2008) also describes the feasibility for small village blacksmiths to manage simple bioenergy technologies and processes such as oil-pressing and alcohol distillation. Among the crops with highest yields are sugarcane and jatropha, both of which are grown in Ranobe. This study argues that bioenergy can have significant economic benefits for local smallholder production as well as export of high-value products (Ejigu, 2008).

Options Analysis

In the following five sections, we present background and field work conducted in each of our five key perspective areas, followed by an analysis of options that we considered.

OA 1: Land Use/Land Cover Change Management

Background
Ranobe is a small village with an estimated population of 1,563 inhabitants (Ho Avy, 2011), located approximately 42 km north from the provincial capital, Toliara (with a population of 114,400), and 5 km inland northeast from the coastal town, Ambolomailaka. The district population of the surrounding communes of Toliara II is estimated at 249,370 (Tangeo, 2011; ILo Project, 2011). The region west of Ranobe to the Mozambique Channel is sparsely populated and mostly cleared with much of the landscape fragmented from agricultural practices and clearing for forest products. East of Ranobe is the Spiny Forest.

Agriculture
Ranobe is predominantly an agricultural community. Areas that are most proximate to the village (within a 1 km range) and inhabited areas have been traditionally cultivated for crop production and zebu grazing. Expansion of clearing for agriculture is evident from Google Earth aerial images taken in 2000, 2004, and 2009, but agricultural activity and grazing on these recently cleared areas have been limited due to drought and water availability. These conditions have limited the amount of arable land in the region, and many newer fields that are slightly higher in elevation are left fallow.

While crops are grown year-round, the peak growing season is in their winter from March to October. These crops include maize, rice, squash, cassava, beans, and sugar cane. Fruit trees such as bananas, papayas, guavas, and mangos are also grown and harvested. Agriculture plots are organized by a larger family group and further split among the families within the larger group. It was observed that men, women, and children engage in the cultivation of field crops. Cultivation of crops is low-scale and the community usually harvests enough to meet subsistence needs and to sell in markets at a nearby village or town. While plots are passed through family lineage and marriage, the clan head also delegates and handles land disputes.

Cover image. Only a few trees are left standing in an area recently cleared for agriculture in the past five years. Fields lay fallow due to drought. Photo credit: O. Lau

Figure 34 (right). Children working in the rice fields. Photo credit: C. Santoro

Forest Use

The Spiny Forest provides a wealth of resources to Ranobe village and its surrounding inhabitants. Villagers rely on forest resources for everyday needs such as fuelwood, construction materials, and medicine. It was also observed that clearing for charcoal was prevalent throughout the forest. According to informal conversations and Ho Avy's account, villagers do not currently engage or actively participate in the charcoal economy; however, with a diligence, charcoal burn-pits can easily appear over just a few days, and invisible migrants are generally blamed.

Land Regime

Currently, the stretch of the Spiny Forest in focus has no formal protection. Ho Avy has developed a plan to protect 12,000 ha of forest with 80 ha under the management of FIMPAHARA, the local community organization of men and women in Ranobe that partners with Ho Avy, with plans of expansion currently under work, and 5 ha of FIMPAHARA's agriculture land for agroforestry activities. A new plan is being worked on between Ho Avy, FIMPAHARA, and the local Forest Service to increase protection; there is little information about its progress and development.

Forest Assessment

The project team used Landsat satellite images to evaluate regional and local land cover change from 2000-2010. The regional analysis focused on an 85 km^2 area of interest between the Fiherenana River and Manombo River. Using the post-classification change detection method (see *Appendix A*), the analysis revealed a precipitous 36.9% (Figure 35) decline in forest cover of the Spiny Forest. In a 10 km^2 area more proximate to Ranobe village, the forest demonstrated a similar trend with 42.6% forest loss (Figure 36).

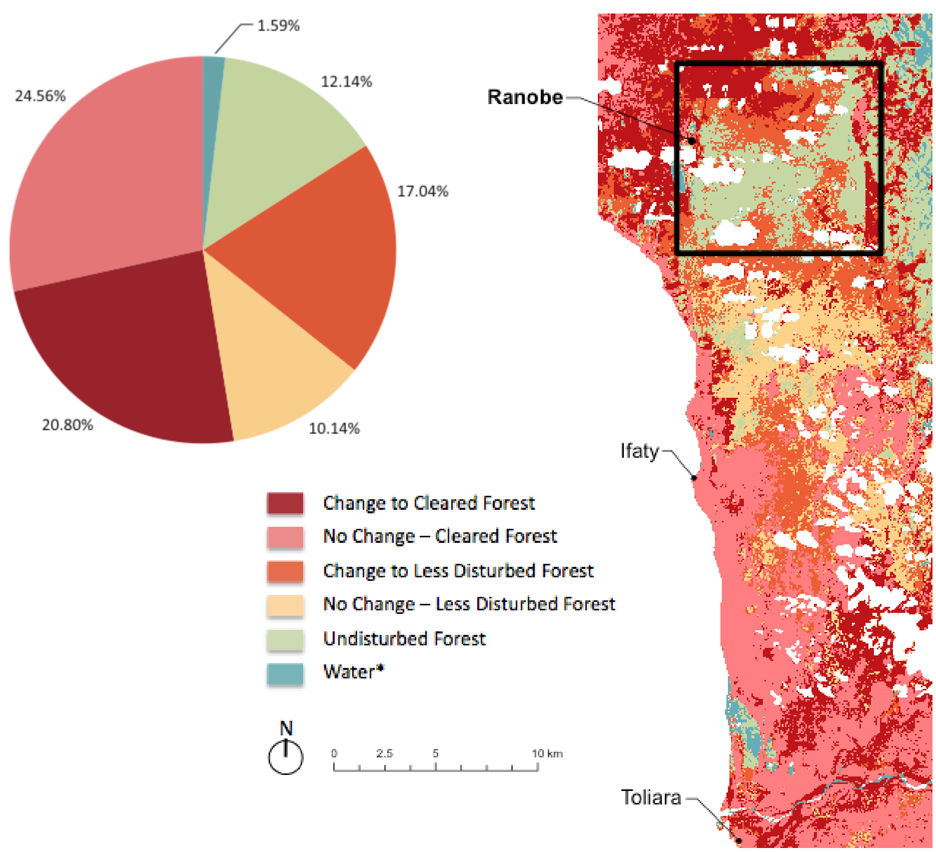


Figure 35. Regional land cover change between 2000 - 2010. Results were generated from Landsat scenes using the post-classification change detection method. Graphic credit: O. Lau & P. Liao

Based on the results from the change analysis, the project team also evaluated areas of risk locally and prioritized areas for protection. These results were combined with field and ancillary data. Primary and secondary road information were obtained from GPS path data from our trail walks and traced from Google Earth images. Land elevation and slope information were determined from Digital Elevation Model (DEM) data from Shuttle Radar Topography Mission (SRTM). Using proximity to primary and secondary roads, villages, existing cleared areas, and land elevation and slope in a multi-criteria analysis (MCA), we determined areas of prioritized risk from anthropogenic destruction (Figure 37). From the risk analysis, the team also defined zones for future protection using MCA based on proximity to the nonprofit field base using the same method (Figure 38). The details of the analysis can be found in *Appendix A*.

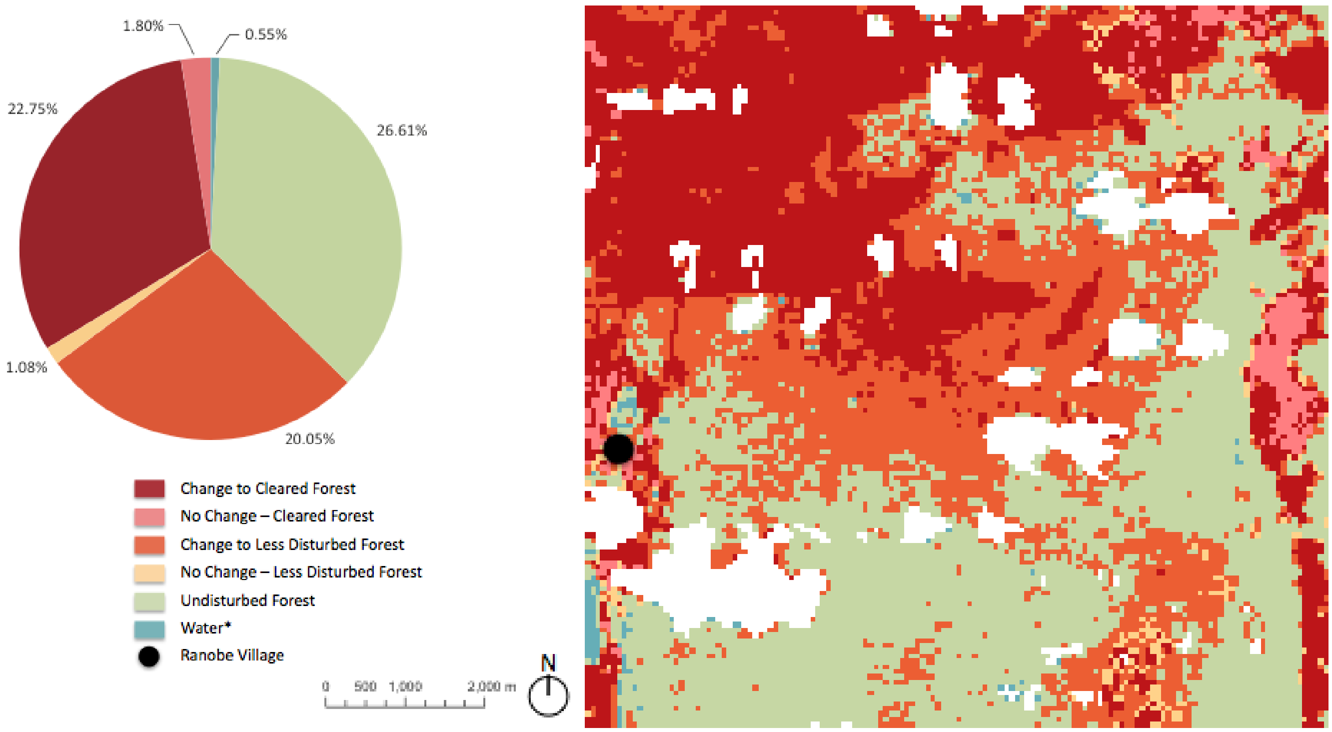


Figure 36. Local land cover change in a 10 km² area between 2000 - 2010. Results were generated from Landsat scenes using the post-classification change detection method. Graphic credit: O. Lau & P. Liao

Options for Land Management

The trend of clearing demonstrates a directional pattern that starts north of Ranobe and moves south and southwest toward the existing forest stand. As described earlier, Ho Avy and FIMPAHARA are in the process of developing a formal protection zone with the local Forest Service in Toliara. As Ho Avy and FIMPAHARA are more familiar with the behavior and incentives of the local community, the process aspects of such a plan are beyond the scope of this paper. Thus, this option analysis considers more generally the benefits and drawbacks of community-based versus government-managed forest management plans for the Ranobe community, as well as the usefulness of the prioritized risk and protection zone maps generated.

1. Community-Based Forest Management Strategy with Ho Avy and Government Support

As a small organization with a strong presence in the field, Ho Avy can move and adapt quickly to changing conditions, both political and natural. Our current understanding is that protected area management will be primarily community-driven, with Ho Avy and local government providing guidance and reinforcement as needed. Such a management structure would benefit greatly from community ownership of forest health and can operate within the national legal framework despite the lack of enforcement. Community members know the forest better than any outsiders, Malagasy or foreign, and can be most effective at protection of the area from intruders. Ho Avy can supplement the villagers' holistic knowledge of the forest with knowledge about forest systems, how to create an ecotourism site, and connections with other nonprofits who may have experience setting up similar management systems. Potential disadvantages of this type of management could be the reliance on government-sanctioned enforcement for violations of protected area protocol, and the dangers of mismanagement of forest funds and lack of transparency with regard to the management system. Additionally, while villagers may not be hesitant about punishment or fines for outsider violations, they may be more averse to such fines to their own and may even protect the guilty, particularly in times of drought and economic need, even as the forest still suffers.

2. Use of Prioritized Risk Area Map and Protection Zones Map

While Figure 37 delineates the areas of prioritized risk within Ranobe's surrounding forest, Figure 38 shows the areas that are at risk and within a close enough distance from the village to be feasibly well protected. These areas can be used as a starting point for negotiating the boundaries of a protection zone. This is, however, subject to many challenges. The forest is dynamic, and an unsupervised area can be cleared overnight. These zones fit neither a visible nor permanent boundary; if the same analysis were repeated with more current data, the results are likely to show more higher risk areas in addition to more areas that are already cleared. However, these maps should be refined if more information is available, and should be used as guidelines to allow flexibility for changes or variables that could not be spatially represented and factored into the mapping criteria.

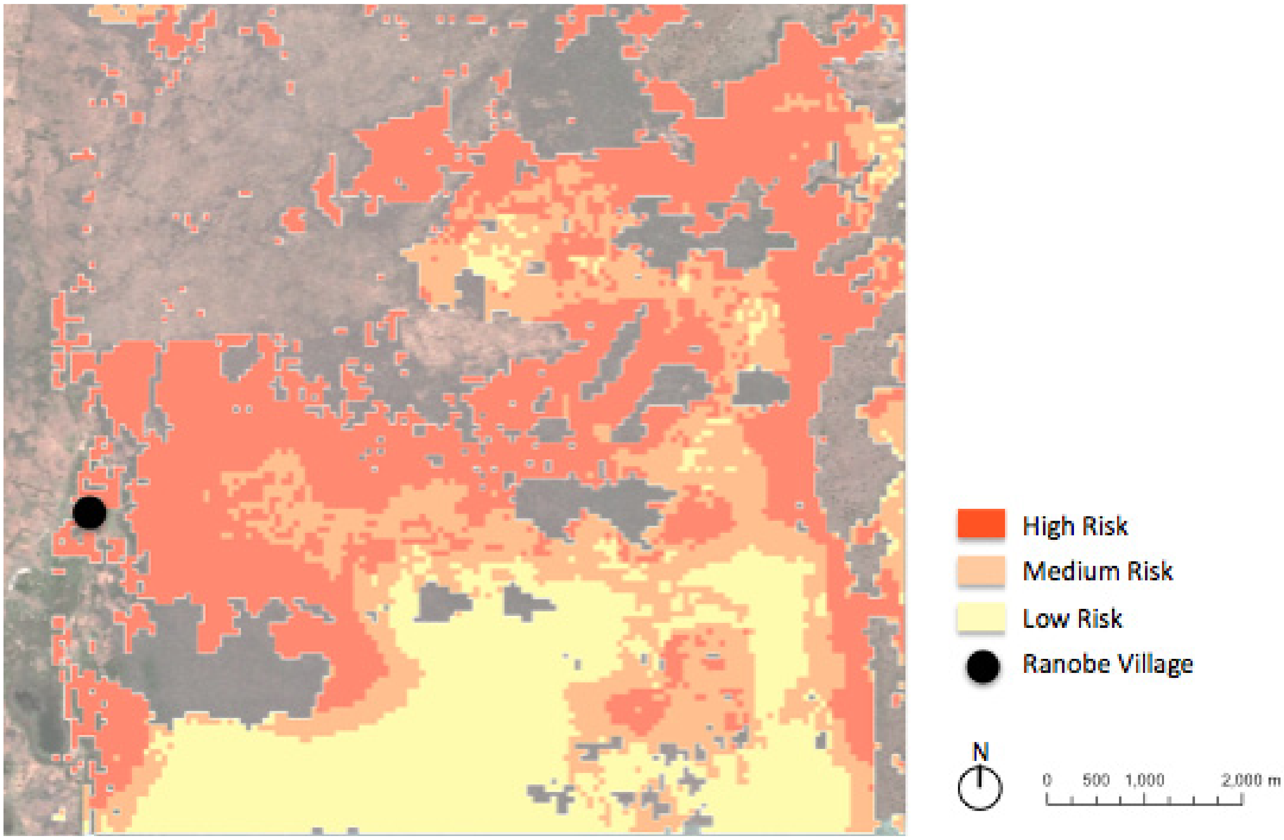


Figure 37. Prioritized risk areas. Graphic credit: O. Lau & P. Liao

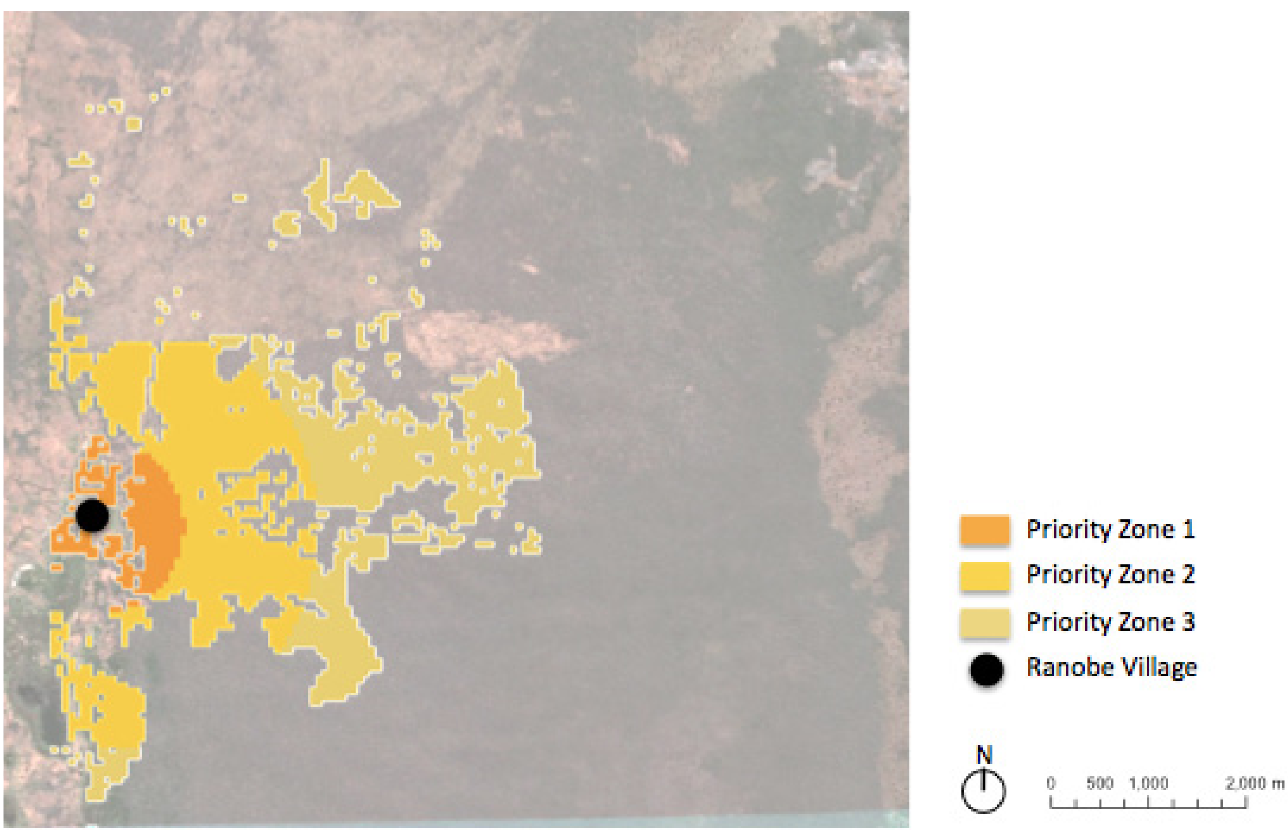


Figure 38. Recommended protection areas based on distance from Ranobe village. Graphic credit: O. Lau & P. Liao

OA 2: Energy Potential

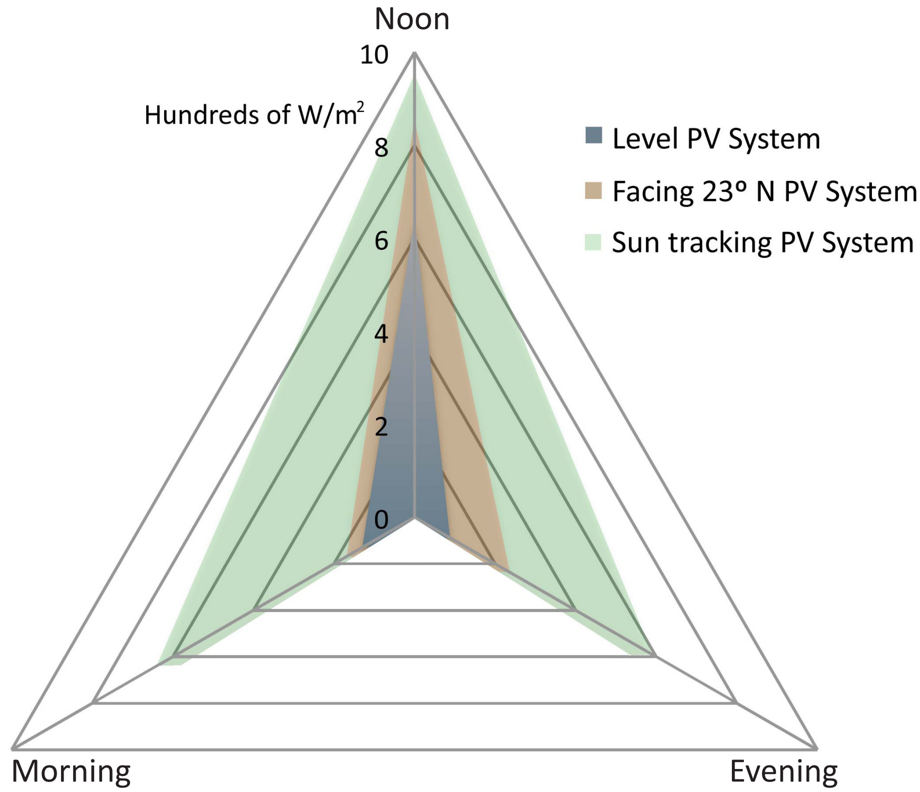
Background
According to the WHO (2009b), only 5% of rural Malagasy have access to electricity. Energy access is important for reducing economic poverty, improving education, and improving health, among other factors, and insufficient access is generally referred to as energy poverty (Mizra & Szirmai, 2010). To eliminate energy poverty in Ranobe, methods must be designed to provide energy for heating, cooking, and lighting; several such systems that could meet current and future energy needs in Ranobe are described below. Integral to each of these is the importance of an educational training program in installation, use, and maintenance of the system. Local skill sets and capabilities may significantly affect adoption by rural households as well as inclusion of those affected in the energy plans. 'Leapfrogging' technologies alone will not be a sufficient strategy to ensure sustainable development.

Measuring Radiative Potential
To verify estimates of solar radiation potential in Ranobe and to select the most effective site for a potential PV system, the team took solar radiation readings three times a day in three locations for the duration of the study period. Two sets of readings simulated the radiation available to fixed panels at different orientations; a third set simulated the added benefit of a sun-tracking system. The three sites evaluated were the top of the Ho Avy research center roof, the site planned for a community center, and a site adjacent to one of Ho Avy's plant nurseries. The three sites were similar in terms of radiative potential, with the nursery having slightly more shading in the afternoon. It should be noted that the only site where we could consistently place the meter above the tree line was on the research center roof. However, if tall pole-mounted PV systems were employed, then any of the three sites could have excellent radiation. It is also significant that the study period fell during the height of Madagascar's winter, so the data collected represents the minimum expected radiation throughout the year.

Cover image. Measuring radiative potential atop the Ho Avy Research Center. Photo credit: C. Santoro

Figure 39 (right). Collecting solar data at the site of the future community center. Photo credit: C. Santoro

Figure 40. Graph depicting the potential of differing photovoltaic system strategies measured in Ranobe. The blue area shows the potential for panels fixed at 90º from horizontal, the Level PV System. The pink area shows the potential from a system fixed facing north and tilted 23º (latitude) above horizontal, the Facing 23º N PV System. Finally the green area shows the potential for a system that tracks the sun throughout the day, Sun Tracking PV System. A sun tracking system would have large benefits compared to other systems. Graphic credit: B. Madden



As shown in Figure 40 above, the benefits of installing PV on a tracking system would be significant. Essentially, a tracking system can be thought of as extending the number of hours of solar radiation from 5 to 9 hours, increasing potential output from a given number of panels. This increases radiation in the mornings and evenings to 600-800 W/m^2 for PV on a tracking system, compared to 100-300 for a fixed PV system. In both cases, average noon radiation is close to 1,000 W/m^2, the on theoretical maximum on Earth. Some of this high number may be explained by the mediocre quality of the solar meter, which does not distinguish between direct and indirect radiation. Nevertheless, the relative benefits should be accurate, and our data is consistent with that found for other locations in Madagascar in NASA databases.

The data collected over our study period confirmed that PV is worth considering for Ranobe. The question then becomes what size system is necessary and where it should be sited. Demand calculations and our proposed three-tiered PV system are discussed further on in *Option 3: Solar Photovoltaics (PV).*

Siting ultimately comes down to a number of tradeoffs. Given the extremely low incomes of households in and around Ranobe and the value of materials used in PV arrays, security from theft becomes a concern. The ideal site would be situated off main roads, keeping panels somewhat hidden from sight. The system should also have a guardian nearby; this could be villagers living in nearby houses, Ho Avy directors staying at the research center, or an appointed guard. Of the three sites considered, security concerns are lowest at the research center and highest in the unattended plant nursery. The community center and research center are both fairly well isolated from major roads. A potential disadvantage of the research center is the height of the building: its three-story roof towers a full two levels above typical Ranobe huts. This draws unusual attention to the building and the wealth of its owners and may affect the security of PV systems installed there.

A final consideration with siting a PV system is the convenience for users. If the system is also intended to power the village, siting at the research center would require installation of aboveground or underground wires than from the more centrally-located community center. Such wires might be aesthetically unpleasing (aboveground) or dangerous given the high water table (underground), and will certainly be expensive to install. Nevertheless, given the ease of installing panels on the existing roof of the research center, some consideration was given to creating a mobile “charging station.” The idea would be to locate panels permanently at the research center and deploy a number of batteries in locations throughout the village to provide power supply as needed. When the batteries were drained, villagers could return them to the research center for recharging. Concerns with this proposal are the frequent transport of batteries, which has the potential to damage them and shorten their lifespans. Moreover, the charging station approach only works with low demand for electricity, and so eventually the question of how to electrify on a large scale becomes inevitable.

Options for Addressing Energy Poverty

1. Grid

Connecting to the grid will be prohibitively expensive for Ranobe unless funding to construct the necessary infrastructure can be obtained; likely venues could be via research funding, ecotourism, or businesses benefitting from the nearby protected forest. The expenses associated with introducing electrical infrastructure and paying for electricity are more feasible for a well-funded NGO than for Ranobe villagers. Individual households would have to weigh electricity payments against other necessary spending, a choice wholly inconsistent with eliminating energy poverty.

2. Wind

Wind power can provide either electrical or mechanical (shaft) power. The former would provide electricity, and the latter could be used for pumping, milling, and other industrial agriculture techniques. Over the study period, 5,819 readings were taken with Ho Avy's weather station. Using wind dispersion coefficients determined by the US EPA, wind speeds were calculated from the weather station data (10 m above ground) to estimate wind speeds at 30 m to determine the feasibility of small-scale wind turbines. Wind in Ranobe flows at an average of 1 m/s at 30 m, which is well below both the needed 5 m/s for effective electricity generation use and the 2.5 m/s needed for mechanical pumping (Cloutier & Rowley, 2011).

3. Solar Photovoltaics (PV)

Figure 41. The current solar panel setup at the Ho Avy Research Center. Photo credit: C. Santoro

Early in this project, solar PV was identified as a significant potential source of energy for southwest Madagascar due to the region's limited annual precipitation and high daily average solar insolation. Moreover, PV has the advantage of combining zero-emissions electricity generation with decentralized sourcing. PV remains ideal for Ho Avy in that they require some operation of electrical equipment (computers, radios, and a refrigerator, for example) to function effectively as a research and logistics center for local deforestation issues.

Installing PV in an area like Ranobe would avoid some of the grid-related tradeoffs such as electricity payments, larger installation costs, and dependence on a utility. Thus it is important to characterize the use of these systems appropriately in conjunction with other types of energy systems. PV systems require proper use and maintenance to retain maximum system efficiencies. Integral to this is a charging regulator, which protects batteries from overcharge and deep discharge, extending their lifetimes and lowering lifetime operation cost of the PV system.

However, the village of Ranobe currently functions without electricity, and therefore the predicted immediate demand for electricity will be low. Ho Avy directly involves a portion of the Ranobe community in the reforestation and preservation efforts; through these pathways, community members could utilize small electronics such as rechargeable flashlights, radios and cell phones to coordinate in the field. The village could find limited-capacity lighting useful for studying for school (Daka, 2011) and coordinating meetings in the planned community center. Over time, electrical demand will certainly grow as Ranobe develops economically and observes Ho Avy using electricity at the research center, and whichever energy system is selected must be able to expand to meet these demands. Given the solar resources in Ranobe and the decentralized nature of PV, this type of scaling up is feasible. As an example, PV installations in Senegal have produced villages “teeming with life after darkness till late hours under the solar light. In the community centres, adult education programmes, meeting of villagers and social gatherings were regular features” (Youm et al., 2000).

Figure 42. Ranobe villgers enjoy a rare movie night at the Ho Avy Research Center, powered by stored solar power. Photo credit: Ho Avy

Although PV is unlikely to be adopted without an injection of funding, Ho Avy still asked the team to recommend suitable solar installations for Ho Avy's operations if such a grant were found. Our recommendation uses a scalable, three-tier approach (see *Appendix B* for detailed calculations). The first tier, shown below (Figure 43), is similar to Ho Avy's current setup of three roof-mounted solar panels on a manually operated tracker that we constructed while in the field. Ho Avy currently has only 120 W of capacity; our recommendation for the first tier increases capacity to 530 W to allow for operation of three laptop computers, several lights, a small water pump, a weather station, and some battery charging on a daily basis.

The second tier, shown opposite (Figure 44), nearly triples the capacity of the panels to 1,400 W, triples energy storage capacity, and is thus able to consistently provide nearly triple the amount of energy while tripling the power supply. This means that more power-intensive devices, such as a large water pump and a refrigerator, can be connected to the power source.

Finally, the third tier is shown in Figure 45. This system builds on the Tier 2 system by increasing battery storage and adding an automated tracking system for the solar panels. This will increase their capacity by 80% but is also anticipated to add a significant cost premium. This system is large enough to provide lighting throughout the village and promote development by allowing for working or studying after sunset (Daka, 2011). This is of particular importance in Ranobe, since its tropical climate means the sun sets between 17:00-19:00 regardless of the season.

In the short term, PV on a large scale remains unlikely for Ranobe given its high cost and low impact on reducing deforestation. As described previously, deforestation results in large part

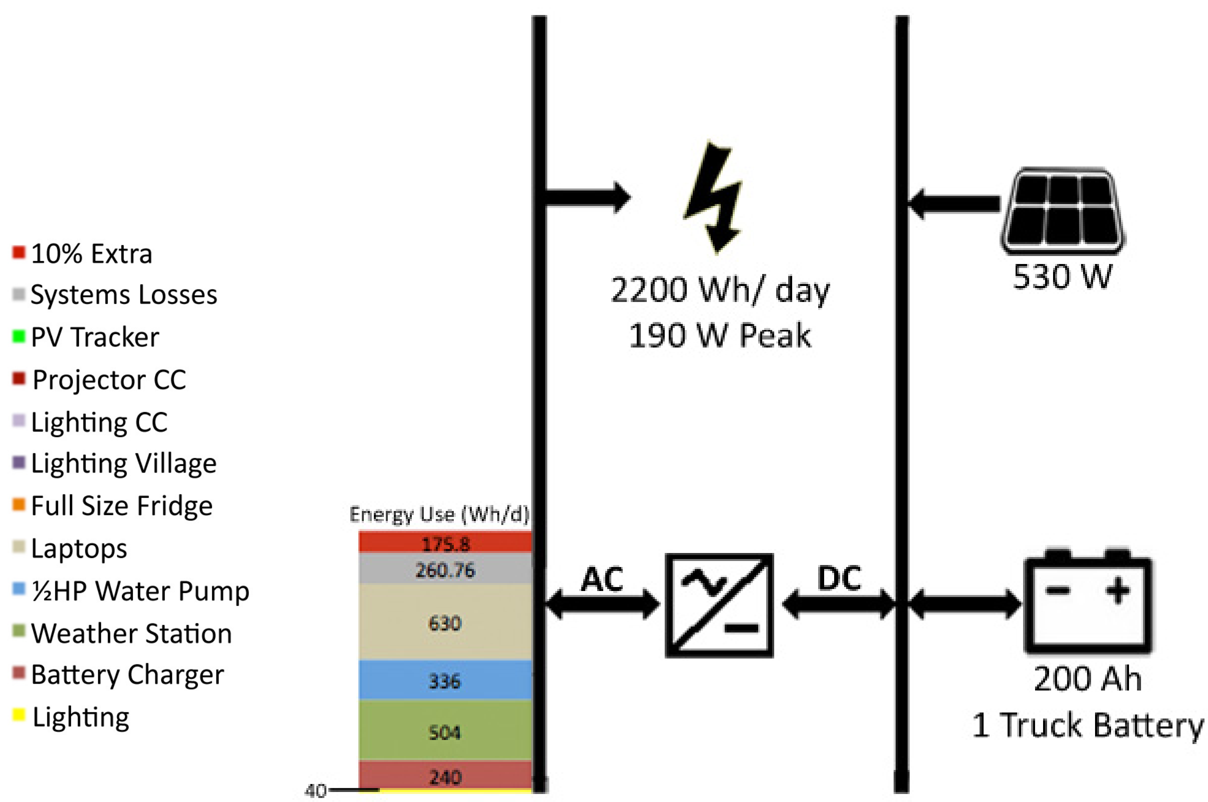


Figure 43. Solar system first tier. Graphic credit: B. Madden

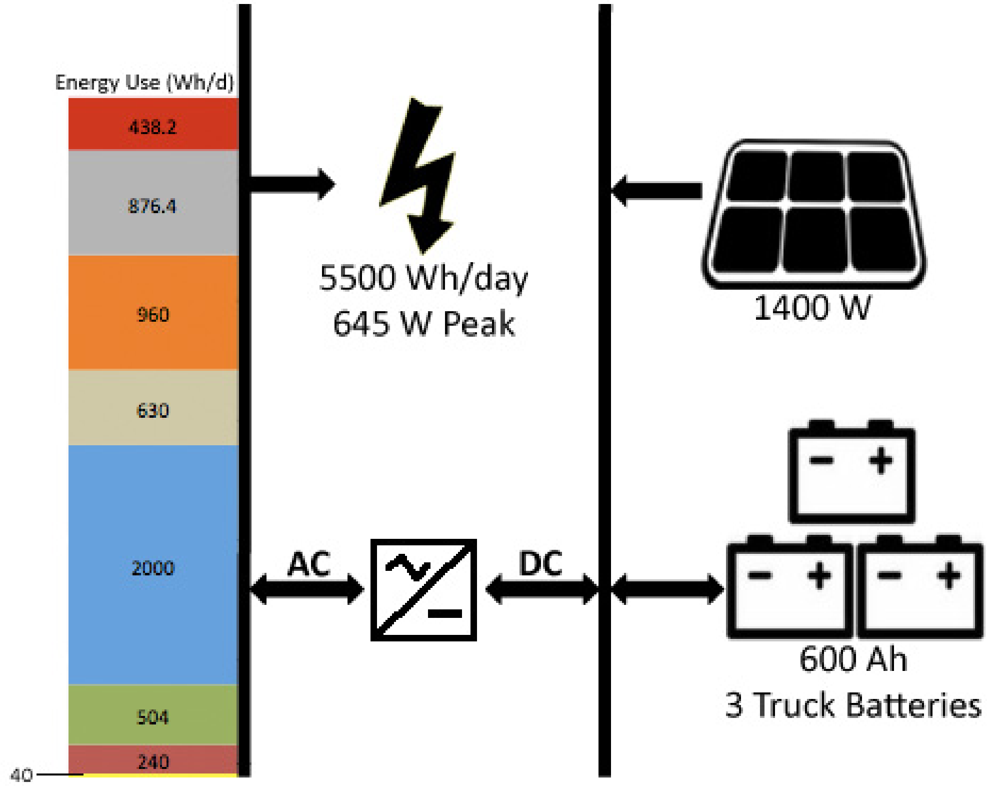


Figure 44. Solar system second tier. Graphic credit: B. Madden

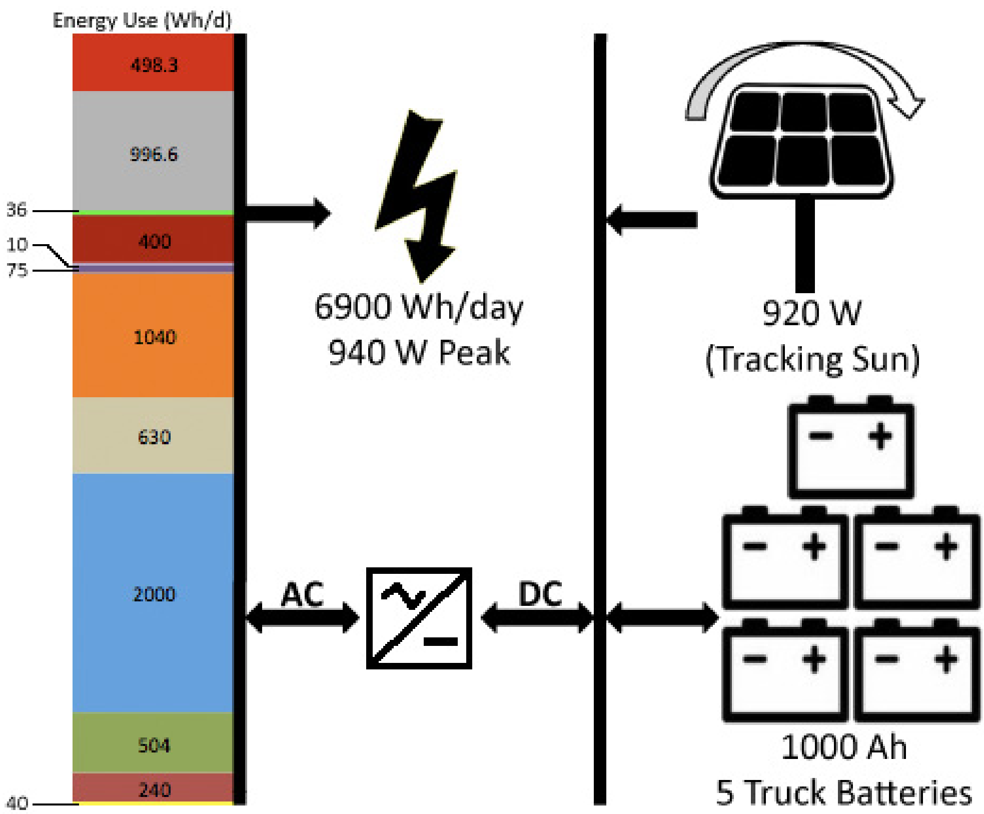


Figure 45. Solar system third tier. Graphic credit: B. Madden

from collection of biomass for cooking, which is currently the predominant use of energy by Ranobe villagers and requires minimal electrical energy. Most small-scale PV systems used by households in Africa produce low-power (18-100 W), direct current electricity instead of the usual alternating current available through the grid; this makes them best suited for appliances that require lower current such as lights, radios, and televisions. Appliances such as electric cooking coils, milling devices, and water pumps require higher current, as well as an inverter. Thus, small-scale PV cannot replace biomass as a means of cooking, and providing a system large enough to reduce deforestation would require significant external funding.

Small or mini-PV systems could satisfy what electricity demands do exist in Ranobe, however, by replacing batteries. Additionally, mini-PV systems create entrepreneurial opportunities for renting LED light systems or charging cell phones. These mini-PV systems cost significantly less than the conventional larger panels meant to replace western style electricity requirements. In the US, mini-PV panels are often used for garden or path lighting; they store energy in small rechargeable batteries and use 1-5 W LEDs. Several social enterprises, such as ToughStuff, currently operate in Madagascar and other African countries providing these systems. Although these systems will still not reduce biomass use, they could aid in other development activities at lower cost than larger PV systems. As mentioned in the literature review, however, successful adoption of these systems only comes with appropriate education on the use, maintenance, and local entrepreneurial involvement.

Figure 46. This expandable bag within the biodigester system holds the generated methane before it is burned. Photo credit: P. Liao

4. Biogas Systems

Biogas systems, also called biodigesters, convert organic waste into biogas that may be used both as an energy source and as fertilizer. These systems, however, remain generally unaffordable given the average income levels common in rural East Africa, primarily due to operational costs such as maintenance of hosing, tanks or bags, and fittings. To illustrate the point, one of the two biodigesters put in place by Ho Avy is currently out of service because of insufficient maintenance. Biodigesters are best suited for permanent, agricultural communities like Ranobe because of the need for organic waste from cattle (Karekezi, 1997), but they can delay the usage of this waste for fertilizer while being used for biodigestion.

Ultimately, cultural influences play a major role in the adoption of this technology. Cooking, flavor, and performance preferences may slow the transition away from wood fuel (Murphy, 2001). Ho Avy has had some success in transitioning villagers to use a biodigester for cooking fuel, but additional systems and a greater focus on behavioral and cultural incentives will encourage more widespread adoption.

5. Improved Efficiency Cookstoves and Solar Cookers

Improved ceramic cookstoves produced by local artisans, women's groups, or entrepreneurs with financial support from NGOs and other agencies have been a popular sustainable energy option throughout Africa (Karekezi, 1997; Kammen, 1995a). These stoves use less wood and produce far fewer emissions than traditional cookstoves (FAO, 2009). Another option is non-portable mud stoves, which are cheaper and more common in rural areas than ceramic stoves (Hosier, 1985). Mud stoves are usually made with local materials such as sand, mud, clay, murrum and gravel with water, grass, dung, or vermiculite, and do not require a kiln for ceramic construction. Both mud and ceramic stoves reduce smoke and associated negative health impacts, and they burn wood up to 50% more efficiently (Skutsch, 1998; Kammen, 1995b; Osei, 1996). Adoption rates are thought to be higher for these stoves compared to other options such as biodigesters because of easier maintenance and the similarity to traditional fire cooking; the only changes are in intensity of lighting and heating and the need to cut wood into smaller pieces (Murphy, 2001).

Figure 46. An example of a cookstove with three sides exposed, which results in a less efficient use of wood fuel. Photo credit: B. Madden

Solar cookers use solar energy to heat food with reflective concentrators instead of with wood fuel. Adoption has not been as widespread as that of improved cookstoves, largely because of price, incompatibility with traditional cooking techniques, discomfort of operation (having to cook under direct sun and the need to continually adjust the stove toward the sun), and dependence on sunny weather (Kammen, 1995a; Skutsch, 1998). However, recent innovations in simple, affordable designs have produced solar cookers from readily available materials such as cardboard and aluminum foil. For example, Solar Cookers International has released solar cookers made from these materials in Kenya for $10 each. These designs reportedly require less than two hours to cook a meal and can also be used to sanitize water. Such designs offer emissions-free, wood-free options that, although not as durable as traditional stoves, do not require special knowledge or skills to construct or maintain.

Figure 48. From left to right, these local plants, castor (Ricinus communis), Jatropha mahafalensis, and Moringa oleifera all have potential for biodiesel production. Photo credit: B. Madden

6. Biofuels

Biofuels stand as both an alternative to fossil fuels and means to diversify agricultural economies. They can reduce almost every type of emission associated with transportation or heating fuels and can provide another agricultural product for farmers. Under conditions like those in Ranobe, where crops are organically fertilized, the industry is powered only by humans and livestock, and seeds come from marginal and perennial plants, which do not require new crop areas, biofuels can effectively reduce emissions. At commercial scales, however, biofuels may compromise food security or ecosystem health by encouraging agricultural conversion of fertile land.

Four plants in Ranobe were identified as possible biofuel sources. Castor (*Ricinus communis*), *Jatropha mahafalensis*, neem tree (*Azadirachta indica*) and *Moringa oleifera* all have potential for biodiesel production. *Moringa oleifera* seems to have the greatest potential given appropriate growing conditions and warmer climate, but castor oil has greater overall oil yield on a per ha basis.

OA 3: Water and Health

Background
Water quality in Ranobe is a significant concern. The US Centers for Disease Control and Prevention (CDC) warns against drinking untreated water in Madagascar, and standing water in the area carries a risk of schistosomiasis. During our study period in Ranobe, we surveyed residents to determine the impacts of this low water quality on residents' health and to note trends in water consumption and source.

From our survey (survey questions and summary table in *Appendix C*), we found that median household consumption was 50 L per day. Per capita, this translates to about 6 L per day. Two-thirds of surveyed households collected their water from Ho Avy's installed water pump, which pumps water from a covered well, but 40% still used an uncovered well. Twenty percent retrieved water from the lake, but all of these respondents also sourced a portion of their water from some type of well. The World Bank estimates that 59% of Malagasy take their water from unimproved sources such as open wells and lakes; for rural populations, this statistic rises to 71% (World Bank, 2011). In this case, the presence of the nonprofit Ho Avy has already significantly improved the village's water supply, just by improving one source. About 23% of households (7 respondents) claimed they would be willing to wait for clean water; less than 2% of respondents claimed to currently treat their water, however, so the translation of the response into a habit may prove challenging.

Our interview results also suggest that Ranobe residents suffer from several significant but preventable illnesses, including malaria, schistosomiasis, and diarrhea. The first, malaria, was identified by name by several respondents and by symptoms – fever, shivers, headache, nausea, and vomiting – by several others. Thirteen of the thirty interview respondents named two or more of those symptoms as common in their households. As a village in a tropical region, Ranobe is at high risk for malaria (CDC, 2010b); presumably the poverty and isolation of Ranobe make preventative care difficult.

Over 40% of respondents reported that their children suffered from diarrhea "often", and another 40% reported diarrheal symptoms in their children "occasionally". Only 17% (5 respondents) reported no diarrhea. All five of these respondents cited a covered well with filtered pump as their drinking water source, though interestingly three of those also admitted to bathing and washing laundry in the lake, which is known to be unclean. In Madagascar, diarrhea is one of the top causes of under-five child mortality, with 22% of deaths attributed to it (WHO, 2008a).

Ranobe children using a treadle pump to draw water from a well in an agricultural field. Photo credit: B. Madden

Finally, schistosomiasis – or its symptoms of distended belly and bloody urine – was identified by nine interview respondents as a common illness. All nine were unaffiliated with Ho Avy, and seven of those cited the lake as their primary bathing and washing water. Four of the nine also cited the lake as a primary drinking water source. None of the interview respondents affiliated with Ho Avy, who almost universally use the covered well pump for drinking and bathing water, acknowledged suffering from symptoms of schistosomiasis.


Figure 49. The basic design of our prototype water filter system with built-in storage tank. Water enters the top tank via a pump or by hand. The water then flows through ceramic candlestick filters and connection hoses into the lower storage tank. The water can then be tapped at any time with the spigot at the bottom of the storage tank. Many villagers stated they would not wait for any amount of time to clean or filter drinking water, which is the motivation behind the storage tank. Photo credit: B. Madden

Prototyping Solutions

The results of the interviews confirmed that water quality is a concern in Ranobe and that Ho Avy has a unique ability to impact residents' health as they have already done with the installation of one hand-pump. However, the interview results also suggest that there is a significant behavioral challenge to improving health through water quality—of the 30 residents interviewed, only seven said they would be willing to wait five minutes or less to treat drinking water. There was no correlation between those with Ho Avy affiliation and those willing to wait.

Thus, our team chose to experiment with drinking water storage solutions. If a water pump could be combined with a storage tank and filtration system, residents could access clean water immediately and conveniently. By connecting a covered well to one holding tank and connecting that holding tank to another via ceramic water filters, the user could pump water when convenient and have it filtered into the storage tank. The user could simultaneously turn the spigot on the storage tank to fill buckets of clean water (assuming the previous user also pumped water while filling his/her own buckets). If the storage tanks were large enough, residents would never have to wait for clean water. Routine maintenance would require cleaning the filters in boiling water and checking hose connections.

In practice, our prototype fell short for a number of reasons. One of the water filters started disintegrating during construction of the system, and others fell apart during the cleaning process. For future construction, better quality filters should be used as available, although the team did use the best available filters in

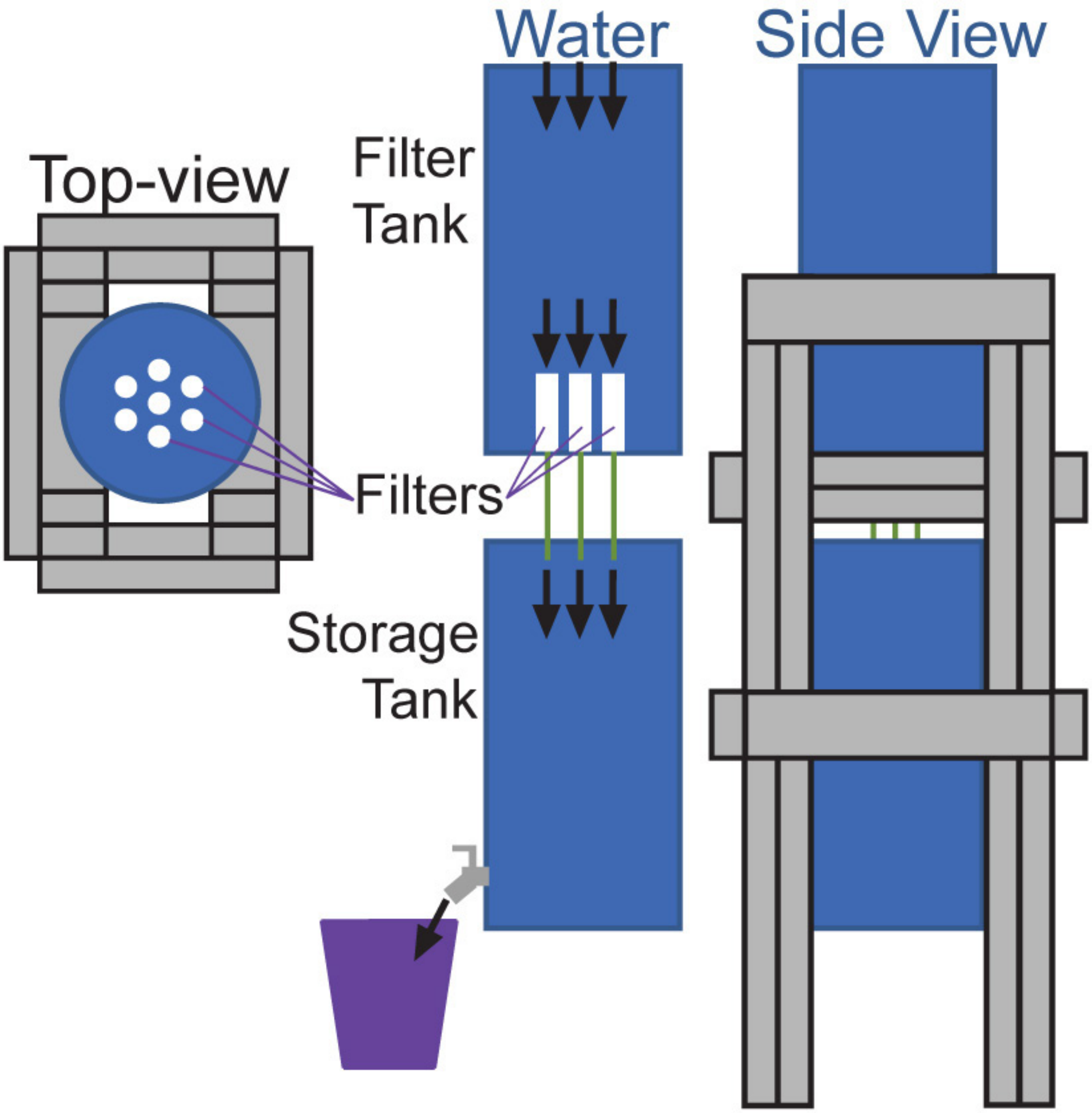


Figure 50. Schematic design of our basic water filter prototype. Graphic credit: B. Madden

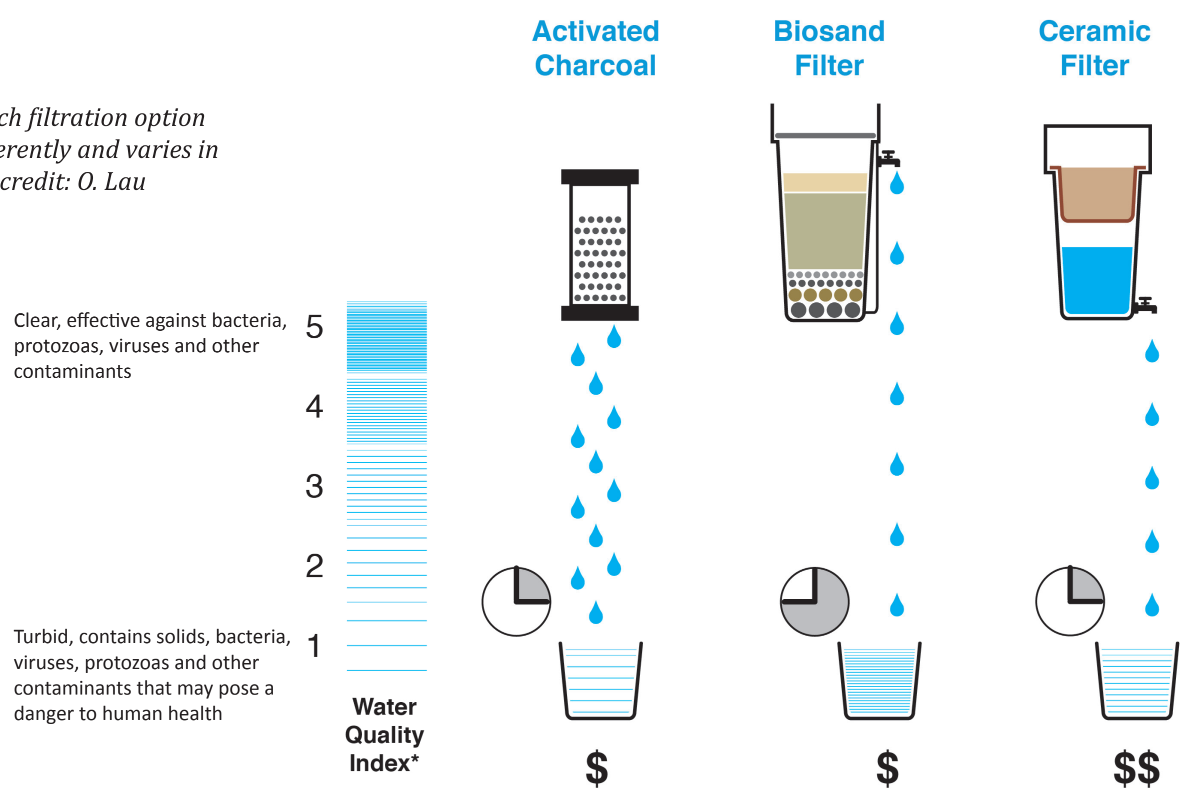
Toliara. Limited availability of tools and materials complicated the process, and the lack of water-quality testing equipment leaves the effectiveness of the filters available in Toliara uncertain. Although we believe that a water storage and filtration system is essential for development in Ranobe, future models should be constructed with higher quality materials and testing equipment to verify their success. Options for addressing the concerns brought up by the survey results are discussed in the following section.

Options for Addressing Water Quality
To address water quality issues, several options are available in Ranobe, including filtration, chemical treatment, boiling, exposing to UV sunlight, or covering wells and extracting water with pumps. These options vary in economic cost, user convenience, scalability, and effectiveness at eliminating all levels of contamination, from sediment to pathogens.

1. Filtration
The first option, filtration, varies itself by type and reliability of filter. There is limited availability of water filters in Toliara, and the ones that we did manage to find were poor quality ceramic filters. A wider selection of higher quality options may be available in Antananarivo, albeit at a cost premium, and the highest quality filters are likely to have to be imported from outside Madagascar. Filters can also be created from local materials, such as sand and activated charcoal. Filtration can be used to treat large amounts of water, making it a feasible option for village water treatment. Additionally, methods and timing of necessary maintenance and cleaning of the filters vary depending on the quality, and may range from periodically reversing the flow of water to boiling the filters or cleansing with acid. Filtration is also able to remove all types of contamination, depending on the type and quality of the filter, but there may be a longer time delay with filtration than with other treatment methods.

Ho Avy has already installed one activated charcoal filter, although their lack of water testing equipment offers no evidence as to its effectiveness at improving water quality. A major concern with this filter is the permanent, underground location that renders cleaning difficult or impossible.

Figure 51. Each filtration option performs differently and varies in cost. Graphic credit: O. Lau



2. Chemical Treatment

Chemical treatment of water, predominantly with chlorine, is perhaps one of the fastest methods of treating water and as such is commonly used in Toliara. Chlorination is much less common in Ranobe, however; only one interview respondent admitted using chlorine to treat his family's drinking water. Chlorination was also the method we used throughout our stay in Madagascar. Chlorine is affordable and widely available in markets in Toliara and other cities, and like filtration, can treat large quantities of water very quickly. Another benefit of chlorine is that it can guard against post-treatment contamination during storage if a residual amount is left in the water. Iodine is another option for chemical water treatment but is not currently recommended by the WHO because too much iodine can lead to other health concerns (WHO, 2008b). Chemical water treatment does not remove sediment and particulate matter and thus may be paired with filtration for better results.

3. Boiling and UV Exposure

Boiling or exposing water to UV rays may be simpler and less expensive processes than either filtration or chemical treatment, but they are generally not as effective at removing all contaminants, especially if turbidity is high. Nevertheless, our interview results show that of the four respondents who acknowledged taking some action to treat drinking water, three relied on boiling or UV exposure. Boiling and UV exposure are difficult to implement at large scales.

4. Covered Wells

A final option that, like boiling and UV exposure, may not be as effective at eliminating contamination but is significantly more convenient, is to cover wells and use pumps to gather water. Ho Avy has experimented with this in Ranobe already by adding one covered well and hand-pump, which is also connected to the aforementioned activated charcoal filter, to a central location in the village. Of 11 interview respondents currently affiliated with Ho Avy, ten said they collect drinking water from this pump rather than other, uncovered wells or the nearby lake. Corresponding data suggests that these households also have a lower prevalence of schistosomiasis, making covered wells with homemade filters a promising short-term strategy for improving village health.

Figure 52. Children use the hand pump with activated charcoal filter in Ranobe. Photo credit: C. Santoro

5. Safe Storage

Once the water has been purified, it must be stored in a clean, sealed environment, or pathogens and contaminants will find their way back into it. The container(s) used for water storage should be different from the container(s) used for water collection. Safe water storage containers should have/be:

- Tightly fitted lid/cover
- Tap or narrow opening for water pouring
- Stable base so it can stand without tipping
- Durable, opaque material
- Easy to clean (CAWST, 2010).

6. Water Testing

Without a way to regularly test the water for pathogens, bacteria, viruses, and other contaminants, it will be impossible to know the rate of improvement of the water or even fully identify water quality as a cause of illness and mortality. The World Health Organization's Guidelines for Drinking Water Quality recommends testing every 3-5 years even for rural and inaccessible locations (WHO, 2008b). While water testing may or may not actively contribute to improving water quality in Ranobe, it should still be considered a vital and necessary component of any successful option addressing water quality concerns. Testing in Ranobe to date has only included sending water samples to the Czech Republic for testing. Testing, ideally, would be done on-site or within a short time frame because long delivery times could affect the conditions that promote pathogen growth thus providing inaccurate results.

7. Education

Ultimately, the interview results and our vision for creating a communal water filter and/or storage system underscore the importance of the water quality and health connection in the village. Health concerns are significant and will continue to hinder development, and behavioral changes are critical to

Figure 53. Children can be taught about drinking and using cleaner water at school. Photo credit: C. Santoro

reverse that trend. Ho Avy is uniquely situated to take a lead in educating villagers and incentivize that behavioral change. Health education should focus on raising awareness of the causes and consequences of illnesses such as malaria, diarrhea, and schistosomiasis, emphasizing the preventable nature of each, and enabling villagers to take charge of their health with tools such as water pumps and filters. Ho Avy needs to respect the villagers' needs (e.g., time and convenience) by providing clean water storage solutions and should work with the villagers to teach them to construct appropriate technologies for cleaner drinking water. Given the potentially devastating impacts of water-borne illness and the clear benefits from relatively simple, low-cost fixes like covered wells, these strategies are best approached by Ho Avy in the short term with education continuing into the long term.

OA 4: Food Security

Background
As a poor rural village, Ranobe faces food security concerns throughout the year. Most families grow at least a portion of their food needs, but many also need food beyond their own growing capacity. This can be a seasonal effect if they face difficulty producing sufficient food during the summer season, or it can be a constant challenge because they do not own enough farmland. In either case, families have to purchase supplementary food from nearby markets as needed. Due to factors such as changing weather patterns, soil conditions, land availability, and population growth, the ability of the local population to provide sufficient food for themselves is becoming increasingly difficult. This will be even further exacerbated during the summer months (November-February), when the climate is too hot and humid for crops to grow.

The described pattern of food shortage, exacerbated by climate change, population growth, and seasonal shifts, is confirmed both in literature and field experience from Ho Avy. In interviews of Ranobe residents, all respondents except for one said the majority of their income went to food purchases. Eighty-three percent of respondents cited difficulties in maintaining a stable and sufficient household income, suggesting that it was also difficult for Ranobe households to reliably afford enough food. Seventeen of the thirty respondents (57%) also attributed this economic difficulty to the lack of rain in recent years; nearly all of the respondents who did not cite drought as a challenge worked for Ho Avy to make supplemental, non-agriculture-based income.

Prototyping Solutions
During the study period in Ranobe, a solar food dryer was designed and constructed with the two-fold purpose of creating a dryer with regionally available materials suited for local conditions while introducing the concept of drying food for preservation to the Ranobe villagers. A solar food dryer uses energy from the sun to dehydrate food, and is most effective if the food is cut into slices. Once dried, the food can be stored, eaten in the dried form, or rehydrated for use in cooking. Of many available solar dryer types, the team decided to build a passive, direct heating solar dryer. A passive solar dryer does not require any external power beyond heating from the sun to generate airflow, which is necessary to speed up the evaporative process that dries the food and removes air saturated with moisture. A dryer that utilizes direct heating uses the sun's rays to directly heat the compartment that the food is in, rather than heating a separate compartment and inducing airflow through layers of food slices. The passive direct heating system was chosen since Ranobe has ample access to sunlight but minimal access to electricity to drive motors or fans and because it was more intuitive to understand (and thus teach). In addition, any rural village in the same region will similarly have the ability to use sunlight to heat air in the dryer and produce airflow, despite differing abilities to use electric systems to create airflow within the dryer.

The older girl prepares food while watching her siblings. Photo credit: P. Liao

The solar food dryer was built and tested in Ranobe using materials and hand tools, which were primarily sourced in Toliara. Ho Avy has continued to test the food dryer and educate Ranobe residents on proper usage and benefits of using the dryer. Lumber, plywood, glass, untreated mosquito netting, black fabric, screws, and black paint were purchased from hardware stores in Toliara as construction materials. Untreated mosquito netting was used to cover ventilation holes, protecting the food from small animals and insects looking for a snack. The interior of the solar food dryer was painted black to absorb heat and raise the temperature of the dryer interior. The properties of glass allow visible light in, but do not let infrared radiation back out, effectively trapping heat within the compartment. The black fabric was beneath the glass and allowed most of the solar energy through but protected the food from harmful UV rays, thereby preserving the nutrients and vitamins in the food. Adobe mixed in Ranobe was used to create a better seal around the glass, compensating for imprecise cutting of the wood pieces. Building the dryer completely out of local materials was explored as an option; however, while it would be possible to locally source the wood, the other materials needed for the dryer would still need to be obtained from a hardware store.

Following the field experience, the team redesigned the food dryer to be better equipped for how it would be used as well as the climate and harsh conditions of the Spiny Forest region. Challenges that the team experienced, along with the resulting design changes, are summarized in the following table:

Challenge	Design Change
• Wood warping made accurate construction difficult.	• More shorter pieces, and fewer long pieces of lumber were used.
• Thin plywood could not be used as part of the structural frame.	• More structural components (equivalent of 2x4s) were added instead of plywood.
• Food compartment was overheated, and food slices experienced case hardening.	• Used indirect heating method instead of direct heating; also education needed.
• Wide area within the dryer and narrow opening width made it difficult to reach the furthest trays.	• Area within the dryer was made smaller; opening width was made larger.
• Large size made it unwieldy for one person to carry.	• Indirect heating design also allowed it to be broken down into more manageable pieces.
• Adobe provided insecure sealing.	• Minimize need for extra sealing by improving construction technique.

A picture book construction manual and a trainer's/user's guide were created to facilitate local adoption both in Ranobe and other developing countries. These are included in *Appendix D*.

Language use was minimized in the construction manual and simplified as much as possible in the trainer's manual. The manuals were designed with Malagasy cultural norms in mind, such as repetition of important points, relatable analogies, and images of Malagasy women using the dryer. Simplifying and minimizing the use of language, as well as designing the manual to Malagasy cultural norms, should help encourage adoption. The construction manual and trainer's guides were intentionally left flexible so that designs and materials can be altered according to local availability. It is expected that Ho Avy and their affiliated interpreters will introduce the manuals to villagers. Following the first few introductions, villagers would then be able to use the picture guides to introduce the techniques and concepts to relatives, neighbors, and friends.

Options for Addressing Food Insecurity

Improving food security in Ranobe requires approaches that increase food availability and also develop a sense of foresight for future household food needs. Based on interactions with Ranobe villagers, it was clear that villagers did not plan ahead for future food needs. Because food was such a large part of each family's spending, food needs were also closely tied to how they budgeted their income. As a result, it was clear that income sources had to be considered when trying to make Ranobe food-secure. The following are analyses of possible options to address food security issues in Ranobe.

1. Solar Food Dryer

The solar food dryer provides a method for Ranobe residents to store fresh food for longer periods of time. Once fresh food has been dried, it can be stored to last for at least a few weeks. If stored in ideal conditions (in a sealed container in a dry environment), it may last even longer. This new possibility for food allows food planning and supplemental income from dried foods.

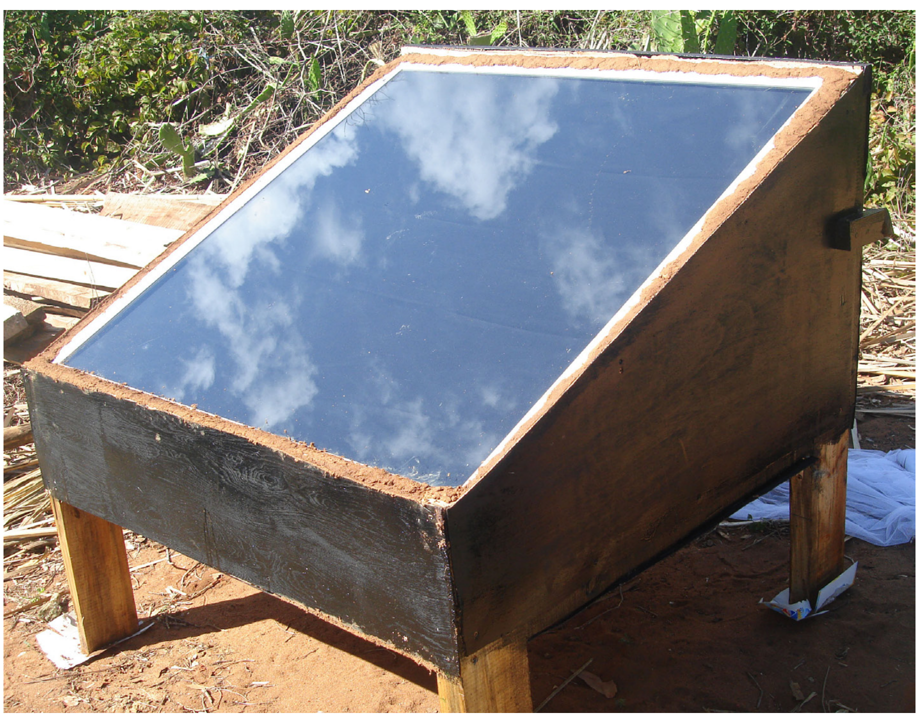


Figure 54. Solar food dryer design. The direct heating design prototyped in Ranobe. Photo credit: P. Liao

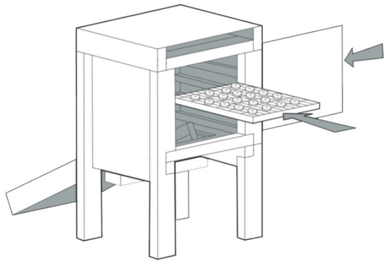


Figure 55. Improved solar dryer design from field prototype. Dryer has an indirect heating design with improved airflow. Graphic credits: C. Nowak

Solar Food Dryer: A Tool for Food Planning
Since dried food can be stored for longer periods of time, villagers would now have the ability to plan ahead with their food supply. Nutrients and vitamins are maintained in dried food, providing nutritional benefits in addition to simply having food to eat. Hence, when there is excess food or income, food can be prepared for storage with the knowledge that it will be available in case of a future food shortage. This can be especially helpful for the summer season when fresh food is harder to come by or more expensive to obtain. Currently, when villagers have a good harvest in the growing season, they will sell or give away the excess food since it will otherwise go to waste. Dried food also allows for flexibility in eating habits: dried food can be taken to school or the fields as a snack. Furthermore, dried food can add variety to villagers' diets. The food dryer can be used to dry fruits, vegetables, meats, fish, and even tea leaves. Saving the food for future consumption was never an option before; it will take time for villagers to become accustomed to having that option. However, drying food only addresses seasonal fluctuations in harvest quantity and not the issues of insufficient arable land to meet food needs of Ranobe's population. In addition, effectively using dried food requires villagers understanding the entirely new concept of storing food for longer than a week. Finally, villagers would also have to adapt to the tastes of eating dried food and the process of cooking with rehydrated food.

Solar Food Dryer: A Means of Alternative Incomes
With Ho Avy's help, Ranobe residents have started growing a variety of different crops and plants, many of which are not grown by any other nearby village. Villagers can dry these more 'exotic' crops – mostly herbs - to sell to nearby hotels and resorts. Since these would be considered specialty items, they would likely have a higher price associated with them compared to foods available in the regional market. Such an agreement would benefit resorts that would want a local, steady supply of these food items; similarly, Ranobe residents would benefit from having a reliable income source. However, diversifying agriculture to include new crops still leaves villagers vulnerable to weather patterns and changing climate, and growing these crops could displace staple crops for village consumption. This option and its implications for Ranobe are more fully described in the *Economic Growth* section.

2. Changing the Agriculture

Ranobe residents can also change the crops they grow to suit the changing climate. If the climate is no longer ideal to grow food staples, they can grow more robust or adaptable crops to eat or to sell. This faces concerns similar to the previous option in that growing crops that villagers will not eat would displace staple foods and make them more vulnerable to market price volatility. Learning to grow new crops would also require an adjustment period. Yet this technique could be a more effective use of the land and yield greater agricultural output. If villagers were amenable to altering their diet, and especially if they would also use food-drying techniques, then this option could have the potential to create a self-sustaining village economy. Irrigation and more productive planting techniques should also be considered as part of this option, but since Ho Avy has already begun more extensive experiments and analysis on these techniques, they are outside the scope of this project.

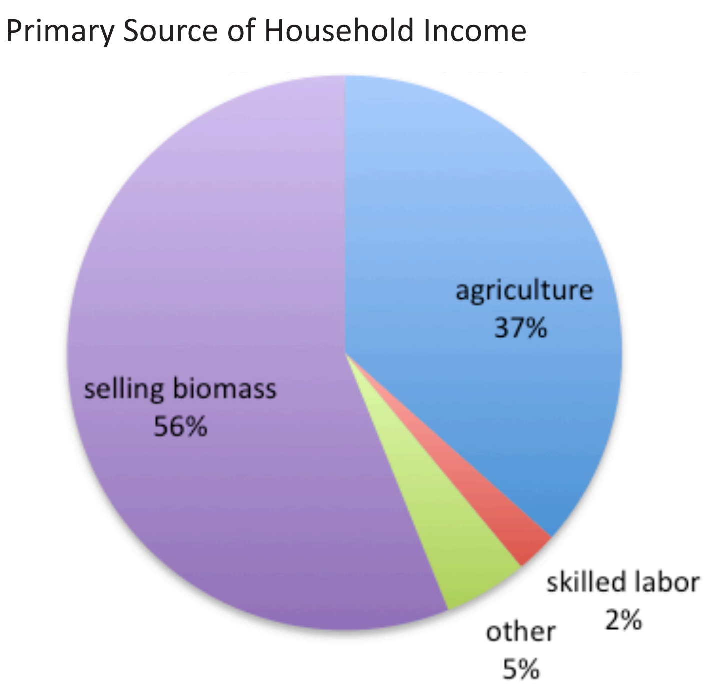
3. Education

Education of residents is vital to change habits that contribute to their unsustainable lifestyles. They are accustomed to a traditional way of life that may cease to be sufficient or sustainable as their environment changes and populations grow. In order to prosper on their land, they will have to adopt new techniques. Teaching villagers to understand the motivations behind these new techniques is one way to encourage long-term adoption. Even if villagers are initially amenable to the idea, however, they could revert simply because the old ways are easier or more familiar. Hence, to successfully increase food security by shifting agriculture and food behavior requires a great deal of time and continual effort to ensure that the villagers convert the newly learned technique into a habit.

OA 5: Economic Growth

Background
Ranobe is in need of a self-sustaining economy. Currently the level of economic development is extremely low with no electricity or running water and only one hand-pump to gather water from wells. According to interview results, 56% of respondents earn a living from gathering and selling biomass and another 37% from agriculture. Only one respondent holds a job that qualifies as "skilled labor" — the local schoolteacher. Of the 30 respondents, the median annual household income was $100 and the mean $202. Only three households had annual incomes greater than $500. When we asked about the frequency with which households needed to find alternative means of income to make ends meet, only five respondents said that had never happened before. These alternative income sources came primarily from agriculture, selling biomass, or borrowing money (15% each). A full 28% of respondents admitted they had no alternative source of income and had to cope accordingly. Other sources mentioned included foraging for food in the forest, renting cattle carts, cooking or washing for others, bartering for necessities, and weeding fields.

It is clear that significant economic development will have to occur in the next decades in order to improve the standard of living. Residents of Ranobe have benefited economically from the direct involvement of Ho Avy in creating jobs, but to be able to provide for a truly sustainable future, Ranobe needs to develop a self-sustaining economy. Several options are presented below in an analysis of tradeoffs, advantages, and disadvantages.



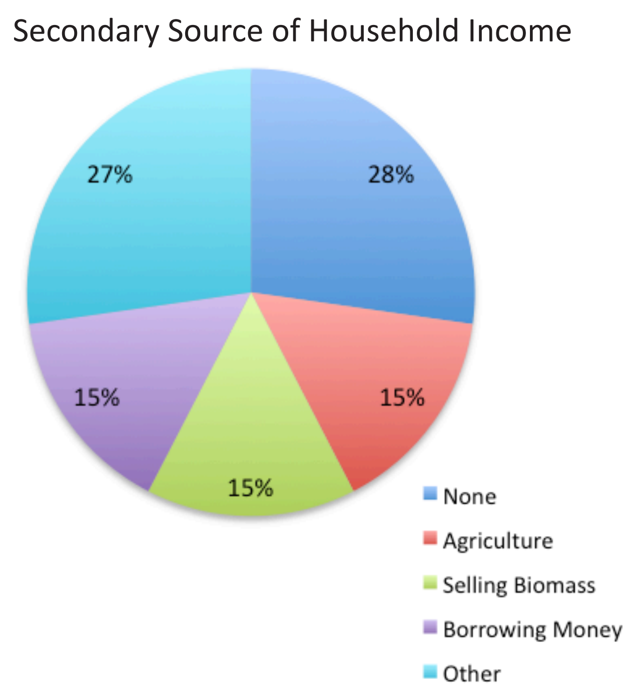


Figure 56 (left). Primary sources of household income by category. Analysis and graphic credit: C. Santoro
Figure 57 (right). Secondary sources of household income by category. "Other" category includes foraging, renting cattle carts, laundering, cooking, bartering, and weeding. Graphic credit: C. Santoro
Cover image. A variety of fresh foods are sold in local markets. Photo credit: O. Lau

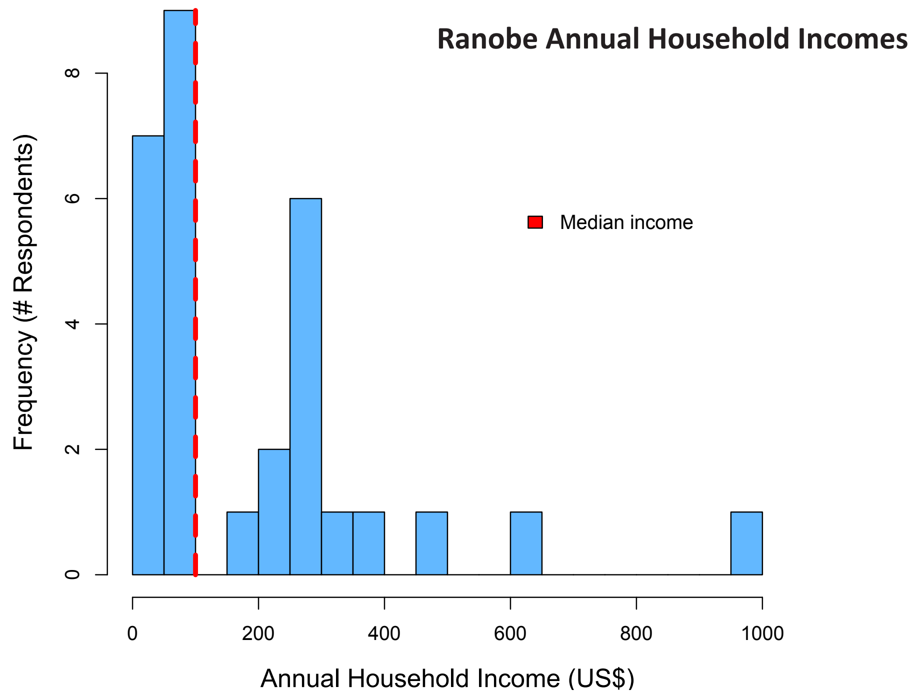


Figure 58. Annual household income of surveyed respondents. Graphic credit: B. Madden

Options for Economic Diversification

1. Agriculture partnerships with local resorts

As described in the interview results above, agriculture is a significant part of Ranobe's economy. Nonetheless, there is potential for increasing the efficiency and profitability. First, simple irrigation systems could dramatically improve the productivity of the land. Because Ho Avy has already started experimenting with these, we leave irrigation beyond our scope.

A more interesting proposition involves finding guaranteed buyers for Ranobe crops. Given the village's proximity to luxury beach resorts on the western coast of Madagascar, we believe Ranobe should forge partnerships with these resorts, growing the types of food they request in exchange for a guaranteed market. Luxury resorts often require more variety of food – especially fruits, herbs, and spices – than is available in local markets and are forced to import from larger cities like Toliara or Antananarivo. If Ranobe can adapt their agriculture to grow more of these high-end crops, they stand to benefit from guaranteed buyers willing to pay higher prices, and the resorts benefit from cutting import costs by using local food.

Although such a shift would require time and possibly training, Ho Avy has already successfully begun growing basil, cilantro, and other herbs in their nurseries. The water table in Ranobe is on average 1-1.5 m below ground, making irrigated agriculture feasible, and Ho Avy is already invested in experimental agriculture at their nurseries and research center. Similar experiments could be created to determine best practices for high-end crops. Moreover, given the number of nearby village markets selling staple crops, Ranobe will still have easy access to food supply if they divert some agriculture to high-end crops. The greatest barrier to forging such a partnership is the need to create a strong, legally enforceable contract with resorts, guaranteeing that they will purchase Ranobe crops. Villagers are unlikely to currently have the level of knowledge of business management to negotiate such a contract, so this is an appropriate place for Ho Avy to offer their support in the form of direct contacts and basic business education. To do this, Ho Avy could bring in business and administrative representatives from more well-established nonprofit institutions or students from the University of Toliara to educate villagers.

2. Dried food

Using the solar food dryers recommended in the *Food Security* section, residents of Ranobe would be able to preserve meats and produce to increase food security as well as to sell in local markets. See *Food Security* section for more information.

Figure 59. Drying banana chips on tray prototypes. Photo credit: P. Liao

3. Construction of solar dryers

Beyond selling food from the solar dryers, there may be a short-term market for solar dryer construction in other villages. If Ho Avy can train Ranobe residents in the construction and use of solar dryers, these villagers could offer their services around the region. Support from Ho Avy would be needed to identify these markets and possibly arrange transportation. Although this represents only a short-term boost to the economy, the regional development benefits may be huge.

4. Essential oils

As many other rural villages around the world have discovered, using natural resources to create luxury goods for Western markets can be extraordinarily lucrative. Essential oils and soapmaking are two such markets that have proven to be profitable and feasible for other villages in Madagascar. Ranobe currently has access to resources such as honey, citrus, basil, eucalyptus, and baobab that can be made into oils and soaps. Seed press equipment, as well as some key chemicals such as glycerol or a natural relative and mixing and setting equipment, are needed to carry out such a venture. Villagers will require some kind of financial support to start operations and to gain the skills and equipment to manufacture quality products. Involvement of Ho Avy or a microfinance facilitator could be integral. Similar to spearheading experiments with high-end agricultural products, cooperation with villagers in experiments determining best products from local materials remains critical.

Some of these products could be sold to tourist markets in larger cities like Toliara, but with the support of Ho Avy, Ranobe could also extend their reach to markets in Europe and the United States. If desired, a corresponding shift in agriculture could be tailored to grow crops especially useful for essential oils. Support from Ho Avy will primarily be needed to identify markets and procure necessary manufacturing equipment. Moreover, as described in the *Agriculture Partnerships* section, Ranobe villagers could benefit from basic business education and training to ensure success of an essential oils market.

5. Handicrafts

Another lucrative Western market is that for handicrafts such as baskets and woodcarvings. Malagasy culture traditionally places significant emphasis on these skills, and many Ranobe residents have the ability to create beautiful products. One advantage of handicraft production is the ability for women to work while cooking or watching children and for men to work while herding cattle in the fields. Moreover, given its proximity to the lake and the forest, Ranobe has ample access to reeds for weaving and wood scraps for carving. Again, some support from Ho Avy would be needed to ensure the proper market for these goods is reached and that Ranobe villagers have sufficient business management knowledge to maintain that market.

Figure 60. Ranobe children sculpt zebu from clay. Photo credit: P. Liao

6. Biofuels

The climate of Ranobe is appropriate for growing *Jatropha*, one of the world's common biofuel crops. Many other locations in Latin America, Asia, and Africa have already tapped into this emerging market, and although the biofuel industry has recently suggested that *Jatropha* may not be as lucrative as once thought, the market is still strong. One of the primary benefits of *Jatropha* is its ability to grow on marginal lands. Given the amount of land degradation that has already occurred around Ranobe, *Jatropha* production is a potential way to extract economic benefit from these lands, however, these plants would likely still require irrigation and possibly fertilizer. Additionally, castor (*Ricinus communis*), neem tree (*Azadirachta indica*) and *Moringa oleifera* grow well in Ranobe and offer advantages in biofuel potential. Although we were not able to successfully produce oil with our small hand seed press, the potential profitability of biofuel crops encourages further research into expected yields, available markets, and necessary investment in equipment (likely to require some level of financing by Ho Avy or other external organization to start). Even if these seed oils prove not to be profitable on a large scale, the oil can still be used by residents for heating, lighting, or cooking fuel. Burning seed oil or related biofuels produces significantly fewer harmful emissions for human health and the environment.

7. Business Education and Training

One common trend in the options presented above is the need for education and training of Ranobe villagers in business management. To ensure a sustainable and self-sufficient economy, villagers need to have basic knowledge of contracts, negotiations, fair market prices, and professional interactions. At the very least, literacy and convincing public speaking will be necessary for a subset of Ranobe villagers. Ho Avy may not be best situated to educate villagers themselves, given their limited time and resources, so it may be more effective to use local connections with the University of Toliara and larger, better-established nonprofit organizations such as WWF or the Alliance Française, to find representatives from those organizations to teach villagers. Business students from the University or administrative managers from the organizations would likely be knowledgeable enough to put together a simple workshop on the basics of business administration. Such a workshop could be held in the Ranobe school, research center, or planned community center to engage as many interested villagers, adults and youth alike, as possible.

Recommendations

From the preceding option analyses, it is clear that there are many paths for Ranobe to take toward development. Our vision is for Ranobe to do so sustainably, both for their surrounding environment and their own lasting livelihoods. We define sustainable development as the improvement of villagers' standards of living without degradation of their natural environment and independent of external organizations, such that villagers become self-motivated and self-improving. Evoking the Brundtland Commission's definition, sustainable development for Ranobe requires that future residents of the area have the same ability to meet their needs as the current villagers. With these ultimate goals in mind, the recommendations put forth in the following section holistically work together to provide Ranobe's residents with the tools and skill sets to become a self-sufficient and independent village, capable of maintaining their own health and economy and finding resources for continued development.

Currently, the nonprofit Ho Avy is the primary driver of development in Ranobe. Ho Avy brings in funding, and with it, experts and new technologies to facilitate experimentation and prototyping. While Ho Avy is sensitive to Ranobe's needs, villagers are ultimately dependent on the nonprofit for advancing development, and are not themselves engaged in planning or higher level decision-making. Ho Avy generally determines what new technologies to work with and use. This scenario is not sustainable, as it does not develop the leadership and management skills in Ranobe villagers that they need to become self-sufficient. Thus, our short-term recommendations propose a series of steps for Ho Avy to facilitate this shift. Initially, Ho Avy should begin to involve villagers in their decision-making, prototyping, and experimentation phases. This needs to be followed by fully training and educating the villagers as part of the implementation. It is essential that training be coupled with education so that villagers are motivated to maintain the techniques and habits learned.

Ranobe children are excited to play with visitors . Photo credit: P. Liao

Furthermore, this general framework will be most effective if applied across all five perspectives that we have assessed: land use/land cover change management, energy potential, water and health, food security, and economic growth. This holistic approach will ensure a diverse skill set for villagers to use and apply as they face new development challenges.

In the long term, we anticipate that villagers will generate their own development agenda. To achieve this, they will use existing network connections from Ho Avy and associated nonprofits in addition to being able to seek out and forge their own connections. In such a scenario, Ho Avy could still play the matchmaker and facilitator roles as necessary, but would have the villagers directing the goals of such interactions. Ho Avy could focus their efforts on Spiny Forest reforestation and land management, which is the main strength of their organization. Villagers would then become responsible for their own training and education by determining their needs, organizing training opportunities, etc. Ideally, they would also be able to train their neighbors in proximate villages, since they would have less of a language and cultural barrier compared to a foreign nonprofit organization.

With these larger goals framing the proposed recommendations, the following short- and long-term action plans aim to equip Ranobe with tools that the villagers can adapt and make useful for their own perceived needs.

Phase 1: Short Term

In the short term, our goal is to begin the process of educating Ranobe villagers to take an active role in their own development, while simultaneously tackling critical issues such as Ho Avy's organizational management, environmental awareness, and public health. The primary components of this plan are outlined below.

Education

First and foremost, educating the Ranobe villagers requires knowledge sharing and outreach from Ho Avy. There are many basic concepts and skills that Ho Avy can teach the villagers to put them on the trajectory toward development. For example, attention to health education is integral to increasing not only standard of living but also economic progress in Ranobe, as sickness results in a diminished workforce. Consequently, it is vital for villagers to understand how they can improve their quality of life through better sanitation and nutrition. This involves teaching them the benefits of water filtration to motivate them to drink cleaner water, teaching them about the nutritional value of different types of local foods, and finally, reinforcing all of these by example (Figure 61). Understandably, many concepts will take time to become part of common behavior, but practice can change; increased use of Ho Avy's hand-pump for water over time is an excellent example. Health programs should also educate villagers about identifying symptoms of common

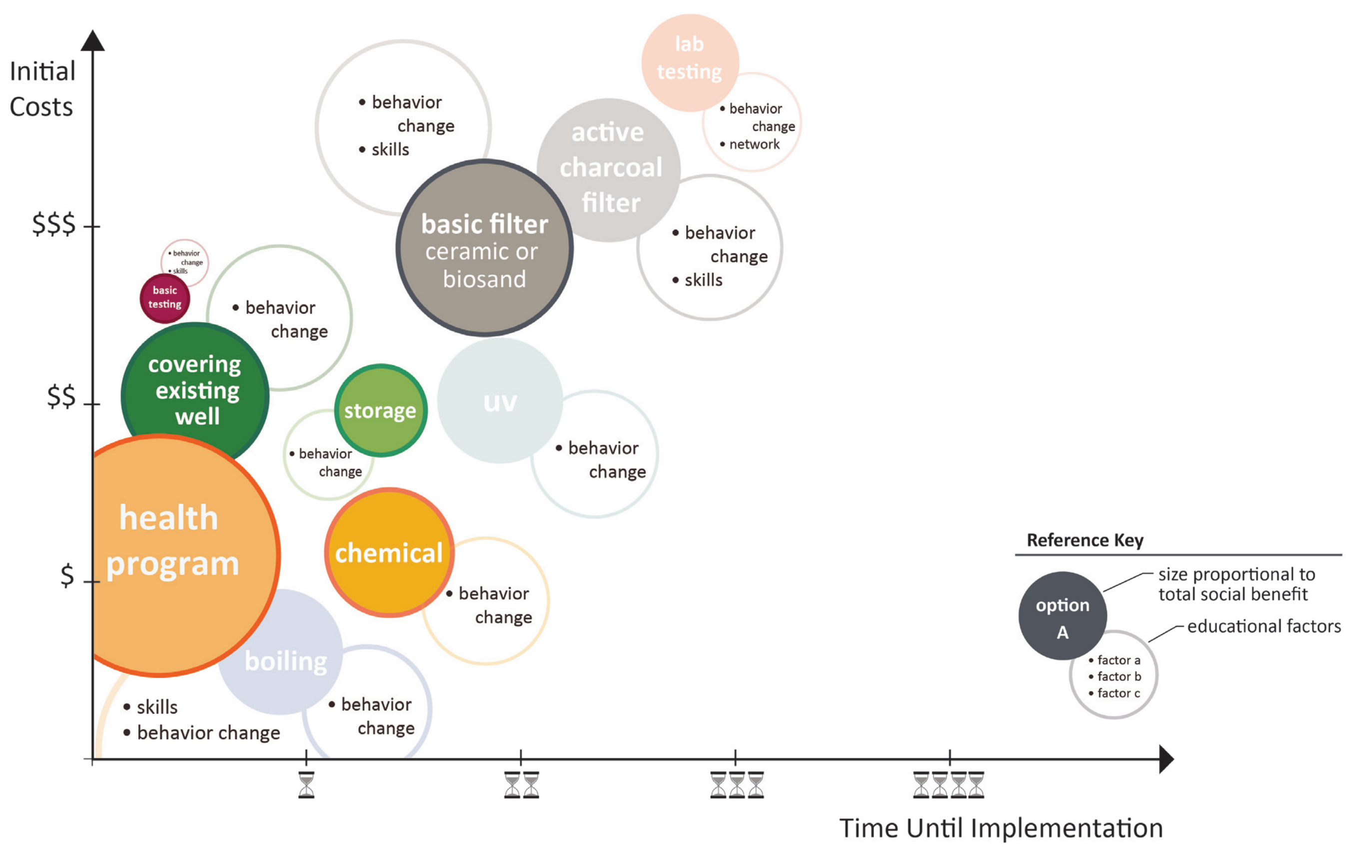


Figure 61. The total social benefit of each health option and the educational attainment required to implement the option based on initial costs and time until implementation. Faded bubbles were not recommended for short-term implementation in Ranobe. Graphic credit: O. Lau

diseases, best practices to reduce disease prevalence, and basic understanding of vectors of transmission. Professional assistance through more regular physician visits, facilitated through Ho Avy, will bring appropriate healthcare for those that suffer from disease or injury as well as preventative rotavirus vaccination. A health education program needs to be developed in conjunction with a health professional but should include information on diseases, i.e., schistosomiasis and malaria; disease prevention, i.e., safe drinking water, improved sanitation, and oral rehydration; and health, i.e., hygiene and nutrition.

Another vital educational component for the villagers will be to study impacts of different types of land use, the tangible and indirect values of their forest, and how they can protect their natural resources from damage by migrants. Ho Avy has already begun this and is also in the process of instituting a government-backed protection area near Ranobe. Villagers are voluntarily involved in these efforts; indeed, villagers not previously associated with Ho Avy have also expressed interest in managing the forest. A portion of this is motivated by recent incidents where migrant populations burned the nearby forest for agriculture and charcoal; villagers in Ranobe already have a sense of ownership of the forest and are uncomfortable with such destruction.

Ho Avy can also act more effectively as a vehicle to transfer knowledge between incoming experts and the villagers. By prioritizing a shortlist of training sessions and maintaining documentation of training or prototyping when it occurs, Ho Avy can better ensure long-term benefits and effectiveness. This requires some reorganization on Ho Avy's part, which will be described next.

Organizational Management

None of this education can happen without a simultaneous shift in Ho Avy's management system and their operations in and with the village. When our team was working in the field with the client over the summer, we witnessed a passionate, enthusiastic two-person team that continually overreached their capabilities. Ho Avy attempted to make every potentially relevant connection and bring those resources back to Ranobe. The motivation seemed to be to raise awareness of Ranobe's issues. While this is a highly effective networking tactic, the breadth of focus may actually be less effective for solving Ranobe's poverty and forest degradation issues.

Figure 62. Ho Avy fixing the treadle pump. Photo credit: O. Lau

As such, we recommend that Ho Avy conduct an internal audit to identify their strongest skills. From this, they can determine what they can individually accomplish in Ranobe; they should focus on these and prioritize a few (less than five) other projects at any given time. This is because Ho Avy lacks the resources to take on more: once the experts leave, Ho Avy may not have adequate training to continue what has been started, and if they do, they still lack the time and manpower to do so. In either case, the impact of the external expert's time and the money spent bringing that expert to the field are likely not maximized, and more experts working on disparate side projects distract from primary development goals and training. On the other hand, focusing attention on a few choice projects allows Ho Avy to nurture these projects to fully develop, which should give confidence to the villagers and inspire them to innovate and continue to develop. Real change takes patience and focus; both Ho Avy and the villagers will require focus for experimentation and patience for troubleshooting problems.

Local Engagement

Another stage of our short-term recommendations requires actively involving Ranobe villagers in the development process. This includes both the physical labor of construction and the planning and design processes. Ho Avy's current management structure uses village manpower extensively for village construction needs; however, villagers are not engaged in making major decisions. Understandably, Ho Avy's concern is that villagers lack understanding of the technologies and structures that Ho Avy is implementing. The way to eliminate this concern, though, is to start training the villagers in these techniques. Ho Avy can actively train villagers both in construction and in more abstract decision-making skills.

Understanding the limited time Ho Avy members have to work on training, the ideal situation may be an apprenticeship program where one or two villagers are trained intensively at one time. These villagers can then disseminate lessons and information learned to others. Villagers can easily learn to construct solar dryers and water filters, select ideal locations for installation based on logistics of cooking and working areas, and pass along those skills to each other. While it may be useful for Ho Avy and

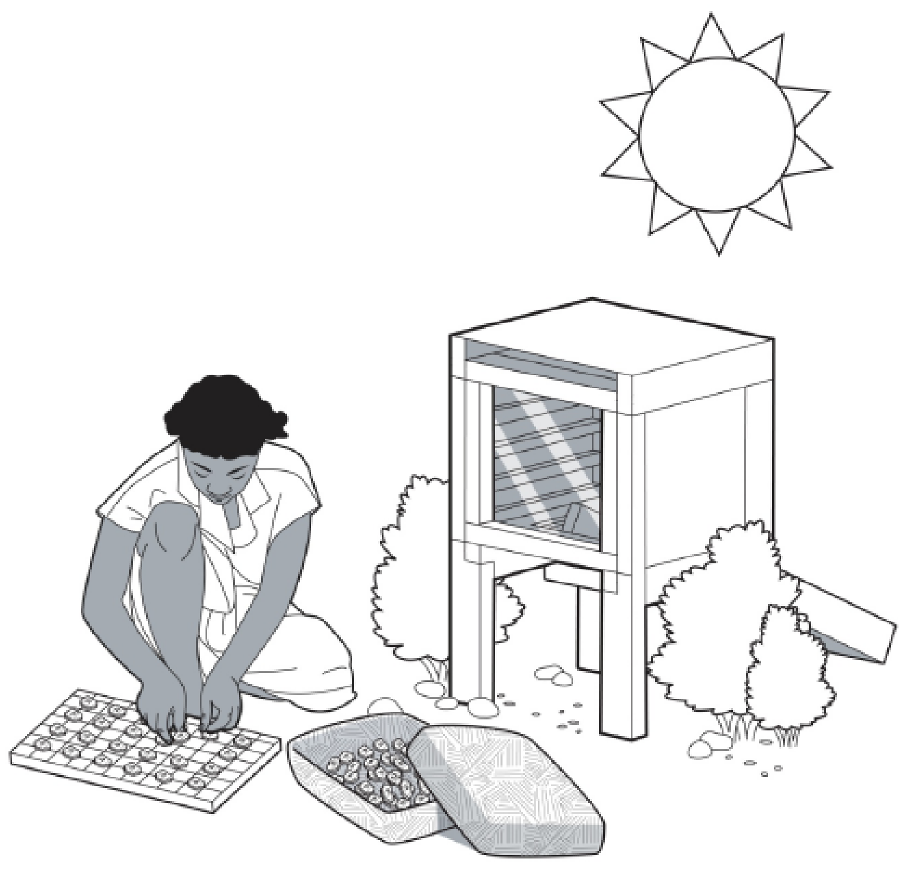


Figure 63. Instructions to use a solar dryer are visually communicated in a manual. Graphic credit: C. Nowak

other outsiders to offer suggestions, more collaboration in the process provides opportunities for key decisions to be made by the users themselves. Ranobe's residents should be encouraged to experiment with different drying techniques, foods, effective communal locations for water filters, etc. A more sophisticated example is to involve villagers in land management design. Villagers are already involved in the discussions to establish this regime; a Ho Avy apprenticeship program that includes using GPS equipment, as well as sharing knowledge of plant ecology, ecosystems, and biodiversity, could be the start to a forest rangers program. Each of these skill sets will make villagers more effective at protecting their forest in addition to granting them a better understanding of its values and vulnerabilities.

Both the villagers and Ho Avy can benefit from cooperation in innovation for conservation and sustainable development. The limited nature of Ho Avy's human power calls for modified apprenticeship programs enabling self-perpetuation of the learning process in a relatively short time. Two integral co-products should result: First, the apprentices will be able to voice their concerns and bring indigenous knowledge to the process, thereby providing Ho Avy with vital information and dialogue concerning their efforts. Secondly, throughout the apprenticeship but especially in later phases, the apprentice will be able to disseminate and discuss conservation and development concepts and ideas with other villagers, continuing the education system without demanding translation and time from Ho Avy's comparatively smaller human resources. The goal of such a program is to bring FIMPAHARA and Ranobe closer to sustainable self-reliance by blending development support with indigenous expertise.

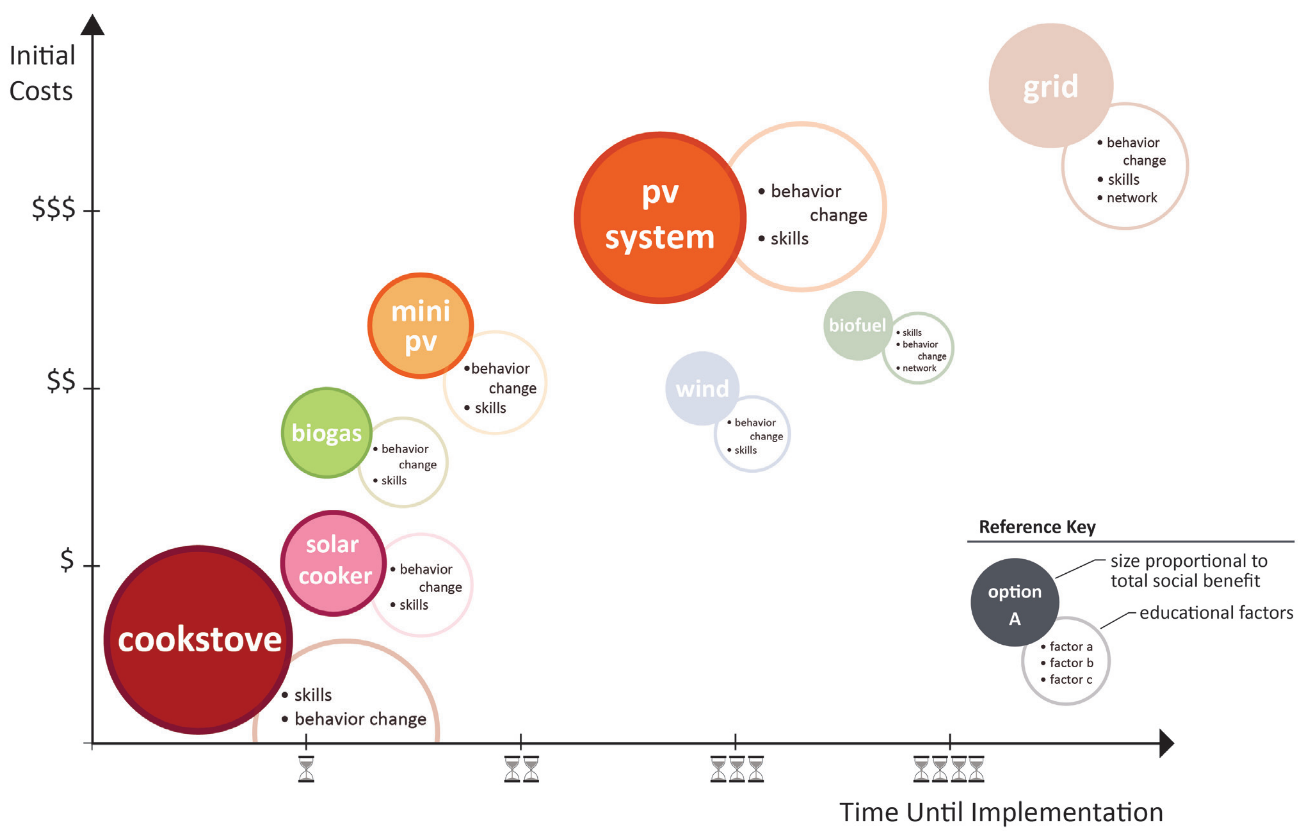


Figure 64. The total social benefit of each energy option and the educational attainment required to implement the option based on initial costs and time until implementation. Faded bubbles were not recommended for short-term implementation in Ranobe. Graphic credit: O. Lau

Forest Management

Ho Avy's current reforestation efforts also include utilization of FIMPAHARA's labor pool. Villagers are paid to tend to nurseries by planting seeds, watering, and eventually transplanting seedlings. One of Ho Avy's most pivotal skills is their knowledge of ecology, scientific processes, and reforestation techniques. Although FIMPAHARA members retain some of the skills learned under Ho Avy's employment and have concern for the well-being of the forest, their current efforts seem to rely more on promised salary than acceptance of the value of reforestation. To induce a shift, an apprenticeship program based on the model described earlier would be effective, especially under the guidance of an in-house expert (one of Ho Avy's co-coordinators, Martina Petru). Here, one or two FIMPAHARA members would intensively train in ecological knowledge, processes, and skills that can then be disseminated other members through enhanced dialogue between NGO and village. Trained members can then become 'teacher assistants' to train other villagers on the knowledge they have gained; new apprentices would cycle in, adding to the dialogue. A program like this can be the foundation for a future ecotourism ranger program for the protected Spiny Forest area.

Figure 65. Mbolo, a Ranobe villager, assists the project team with data collection of the Spiny Forest. Photo credit: C. Santoro

Economic Diversification

A final piece of the short-term plan for development in Ranobe must focus on increasing economic growth. Currently, the economy relies heavily on agriculture and the sale of natural resources such as thatching material. In the short term, it is unlikely that the economy will transition far from these familiar fields, but Ho Avy can encourage contract farming with production and distribution targeted to tourist resorts or restaurants in the nearby coastal areas. Contract farming has the advantages of a guaranteed market as well as sale of higher-profit goods. Starting immediately, Ho Avy should experiment with the villagers to determine what types of high-end crops, for example herbs and spices, are most suitable for Ranobe climate patterns. Villagers may also need additional training to ensure the quality of their crops is suitable for organizations catering to Western tourists.

Figure 66. Older generations of women in Ranobe weave reeds into beautiful mats and baskets. Photo credit: P. Liao

Ranobe can also take advantage of its access to natural resources to develop products such as crafts, soaps, and essential oils for sale to tourist markets or export to developed nations with the

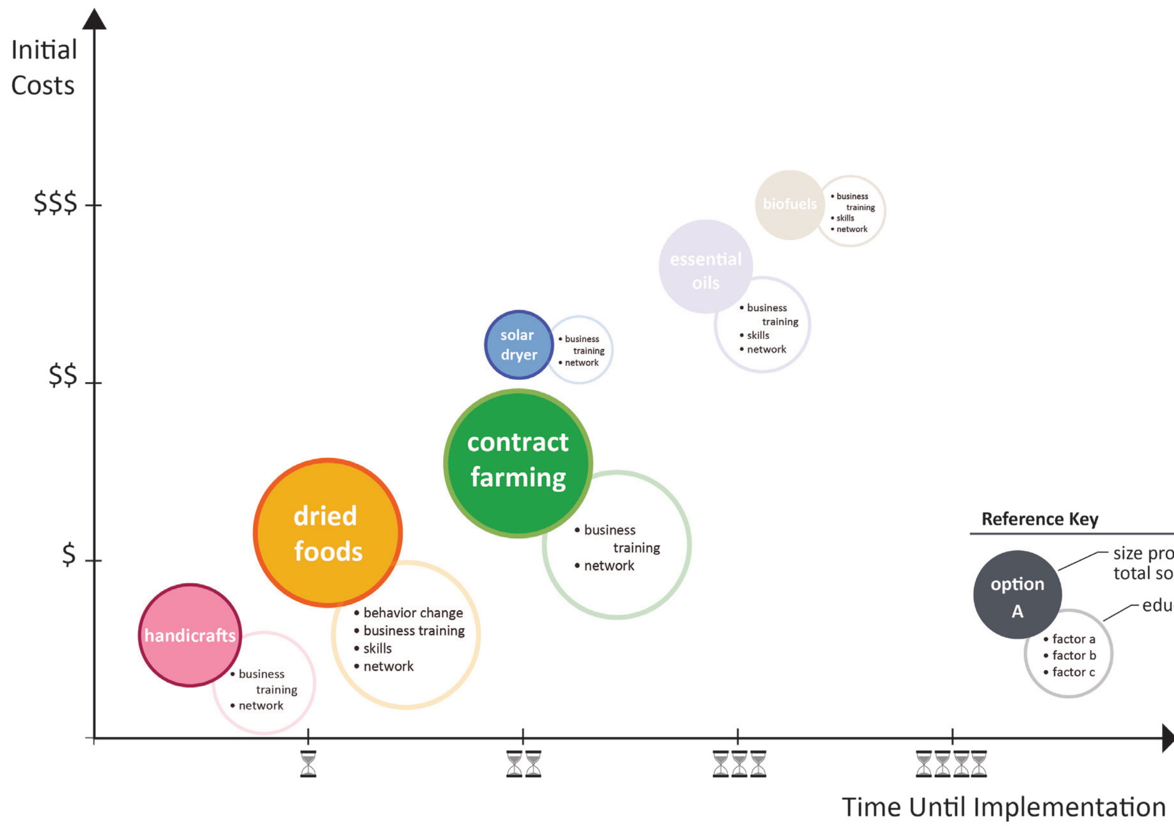


Figure 67. The total social benefit of each economic development option and the educational attainment required to implement the option based on initial costs and time until implementation. Faded bubbles were not recommended for short-term implementation in Ranobe. Graphic credit: O. Lau

assistance of Ho Avy, who has connections across the world. Woodcarvings, for example, are highly profitable in tourist markets, and Ranobe has access to sufficient wood scraps from its proximity to the forest. Plants and crops grown in the area, such as eucalyptus, baobab, and citrus, also serve well as soaps or essential oils. Women can make Madagascar's unique baskets to export. These also have the advantage of being simple to make and do not require expensive capital; men, women, and older children can create goods for sale while engaging in other daily tasks such as herding cattle, watching infants, or cooking meals.

Finally, we also recommend that Ranobe villagers become involved in constructing and selling products, such as solar ovens or water filters, to aid development in nearby villages. Solar ovens and cookers are currently being built by NGOs in Toliara and throughout Madagascar; these could just as easily be made by villagers in Ranobe with assistance from Ho Avy to seed the program. By engaging villagers in the design and construction of these products, Ho Avy could not only bolster development in Ranobe but also throughout the region (Figure 67).

Figure 68. Curious Ranobe children crowd around a laptop. Photo credit: C. Santoro

Phase 2: Long Term

In the long term, the goal is to have Ranobe function more autonomously in all capacities, such that they are able to develop and carry out their own sustainable agenda specific to their needs. This transition assumes that short-term plans are able to grow with time, allowing villagers to be more involved and assume more active decision-making roles in the community and elsewhere. In this way, Ranobe villagers can have a direct impact in shaping their livelihoods and the outcomes of their future. To achieve this, we have identified several elements that are essential for Ranobe. Again, some of these echo the long-term visions that Ho Avy has already identified; however, these features envision a more holistic and sustainable development path for the community of Ranobe.

Collaborative Relationship. A gradual shift in management from Ho Avy to Ranobe villagers must occur. Given the limited human capital of Ho Avy and its current management structure, villagers must be more involved in leadership and implementation of various projects. Ho Avy should provide support through guidance and allow villagers to graduate toward training and educating others.

Developing a Strong Network. Developing a strong network of allies allows Ranobe village to expand their efforts and development goals. This process requires Ho Avy and Ranobe to maintain and build on their existing connections and resources to develop partnerships with other communities and organizations. The continuation and expansion of a support system will be vital for expanding the area of forest monitoring and protection, capturing new markets for economic development, continuing education, and improving overall health and awareness.

Reducing Energy Poverty. Providing improved access to energy is vital to improving livelihood conditions in village. More efficient cookstoves can reduce (or even eliminate) the burning of forest biomass. Given the solar potential of the area, the benefits of powering the village are great using a PV system. Developing an energy infrastructure requires financial resources and time. However, the benefits to supplying power are astronomical for a remote village. Children can extend their hours of learning into the night; the village's dependency on fuelwood for light and cooking can be reduced. Additionally, PV could benefit economic development by expanding productivity into evening hours.

Developing a Self-Sustaining Economy. Having economic autonomy and less reliance on outside funding sources (i.e. Ho Avy) is crucial for villagers. The village can expand its economic base by developing new networks for specialty goods, such as medicinal products and crops, or by producing goods for sale to Western markets.

Continuing Education. Continuing education is essential for Ranobe to become self-sufficient. Assuming that short-term training and education are in progress and ongoing, the knowledge and skills attained are likely to help facilitate greater action and innovation among villagers. From this perspective, education is not only a tool, but also a form of empowerment that is value-added. The more villagers learn, the more they are able to effectively plan, design, and implement their own vision for Ranobe.

Figure 69. Ho Avy staff teaches Ranobe villagers how to use weather station. Photo credit: B. Madden

Conclusion

In many ways, Ranobe is characteristic of rural, poor villages internationally. The issues plaguing the village are certainly not unique: land degradation, energy poverty, food insecurity, poor water quality, lack of sanitation, and high rates of unemployment and underemployment. Due to the community's dependence on the Spiny Forest, we have shown in this paper that environmental sustainability and social and economic development are inextricably linked; to alleviate these, we have proposed a series of integrated recommendations to simultaneously promote sustainable development of the village and its supporting ecosystems over the short and long terms. By effectively managing interactions with the nonprofit Ho Avy and increasing focus on education and villager empowerment and capacity-building, the village of Ranobe can become an independent and self-sustaining community, concurrently developing and minimizing impact to its valuable forest resources. The recommendations and guidance provided here may be used not only by Ho Avy and the village of Ranobe but also by other villages in southwest Madagascar or, if properly adapted and applied, by the rural poor worldwide.

Under a double rainbow, the village Ranobe is lush and green after a rare winter rainstorm. Photo credit: P. Liao

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Glossary

<u>**Units**</u>

Ah (Ampere-hour)
Unit of electric charge

Ariary (Ar)
Malagasy currency (MGA); ~2000Ar = 1USD (May-August 2010)

ha (hectare)
Unit of area defined as 10,000 m^2

kg (kilogram)
Unit of mass in the International System of Units (SI). 1 kg = 2.20 pounds

km (kilometer)
Unit of length in the International System of Units (SI). 1 km = .62 miles

km^2 (square kilometer)
Unit of area defined as 1,000,000m^2 or 100ha

L (liter)
Base unit of volume in the International System of Units (SI). 1 L = 2.64 gallons

m (meter)
Base unit of length in the International System of Units (SI). 1 m = 3.28 feet

mm (millimeter)
Unit of length in the International System of Units (SI). Used to measure rainfall.

W (Watt)
Unit of power

Terms

Alliance Française (AF)
French organization whose mission is to promote French language and culture. Alliance Française has a center in Toliara.

Alternating Current (AC)
An electric current that reverses its direction many times a second at regular intervals, typically used in power supplies. AC is typically delivered to businesses and residences.

Ambolomailaka
Town approximately 5.57 km from Ranobe (distance based on straight-line distance, not actual travel distance). It takes about one hour to get there by zebu cart.

Antananarivo
Capital of Madagascar, commonly referred to as the place from where things must be imported.

Bangladesh Rural Advancement Committee (BRAC)
Organization responsible for starting education program on oral rehydration and diarrhea prevention.

Bruntland Commission
Officially, the World Commission on Environment and Development (commonly called by the name of its Chair, Gro Harlem Brundtland), which was convened by the United Nations in 1983. The report from this Commission (titled "Our Common Future") is best known for its definition of sustainable development.

Castor
Ricinus communis is a taller shrub with large leaves. The seeds have a high oil content (45-50%). The oil is also used for coating fabrics, lubricating machinery, producing printing inks, textile dyeing and leather preservation.

Centers for Disease Control (**CDC)**
US organization that publishes information on schistosomiasis and other diseases of concern for Madagascar (in addition to everywhere else in the world).

Dina (Malagasy)
Customary rule that governs how people live within a community. This includes social interactions, collective action, and land tenure.

Direct Current (DC)
Unidirectional flow of electric charge. Direct current is produced by such sources as batteries, thermocouples, solar cells, and commutator-type electric machines of the dynamo type.

Environmental Protection Agency (EPA)
US organization that publishes relevant data on renewable energy sources.

FIMPAHARA
Primary Ranobe-based organization collaborating with Ho Avy on conservation and development efforts.

Food and Agriculture Organization (FAO)
A division of the United Nations that publishes relevant data on food and agriculture.

Geographic Information System (GIS)
Used for geoprocessing and to complete land use/land cover change analysis.

Global Positioning System (GPS)
Used to collect spatial data on land use and charcoal production.

Ho Avy
The client organization for this project; a nonprofit based in Ranobe that is focused on forest conservation and protection.

Jatropha
Jatropha mahafaliensis – species tested for biofuel potential and also used for construction. Vernacular name is hatratra.

Light-Emitting Diode (LED)
A highly efficient and long-lived form of light bulbs (compared to incandescents or compact-fluorescents).

Ministère des Eaux et Forets (MEF) (Fr.)
Ministry of Water and Forest.

Moringa
Moringa oleifera is native to India but is now found in tropical areas around the world. The 5-10 meter tree's seeds hold 33-41% oil (also known as ben oil) by weight, an acceptable feedstock for biodiesel.

Neem Tree
Azadirachta indica is native to India and is found around the Indian Ocean. It grows to 12-18 m and the seeds contain 40-50% acrid green to brown colored oil.

Non-Governmental Organization (NGO)
Used synonymously with nonprofit.

Photovoltaic (PV)
Solar panel. Converts solar radiation into electricity.

Pirogue
Wood boat constructed from very low-density tree species.

Ranobe
Village and study area of interest in southwest Madagascar.

Route National (RN)
Major road system in Madagascar.

Schistosomiasis
Water-borne parasitic illness that is common in tropical areas and may have severe and debilitating effects, also known as bilharziose (Fr.).

School of Natural Resources and Environment (**SNRE)**
Program at the University of Michigan sponsoring this project.

Taxi-brousse
Common mode of transit in Madagascar.

Toliara
Capital of Toliara Province and Atsimo-Andrefana District (geographic coordinates). City was also the home base for the project team.

Ultraviolet radiation (UV)
UV is useful for killing bacteria and other microorganisms in drinking water.

University of Toliara
The nearest university to Ranobe, also where Ho Avy's translator goes to school.

Vondron (Malagasy)
Typha angustifolia – building material commonly used for walls and roofing; often sold as an supplementary source of income.

World Health Organization (WHO)
A division of the United Nations that coordinates information on international public health.

Zebu (Malagasy)
Common name of cattle in Madagascar.

Appendices

Appendix A:
Land Use/Land Cover Change Analysis

Appendix A: Land Use/Land Cover Change Analysis

Methods

To better understand the changing ecosystem dynamics and compare local changes to the regional picture, aerial images were analyzed for changes in land cover. Images were collected from Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper Plus (ETM+), then processed and analyzed using ArcGIS and ERDAS Image (Earth Resources Data Analysis System) software. Images were pre-processed prior to running the post-classification change detection method to assess the rate of regional and local land cover change. Scene selection was based on the following criteria:

1. Seasonality when precipitation levels are highest to distinguish vegetation characteristics
2. Scene quality in terms of cloud-free and SLC-on
3. Date for most recent data and availability of scenes to match existing Google Earth images

Based on these criteria, scenes from path 167 row 076 of the Worldwide Reference System (WRS) for February 4, 2000 and January 22, 2010 were selected from the United States Geological Server (USGS) Earth Resources Observation and Science (EROS) Data Center with Level 1T correction.

Pre-processing

Each scene was imported and layer stacked into a single multi-layer stack with bands 1, 2, 3, 4, 5, and 7. Once stacked, the images were re-projected from the original projection in World Geodetic System (WGS84)/ Universal Transverse Mercator (UTM) coordinate system to WGS84/UTM, Zone 38-South, which was established as the standard projection for the project. The images were resampled using bilinear interpolation, applying force square pixels and polynomial approximation with a maximum poly order of 3 and a tolerance of 0.100. All data files in the analysis underwent bilinear interpolation when required to process the information. The data were clipped to focus in on the area of interest between Toliara and the Manombo River (Figure 1) before applying radiometric correction to remove unwanted atmospheric effects (i.e. path radiance, scattering, etc.) and normalize solar illumination in the images using the COST Method (without Tau) and dark pixel subtraction technique.

43˚34'57.09" E, 22˚57'31.69" S	43˚43'18.19" E, 22˚57'31.69" S
43˚34'57.09" E, 23˚18'32.45" S	43˚43'18.19" E, 23˚18'32.45" S

Figure 1: GIS data clipped to the coordinates illustrated above.

Additionally, clouds and their associated shadows and large water bodies were removed to enhance visualization and analysis of the image. Polygons were drawn around clouds, cloud shadows, and large water bodies in ArcGIS for the 2000 and 2010 scenes and converted into a single binary raster mask. Each band of the 2000 and 2010 image format Landsat scenes were converted to GRID format in ERDAS Imagine, and then taken back into ArcGIS to apply the raster mask. Following this process, the modified bands were restacked for each scene to produce cloud-free and large water body-free scenes to analysis (Figure 2). The pre-processing techniques resampled the images from the 30m standard for Landsat TM and ETM+ to 66m resolution, thus setting 66m as the standard for the analysis.

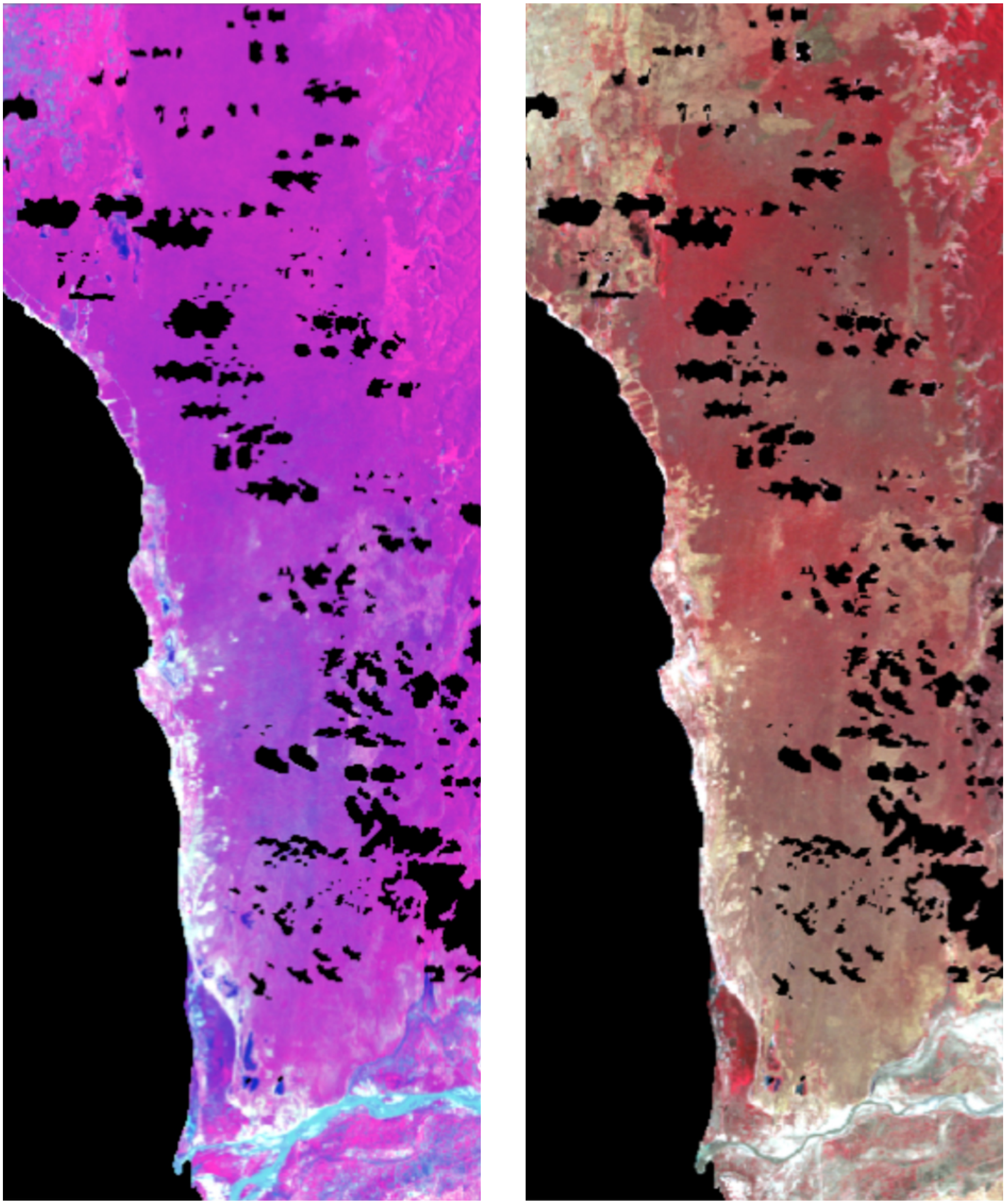

Figure 2. Landsat ETM+ scene from 2000 (left) and Landsat TM scene (2010) following atmospheric correction, and cloud removal.

The classification scheme was developed using the ISODATA automatic algorithm. Clustering was set to 20 classes with a maximum of 10 iterations and a 0.950 convergence threshold. The clusters were re-classed into five land cover categories: cleared land (value=5), less disturbed forest (value=4), undisturbed forest (value=3), water (value=2), and unclassified or no data (value=1). Data collected in the field and ancillary aerial images from Google Earth (taken in 2000 and 2009) and from World Imagery provided by ESRI online map service (taken in 2000) were used to reclassify the images. The process produced two maps, each identifying existing land cover in 2000 and 2010 (Figure 3).

Post-Classification Processing

The post-classification change detection method was applied to determine the rate, locations, and patterns of land cover land use change between 2000 and 2010. Using ArcGIS Spatial Analyst tools, the 2010 scene was recoded by multiplying the land cover code values by 100. The summation of the 2000 and 2010 scene produced an output raster that identified areas of land cover change based on the pixel value. Pixel values of 101, 202, 303, 404, and 505 represent no change in land cover. Other values indicate change direction in land cover composition.

Class Name	2000 Code	2010 Code	Sum (No Change)	Other Values (LC Change)
Unclassified (No Data)	1	100	101	102-105
Water	2	200	202	201, 203-205
Undisturbed Forest	3	300	303	301-302, 304-305
Less Disturbed Forest	4	400	404	401-403, 405
Cleared Land	5	500	505	501-504

Table 1. Recoded values for each class and output pixel values from change detection process.

To examine the patterns of land cover change around Ranobe, both Landsat scenes were clipped to an approximately 10 sq. kilometer area surrounding the village (Figure 3).

43°36'19.843"E, 22°57'33.059"S	43°41'41.59"E, 22°57'33.059"S
43°36'19.843"E, 23°2'26.934"S	43°41'41.59"E, 23°2'26.934"S

Figure 3. Landsat scenes lipped to the coordinates above for the local analysis.

Results

In the 85 sq. kilometer area of interest, the findings illustrated a precipitous decline of undisturbed forest from 27.54% to 9.68% between 2000 and 2010. The amount of cleared land and undisturbed forest increased 12.67% and 4.81%, respectively, while less than 1% converted back to undisturbed forest. In 2000 near Ranobe in a roughly 10-sq. kilometer area, the forest was intact with 82.44% of the cover identified as undisturbed forest while 6.03% was classified as disturbed and 2.36% of the area cleared. By 2010, the area experienced a major transformation.

Nearly 50% of the undisturbed forest from 2000 has either been cleared or experienced some disturbance. Areas of cleared forest and less disturbed forest increased by 28.48% and 20.56%, respectively.

These results describe a high rate of deforestation in the past 10 years in the Ranobe area relative to the larger Spiny Forest extent. At the current rate of clearing, the landscape will be predominately barren and sparsely populated with vegetation in the coming decades. The alarming rate clearly illustrates that urgent action is needed to protect the remaining forest cover while simultaneously addressing forest regeneration options.

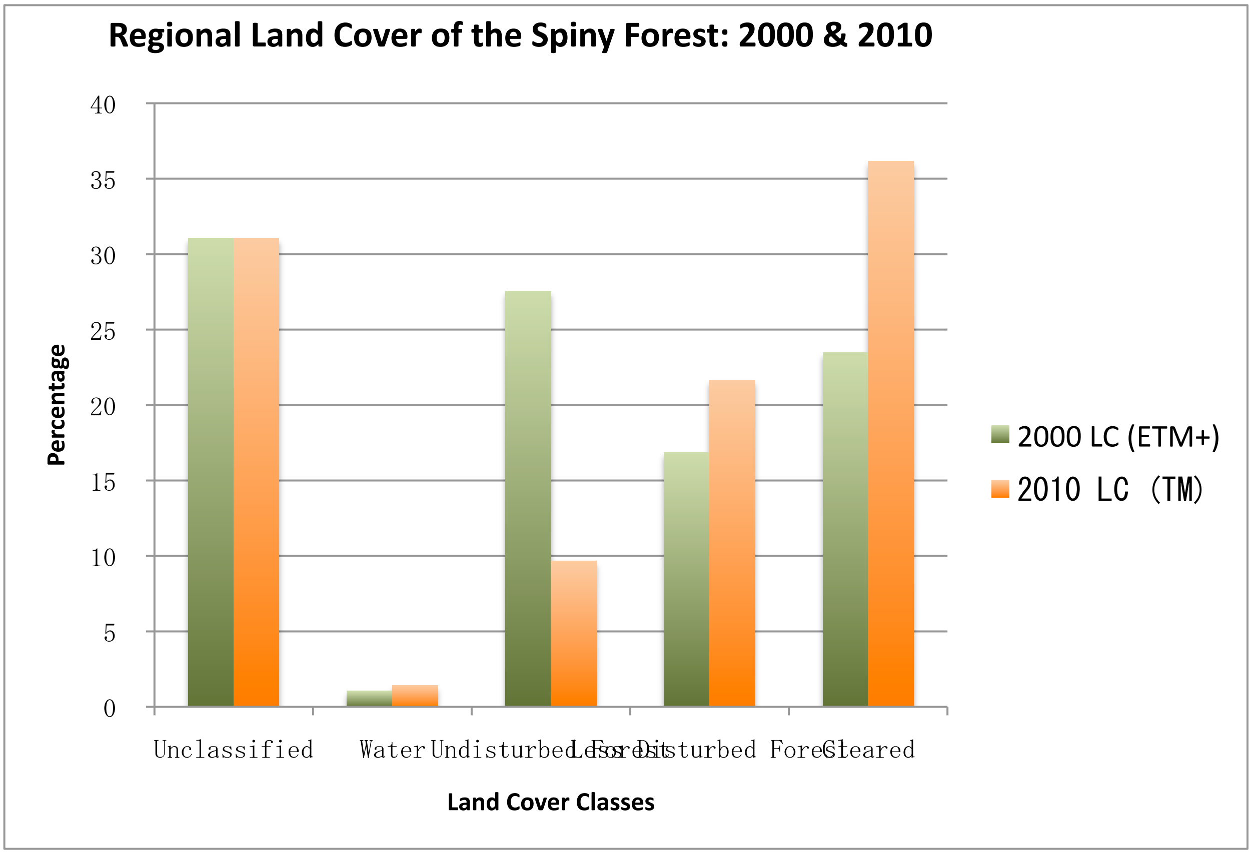

Figure 4: Percentage of Land Cover Type within the Spiny Forest Region for 2000 and 2010

In the local area of interest, the rate of land cover change was consistent with the regional trend. The analysis found that 22.75% of the land cover changed was cleared over the 10 year period.

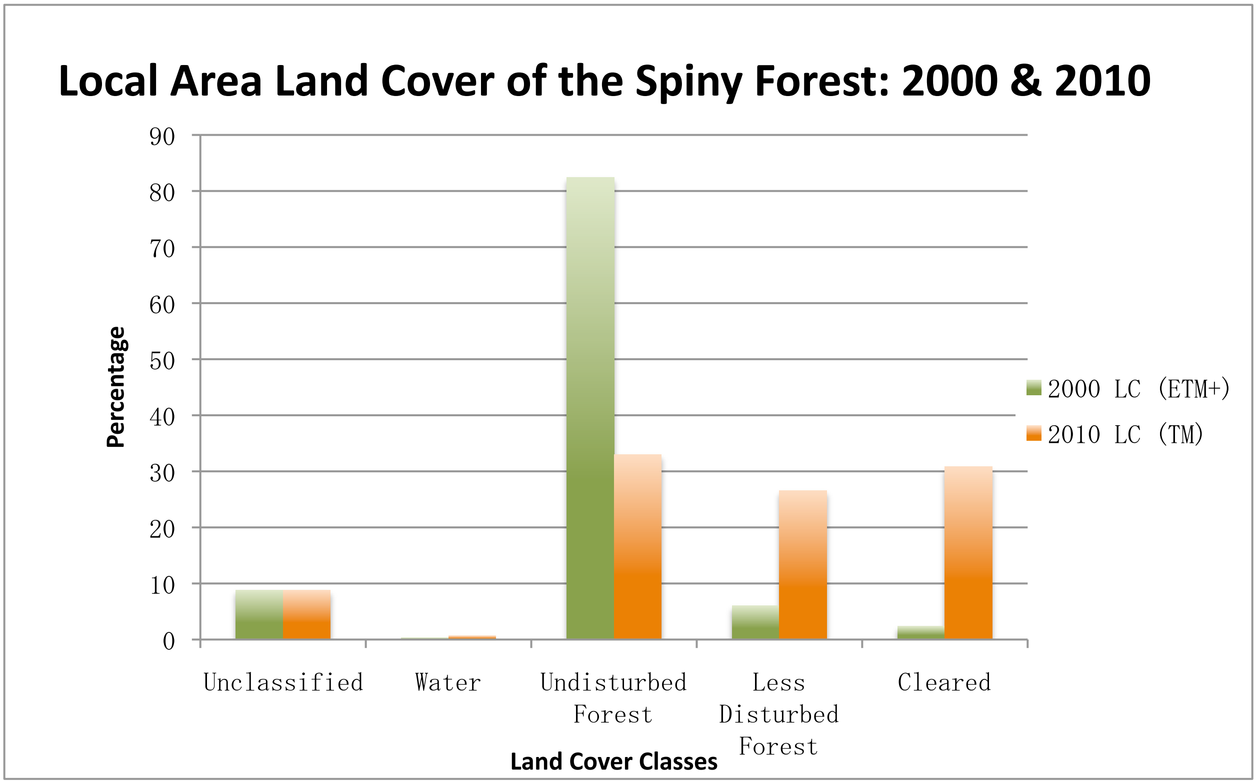

Figure 5. Percentage of land cover type within the local area of interest surrounding Ranobe village

Identifying Areas of Risk and Areas for Protection Using Multi-Criteria Evaluation

The results of the land cover and land cover change analyses were then combined with field and ancillary data to spatially determine areas of risk and allocate areas for protection. Using proximity to primary and secondary roads, villages, existing cleared areas, and land elevation and slope in a multi-criteria analysis, these variables were weighted and summed to determined areas of prioritized risk from anthropogenic destruction. From the risk results, zones were also defined for future protection based on proximity to the non-profit field base using the same method.

Data Preparation

The primary and secondary road data were obtained from GPS path data from our trail walks and gaps were traced from Google Earth images. Elevation data were retrieved from the Shuttle Radar Topography Mission (SRTM) database at a resolution of 90m and slope was calculated from the ASCII data format. The digital elevation model (DEM) and slope were clipped to the local scale and resampled to 66m resolution. The local DEM ranged from 10m to 186m. From the 2010 reclassified scene, binary masks were created for cleared forest and for less disturbed forest.

Multi-Criteria Evaluation

All features, i.e. primary and secondary roads, and villages were converted to raster using Euclidian distance. All of the independent variables were then sliced into 100 and recalculated using a weighted sum. The values assigned to each variable were based on our knowledge and research of the forest, and information shared by the Ranobe community and ho Avy. Therefore, higher weighting was attributed to roads and lower weight values were assigned to slope and elevation. The assigned values in the multi-criteria analysis are given in the following table:

Criteria	Weight
Cleared Forest	0.4
Primary Roads	0.15
Secondary Roads	0.15
Slope	0.05
Elevation	0.05
Village	0.2

Table 2: Multi-Criteria Analysis Weightings

The output map was multiplied by the undisturbed and less disturbed forest binary masks to extract out the relevant areas. Since our interest is in areas of risk that still have forest left to protect, all other areas were defined with zero output values. These outputs were then sliced and added together in a weighted sum: 0.4 to undisturbed and 0.6 to less disturbed. These values were based on the importance to protect less disturbed forest since these areas were already more vulnerable. Finally, the results were reclassified to create a risk map of three levels: high, medium, and low. These were divided equally after excluding the already cleared areas. The values for the upper boundaries of each level of risk are given below (range is from 1-6.4), followed by the map:

Output Risk Map Upper Boundary	Risk Assessment
1	N/A (Cleared)
3.05	High Risk
4.73	Medium Risk
6.4	Low Risk

Table 3: Risk Map Boundaries

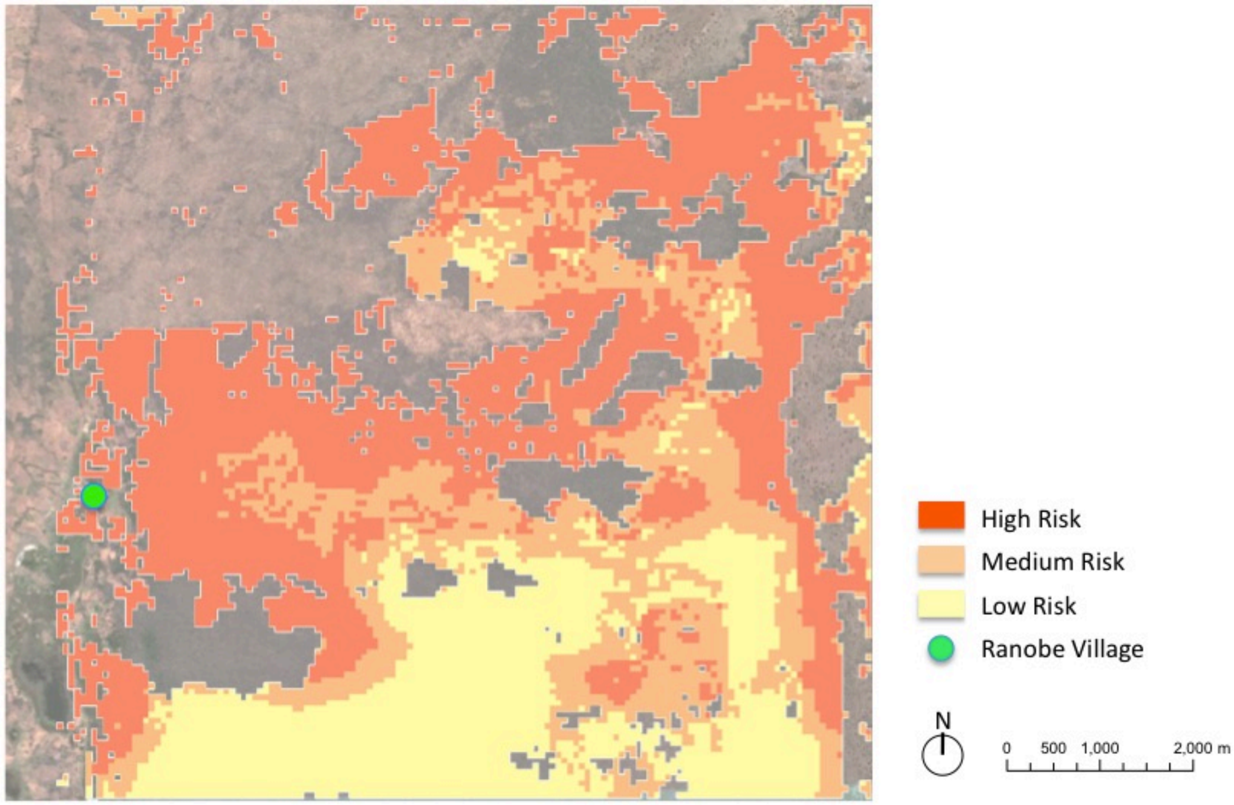

Figure 6: Map of Prioritized Risk

Additionally, a model was developed to identify protection areas. The risk map was sliced by 100 and combined using map algebra with a clipped reclassified raster describing distance buffers from Ranobe. The multiple rings buffer feature created stratifications at 1,000m, 2,500m, 5,000m, 7,500m, and 12,500m from Ranobe. These distances from Ranobe reflect the capacity and range to which Ho Avy and FIMPAHARA can provide protection to the forest. After combining the two rasters, the extract by attributes function was applied to determine protection areas by identifying areas of medium and high risk that were within a 5,000-m radius of the village. The raster was reclassified by equal area to produce a map identifying three zones of protection based on proximity to the village, shown in the following figure.

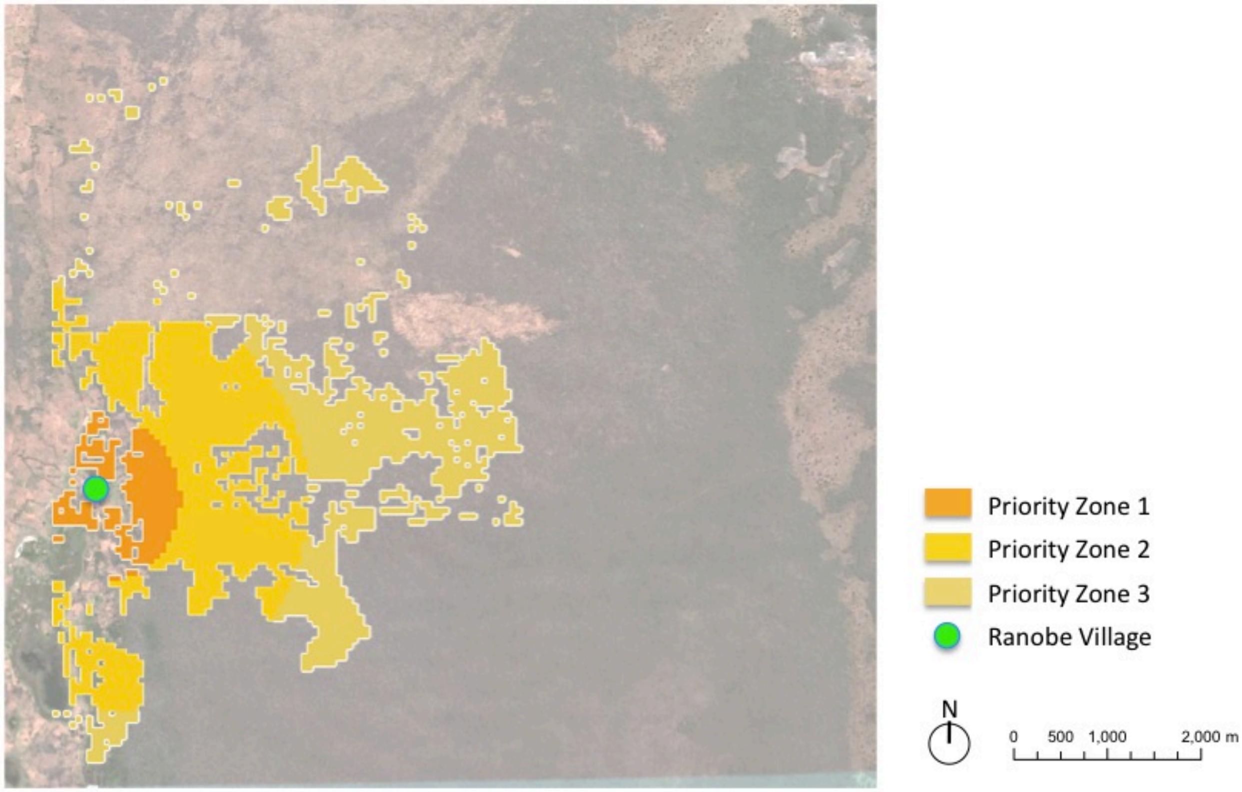

Figure 7: Map of Prioritized Protection Areas

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Appendix B:
Solar Irradiation Readings:
Methodology and Data

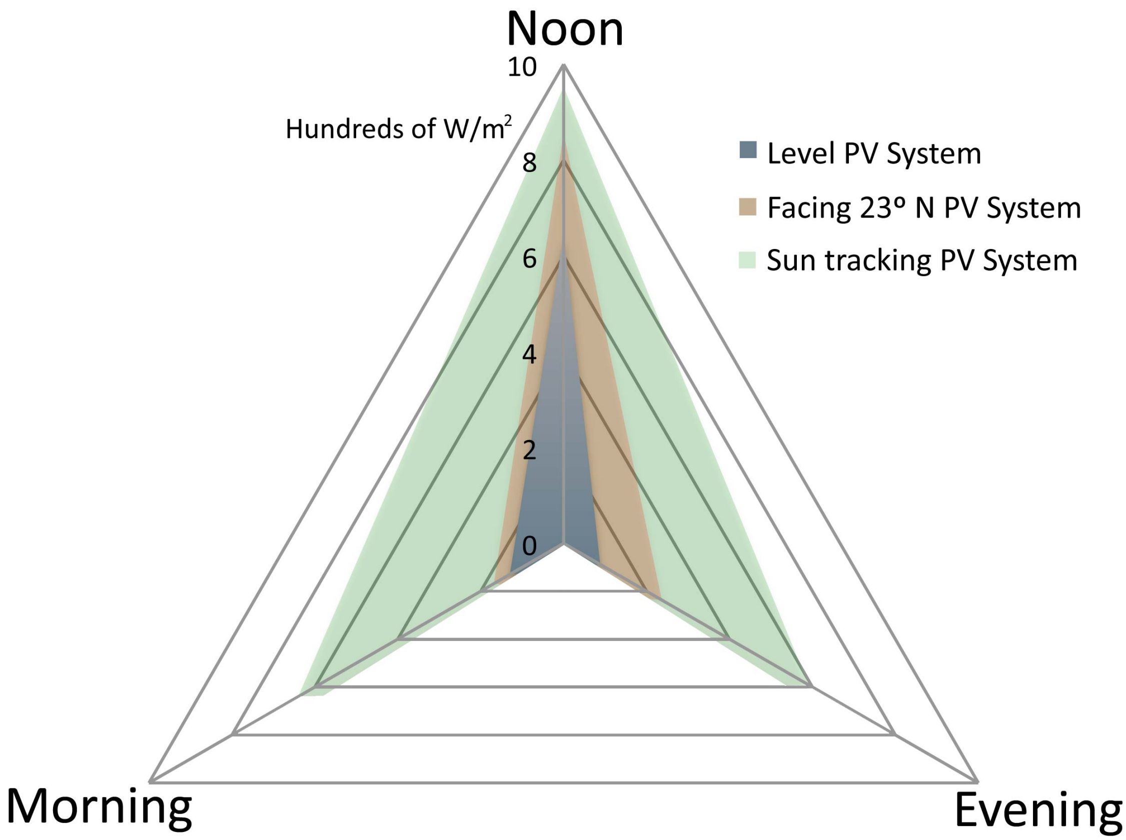
Appendix B: Solar Irradiation Readings: Methodology and Data

To verify estimates of solar radiation potential in Ranobe and to select the most effective site for a potential PV system, the team took solar radiation readings three times a day in three locations for the duration of the summer. (A fourth location was included for the first weeks but dropped soon after discovering that shading rendered late afternoon readings impossible.) The measurements were taken using a tripod-mounted solar meter (TES-1333R) at approximately one hour after sunrise, noon, and one hour before sunset. At each time and each location, readings were taken with the meter oriented directly at the sun, directly upwards at 90º from horizontal, and at 23º (latitude) above horizontal facing North. The readings for 90º and 23º from horizontal simulate the radiation available to fixed panels, while the readings pointed at the sun simulate placing panels on a tracking system. The three sites evaluated were on top of the Ho Avy research center roof, at the site planned for a community center, and adjacent to one of Ho Avy's plant nurseries. (The fourth site, dropped due to shading, was Ho Avy's second nursery.) The results of our measurements were catalogued and analyzed to determine average solar radiation over time at each site.

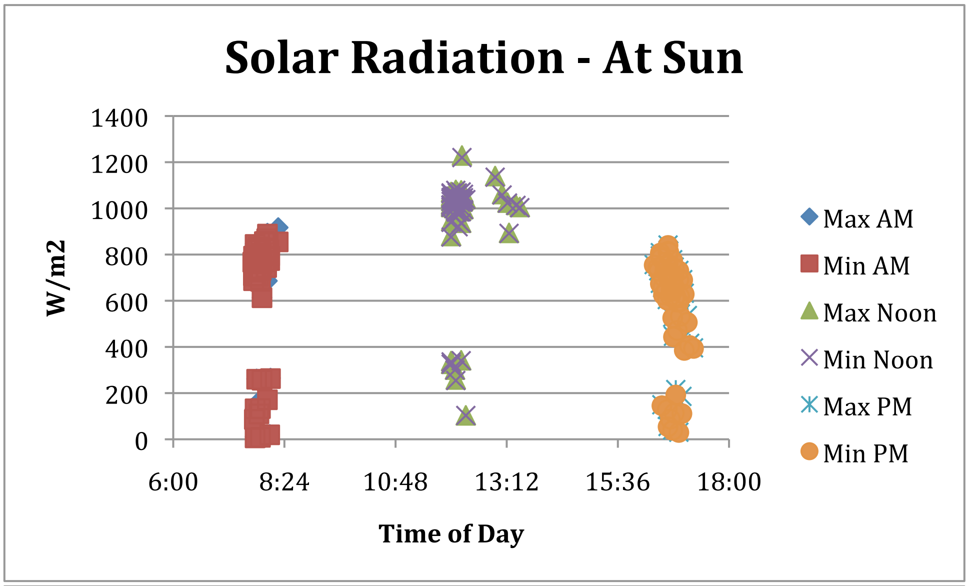
The three sites were similar in terms of radiation potential, with the nursery having slightly more shading in the afternoon. It is important to note that the study period fell during the height of Madagascar's winter, so the data collected represents the minimum expected radiation throughout the year.

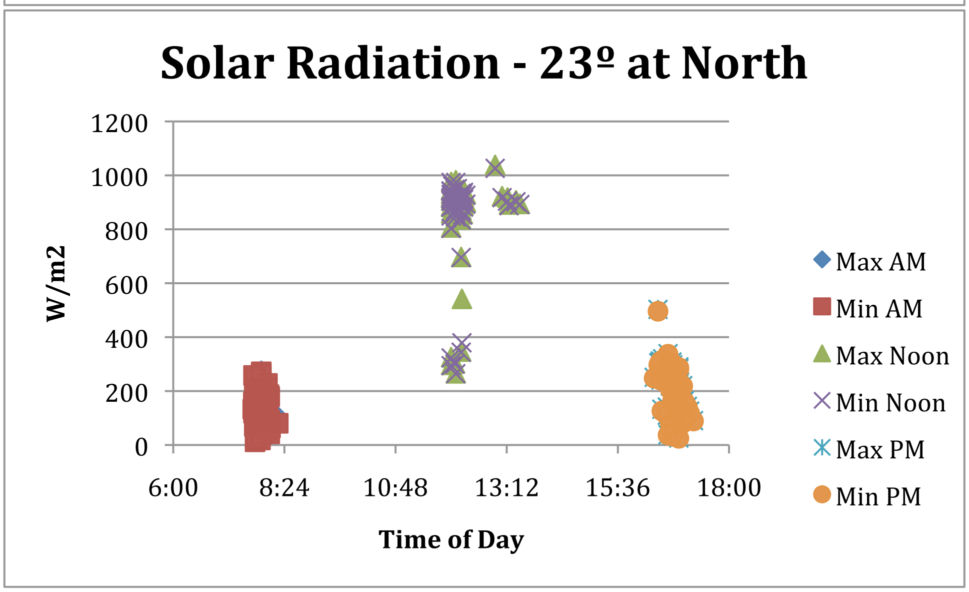
As shown in the graphs below, tracking increases radiation in the mornings and evenings to 600-800 W/m^2, compared to 100-300 for fixed PV. Noon radiation is always close to 1000 W/m^2, the theoretical maximum.

The first graph below uses three axes to illustrate the differing amounts of average solar radiation observed at various times of day. The colors refer to the amount that would be captured by the different tiers of solar systems that we envisioned, as marked on the legend. We can easily see that the Sun tracking PV System captures the most solar energy, whereas the Level PV System captures the least.



These next graphs show all the solar insolation measurements taken throughout our study period. We took maximum and minimum readings at each point, due to the way our instrument took readings. Again, we can see the trends of there being higher measurements during the noontime readings than at either sunrise or sunset. Furthermore, the difference between the irradiation at different times of day is less drastic when the meter tracks the sun (~400 W/m^2 difference) compared to when the meter is fixed at 23° above the horizontal (~700 W/m^2 difference).





The data collected over our study period confirm that PV is worth considering for Ranobe. The question then becomes what size system is necessary and where it should be sited. Demand calculations for our proposed three-tiered PV system are outlined below.

<u>Tier I – Basic Needs</u>

- 3-laptops = 3*70W*3hrs = 630 Wh
- 12-1W LED lights = 12*1W*4hrs = 48 Wh
- AA/AAA battery recharging = 1*10W*24hrs = 240 Wh
- weather station = 1*21W*24hrs = 504 Wh
- small water pump (mini typhoon) = 1*84W*4hrs = 336 Wh

- Total usable energy needs = 1758 Wh
- Account for 0.8 factor in losses/inefficiencies; total energy generation needed = 2198 Wh

- Nameplate capacity needed to achieve this, based on current system and 5 hours of sunlight per day = **528 W**
- Nameplate capacity needed to achieve this, based on current system and 9 hours of sunlight per day (manual tracking) = **293 W**

Tier II – Research Center Plus

  - 3-laptops = 3*70W*3hrs = 630 Wh
  - 12-1W LED lights = 12*1W*4hrs = 48 Wh
  - AA/AAA battery recharging = 1*10W*24hrs = 240 Wh
  - weather station = 1*21W*24hrs = 504 Wh
  - *larger water pump (1/2 HP) = 1*500W*4hrs = 2000 Wh*
  - *small refrigerator = 1*40W*24hrs = 960 Wh*
- Total usable energy needs = 4382 Wh
- Account for 0.8 factor in losses/inefficiencies; total energy generation needed = 5478 Wh
- Nameplate capacity needed to achieve this, based on current system and 5 hours of sunlight per day = **1315 W**
- Nameplate capacity needed to achieve this, based on current system and 9 hours of sunlight per day (manual tracking) = **731 W**

Tier III – Solar-Powered Ranobe

  - 3-laptops = 3*70W*3hrs = 630 Wh
  - 12-1W LED lights = 12*1W*4hrs = 48 Wh
  - AA/AAA battery recharging = 1*10W*24hrs = 240 Wh
  - weather station = 1*21W*24hrs = 504 Wh
  - larger water pump (1/2 HP) = 1*500W*4hrs = 2000 Wh
  - *full-size refrigerator = 1*130W*8hrs = 1040 Wh*
  - *lighting for village = 25*1W*3hrs = 75 Wh*
  - *lighting for community center = 5*1W*2hrs = 10 Wh*
  - *projector for community center = 1*200W*2hrs = 400 Wh*
  - *ground-mounted tracker = 1*4W*9hrs = 36 Wh*
- Total usable energy needs = 4983 Wh
- Add 10% excess capacity for expansion = 5482 Wh
- Account for 0.8 factor in losses/inefficiencies; total energy generation needed = 6851 Wh
- Nameplate capacity needed to achieve this, based on current system = **914 W**

Appendix C:
Interview Questions and Results

Appendix C: Interview Questions and Results

The project team conducted interviews with Ranobe villagers between July 15-21, 2010 to better understand economic conditions, villagers' relationship with the forest, and health and sanitation behaviors. The interviews were conducted in Malagasy with the assistance of Clement Landrianjohary, a student from the University of Toliara and Ho Avy's translator. Thirty households were interviewed, 11 from FIMPAHARA and 19 unaffiliated. The survey questions and results are presented below.

C1: Interview Questions for Residents of Ranobe Village

Introduction: We are university students working with Anthony and Martina and Ho avy. Ho avy is trying to protect the Ranobe forests while helping people here improve their quality of life, so we are trying to figure out how you use forest resources and what you need from the forest to live. We are also working with Ho avy to build a water filter to one day give all villagers healthy drinking water, so we also have some questions about your family's water use and health. It's okay if you can't answer some of the questions; we'd just like to know what you know.

Part I – Economic Impact of the Forest

1. Does your household burn biomass (wood, charcoal, plant material) to cook or for other purposes?

    If you gather it yourself: how much do you collect each week? Do you sell any of it?

    If you buy the material: how much do you buy per week? How much does it cost?

2. How does your household earn income, and how much do you earn per week?

3. How easy or difficult is it to maintain a steady and sufficient income?

    For Fimpahara: Has this changed since Ho avy started working with Fimpahara?

    For other Ranobe families: Has this changed in the last few years?

4. If your primary source of income is low or missing, how do you survive? Has this happened before?

5. Have you or anyone you know made charcoal in the past? What were your reasons for doing so?

Part II - Water Quality

1. How much water does your household use in a day for drinking and other uses?

    How many people are in your household? (Age range, number of children)

2. How many times has each of your children been severely sick during their lives?

    What were the symptoms of their sickness?

Did they go to the doctor or take any medicines?

Do your children suffer from diarrhea often, especially as infants?

3. How often do children in this village die of sickness?

4. Where do you usually get your drinking water?

5. Would you wait 5-10 minutes longer each time to get a cleaner bucket of water if you knew it would be healthier for your family? (You can't notice the health benefits immediately; they are gradual.)

C2: Tables of Results

See following tables for:

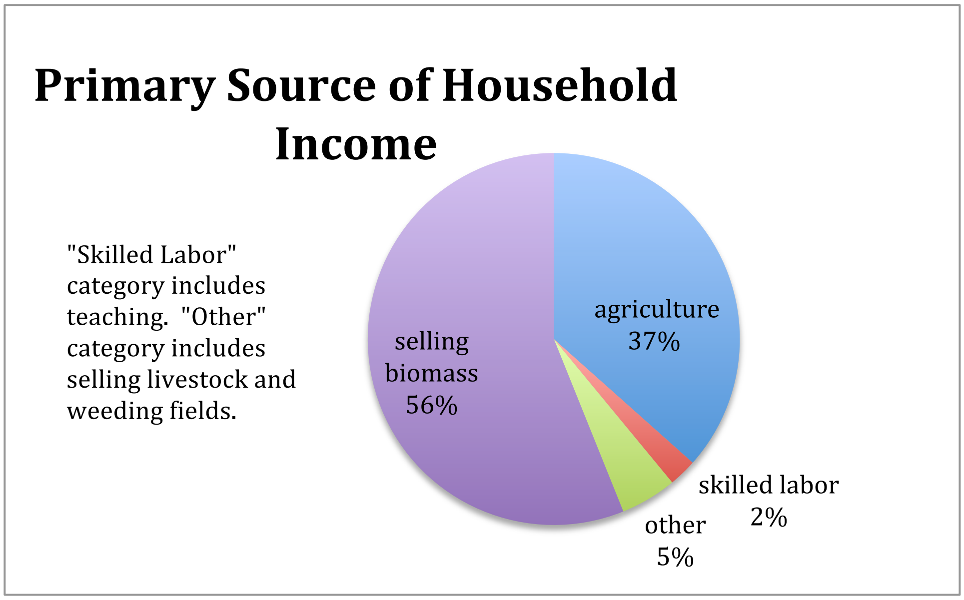
1. Economic Impact Results

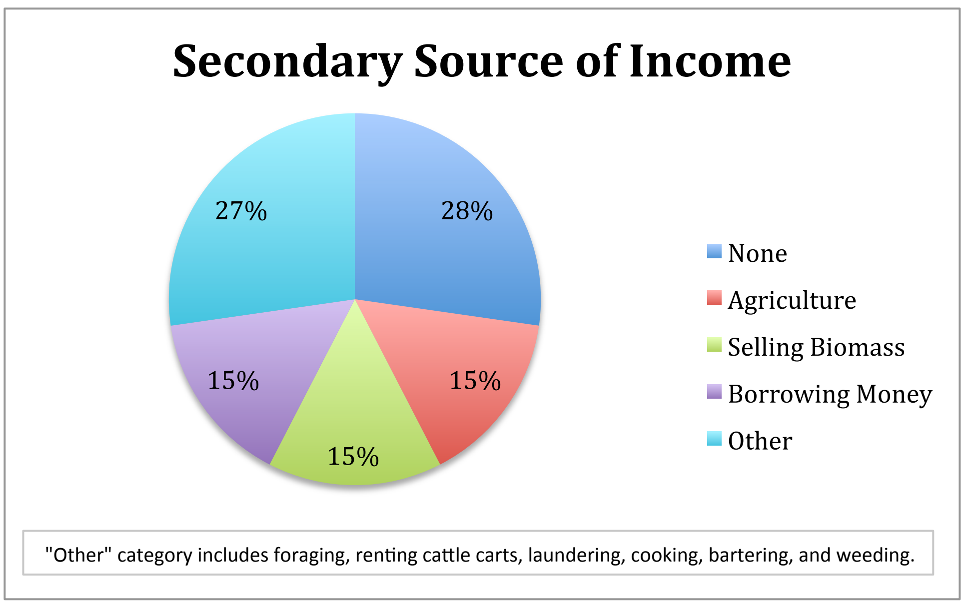
2. Water Quality Results

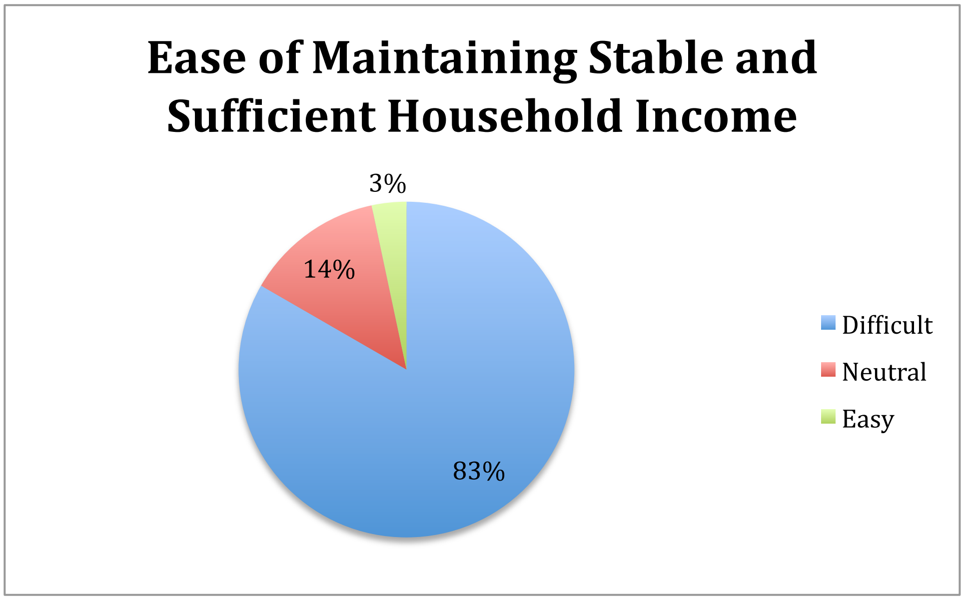
Response ID	Ho Avy Affiliation	Gender	Fuel Source	Sell/ Buy	Income Source	Income Amount (in Ar.)	Stability of Income	Change over Ho Avy presence	Alternative Income	Made Charcoal
1	yes	female	wood	no	vondron	14k per month	difficult	positive	buy/resell vondron, rent zebu cart	yes
2	yes	female	wood	no	vondron	10k ~per month	difficult	none	borrows, agriculture	no
3	yes	female	wood	no	ag	200k per year	difficult	positive	vondron	no
4	yes	male	wood	no	ag	2mil per year	difficult	positive	borrows	no
5	yes	male	wood	no	ag, livestock	700k per year	difficult	negative	borrows	no
6	yes	male	wood	buys	ag	70k per year	difficult	positive	vondron	yes
7	yes	male	wood	sells	sells wood	8k per 3 wks (~10k per month)	difficult	positive	ag	yes
8	yes	male	wood	no	ag	200k per year	neutral	positive	borrows	yes
9	yes	male	wood	no	vondron, barata, ag	150k per year	difficult	positive	none	no
10	yes	female	wood	-	ag	1mil	neutral	positive	vondron	yes
11	yes	female	wood	no	vondron, ag	100k per year, plus 40k per month	neutral	positive	rent zebu cart	no
12	no	female	wood	-	vondron	5k per ~month	difficult	none	washing, cooking	no
13	no	female	wood	-	vondron	10k ~per month	difficult	none	sells foraged plants	no
14	no	male	wood	-	ag, vondron	300k per year, plus 40k per ~2 weeks	difficult	negative	none	no
15	no	female	wood	no	ag, vondron	200k per yr plus 10k per ~2 wks	difficult	none	none	no
16	no	female	wood	buys	vondron, working fields	3500 per month plus 3000/day weeding	difficult	none	weeding	no
17	no	m/f spouses	wood	no	vondron	2k per month	difficult	none	none	yes
18	no	m/f spouses	wood	no	vondron	8k per month	difficult	none	ag, trade sugarcane for fish	yes
19	no	male	wood	-	vondron, ag	100k per year, plus 30k per month	neutral	negative	forage, sell bararata	no
20	no	female	wood	-	vondron	50k per month	difficult	negative	none	no
21	no	female	wood	no	vondron	10k per week	difficult	negative	ag	no
22	no	female	wood	no	vondron	6k per ~week	difficult	negative	borrows	no
23	no	female	wood	-	vondron	10k ~per month	difficult	negative	none	no
24	no	female	wood	no	vondron	50k per month	difficult	negative	forage	no
25	no	m/f spouses	wood	no	teacher, ag	undisclosed, plus 100k per year	easy	negative	vondron	no
26	no	female	wood	no	vondron	60k per month	difficult	negative	ag	no
27	no	female	wood	-	vondron, ag	10k per week plus 10k per year	difficult	positive	none	yes
28	no	female	wood	no	vondron, ag	20k per year plus 50k per year	difficult	negative	weeding	no
29	no	male	wood	no	vondron, bararata	50k per month	difficult	negative	none	no
30	no	male	wood	no	vondron, ag	10k ~per month	difficult	negative	none	no

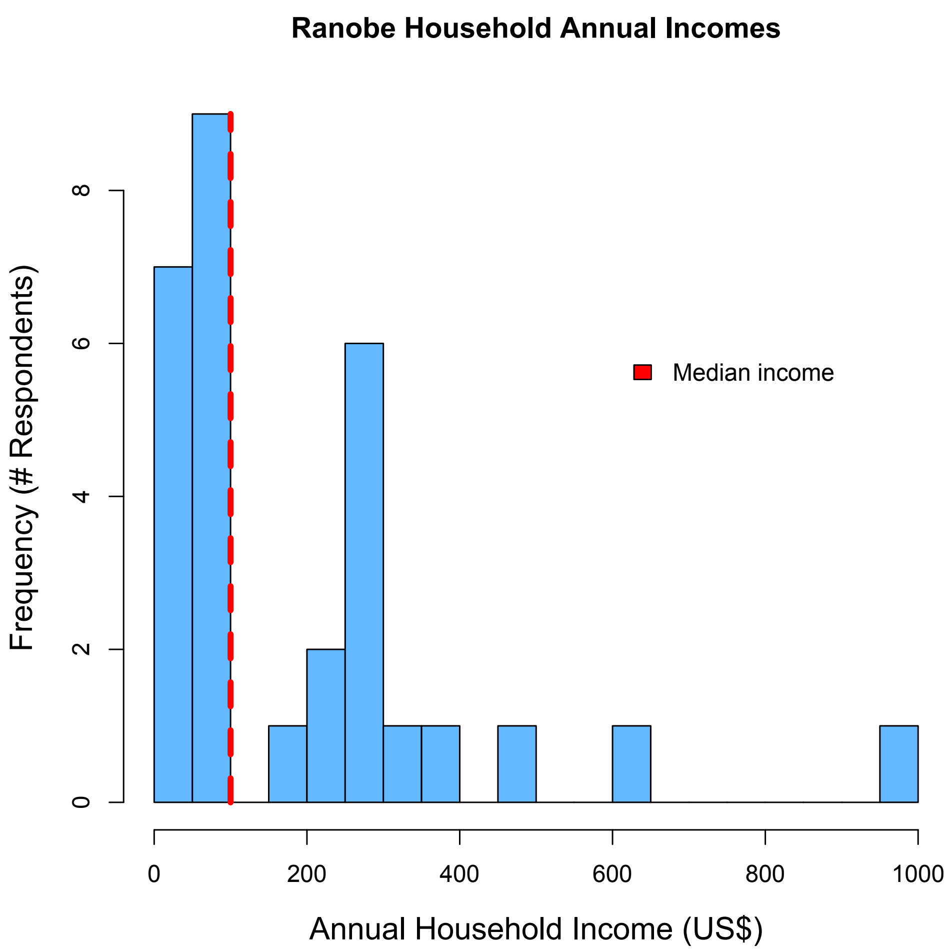
Response ID	Water Consumption (in buckets)	Bathing Source (if separate)	Laundry Water	Household Size	Number of Children in Household	Age of Youngest Child	Common Symptoms	Diarrhea	Last Year's Child Mortality	Water Source	Willing to wait?
1	2		10 buckets	5	3	5	coughing, headache, fever, nausea	often	-	pump	no
2	4		15 buckets	6	4	1	bellyache	often	5	pump	no
3	22		15 buckets	12	10	2	headache	occasional	5	pump	no
4	160L		60L	22	8 grandkids	2	fever, headache	often	3	well	no
5	10		10 buckets	5	3	4	bellyache, headache, cold	occasional	11	pump	yes
6	200L		-	11	9	1	headache, cold, congestion	occasional	5	pump	no
7	4		-	6	4	3	headache, bellyache	often	10	pump	no
8	2		4 buckets	6	4	2	shivers, fever	occasional	6	pump	yes
9	3		-	8	6	-	malaria (all 6), shivers	often	2	pump	yes
10	100L		100L	12	-	-	fever, headache, bellyache	none	6	pump, well	no
11	10		5 buckets	8	6	1	dizziness, headache	occasional	5	pump	no
12	3	lake	4 buckets	12	10	2	fever	occasional	1	pump, lake	no
13	20		50 buckets	5	4	-	malaria, bilharzia	none	50	pump	no
14	1	lake	lake	6	4	1	coughing	occasional	-	well	no
15	4	lake	lake	20 (incl grandkids)	-	-	schisto	often	20	well	no
16	4	lake	lake	25	19	-	schisto, headache, fever	often	10	pump, lake	no
17	10	lake	lake	15	13	12	cough, schisto, headaches, fever	occasional	7	pump, lake	no
18	5	lake	lake	10	8	1	schisto, fever	often	7	pump, lake	no
19	20	lake	lake	5	3	4	itchy, hair falls out, schisto	-	6	well	no
20	10	lake	lake	3	2	4	cough, cold	none	6	pump	no
21	10	lake	lake	5	3	<1	fever, cough, vomit	often	6	pump	no
22	10	lake	lake	5	3	<1	cough, fever	often	7	pump, lake	no
23	1	lake	lake	4	3	8	schisto	none	0	pump, lake	yes
24	2	lake	lake	4	2	12	schisto	none	5	pump, well	yes
25	6		12 buckets	10	8	7	fever, schisto, cough	occasional	5	well	yes
26	2	lake	lake	2	0	-	cold, headache, dizziness	occasional	30	well	no
27	5		7 buckets	8	6	18	fever, cough	often	5	well	no
28	5	lake	-	6	4	1	fever, fainting	often	10	well	no
29	6	lake	lake	10	8	1	malaria	occasional	10	well	yes
30	-	-	-	43 (incl grandkids)	-	8 (kids)	bellyache	occasional	-	well	no

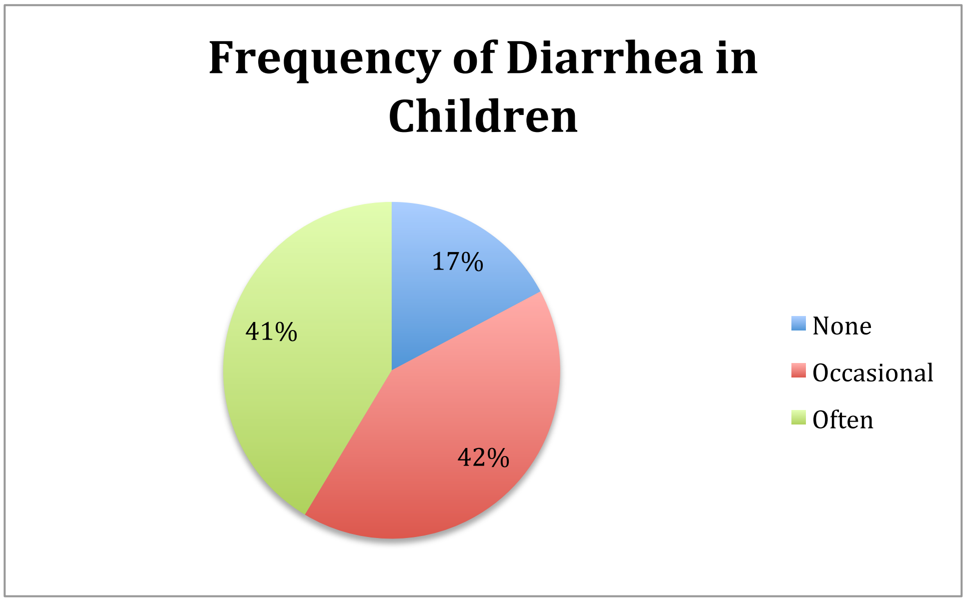
C3: Graphical Analysis

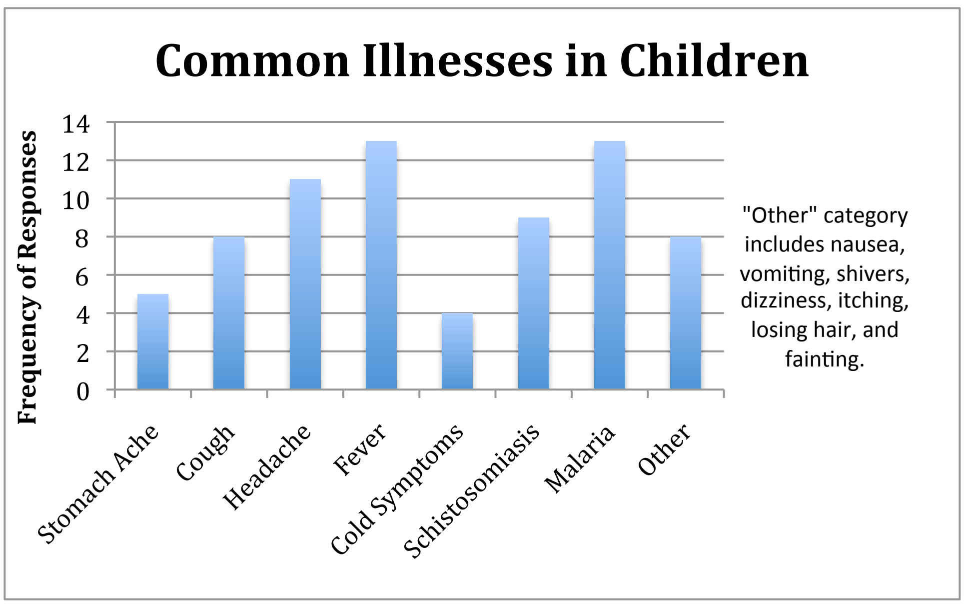


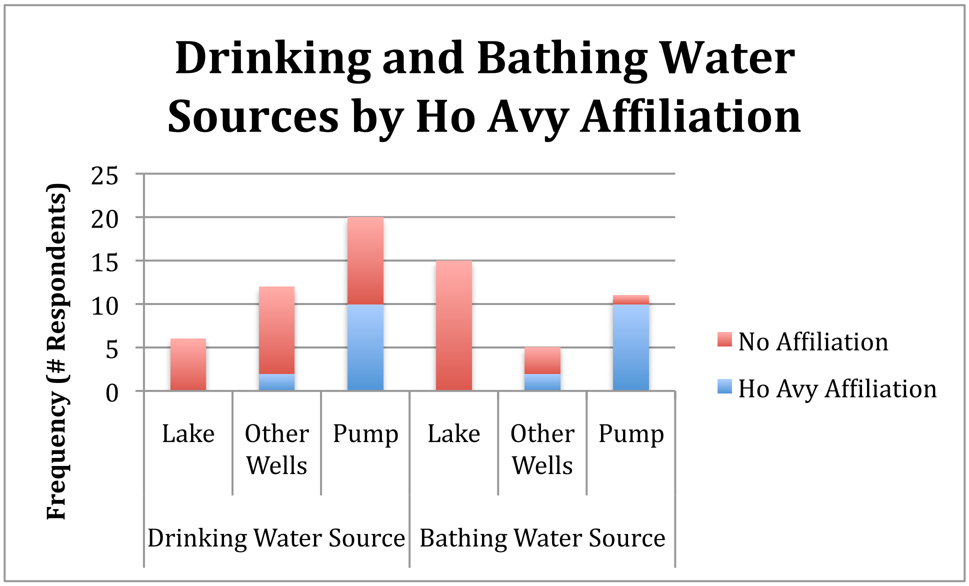



Ease of Maintaining Stable and Sufficient Household Income
3%
14%
83%
Difficult
Neutral
Easy


Ranobe Household Annual Incomes
Frequency (# Respondents)
0
2
4
6
8
Median income
0
200
400
600
800
1000
Annual Household Income (US$)

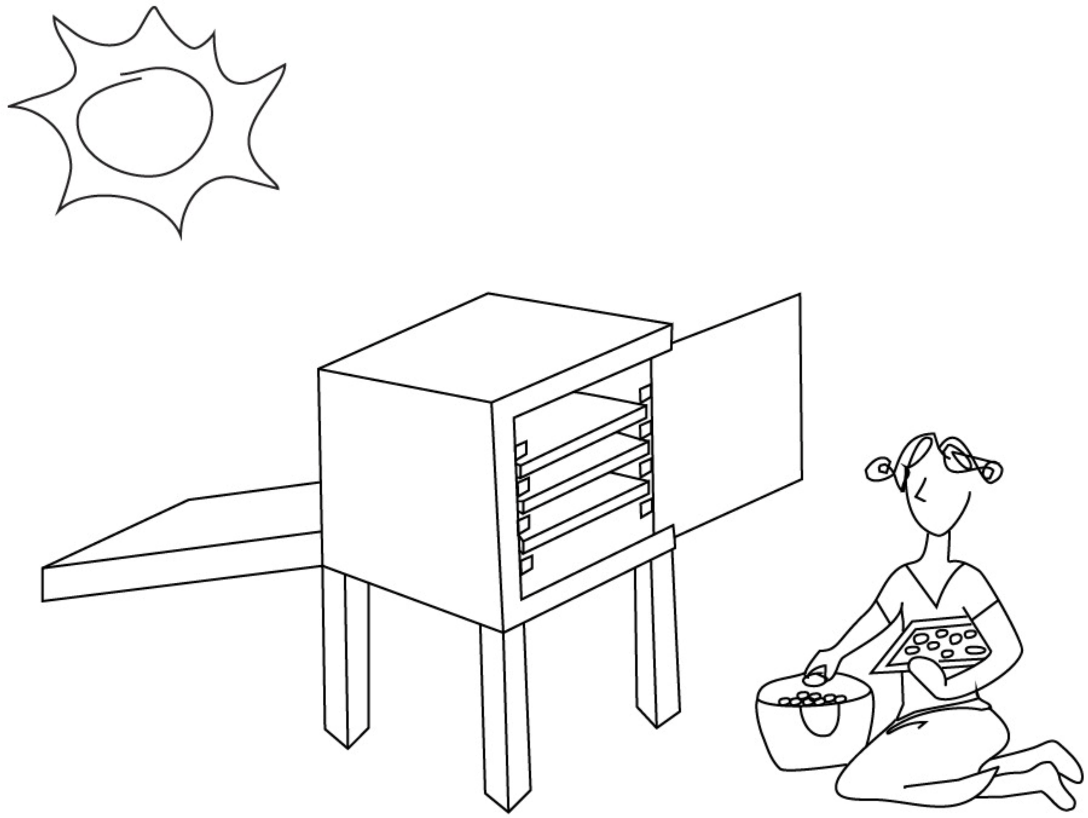

Frequency of Diarrhea in Children
17%
41%
42%
None
Occasional
Often


Common Illnesses in Children
Frequency of Responses
14
12
10
8
6
4
2
0
Stomach Ache
Cough
Headache
Fever
Cold Symptoms
Schistosomiasis
Malaria
Other
"Other" category includes nausea, vomiting, shivers, dizziness, itching, losing hair, and fainting.


Drinking and Bathing Water Sources by Ho Avy Affiliation
Frequency (# Respondents)
25
20
15
10
5
0
Lake
Other Wells
Pump
Lake
Other Wells
Pump
Drinking Water Source
Bathing Water Source
No Affiliation
Ho Avy Affiliation

Appendix D:
Solar Food Dryer Training Materials

The Solar Food Dryer Trainer's Manual
Tekniki Malagasy



This guide will teach you how to train villagers to use a tool called a "**solar food dryer**." We will call it a "dryer" for short. The dryer uses energy from the sun to change food into a form that will last longer. The guide will suggest types of food that villagers can use it for. It will teach how to use it to better their lives both immediately and in the long term. As you become more familiar with how the dryer works, you can also create your own ideas about what you can dry and how to dry it.

How to Teach?

Workshop | You can hold a workshop with the villagers to get everyone together and excited about trying a new type of food preparation technique. Pick a sunny day when there are not a lot of other activities happening. For example, do not try to get people's attention on a day when everyone is helping to harvest crops. You can also make and give out samples of different dried fruits or meat. Fresh and different food will get their attention and keep them interested.

As the trainer, you should have already reviewed this document, including the two main components: the builder's **construction manual** and the user's **how-to guide**. The men will be more interested in building the dryer, and the women will be more interested in using the dryer and what kinds of foods they can make. You can talk about these topics separately as the schedules of the two groups will also be different. You should talk to everyone about how the solar food dryer works and what it is. It will be helpful if you already understand how the solar food dryer works.

What is it?

Food storage method | A solar food dryer provides a way for the villagers' food and crops to last longer. It will dry out the food so that it does not spoil for a long time. This can lengthen the useful time of your harvest if you have extra food. When the food is dried, it will be more difficult for mold and bacteria to grow on it or in it. The food will stay healthy because vitamins and other nutrients in the food are preserved. The food will also be easier to store because it will be smaller and lighter after it has lost its water content. The food should last for months if it is kept in a cool, dark, and dry place.

Easy to use & low maintenance | It is simple to use a solar food dryer. There is very little preparation once the dryer has been built, and once the food is put into the dryer, the hardest part will be waiting long enough to let the drying process occur! Most of the time involved in using the dryer is letting the dryer, with food inside, sit in the sun during the day. The dryer and the frames should be cleaned between uses. These have been designed to be easy to take apart for cleaning. There will be more information on this in the how-to guide.

How can it Help Villagers?

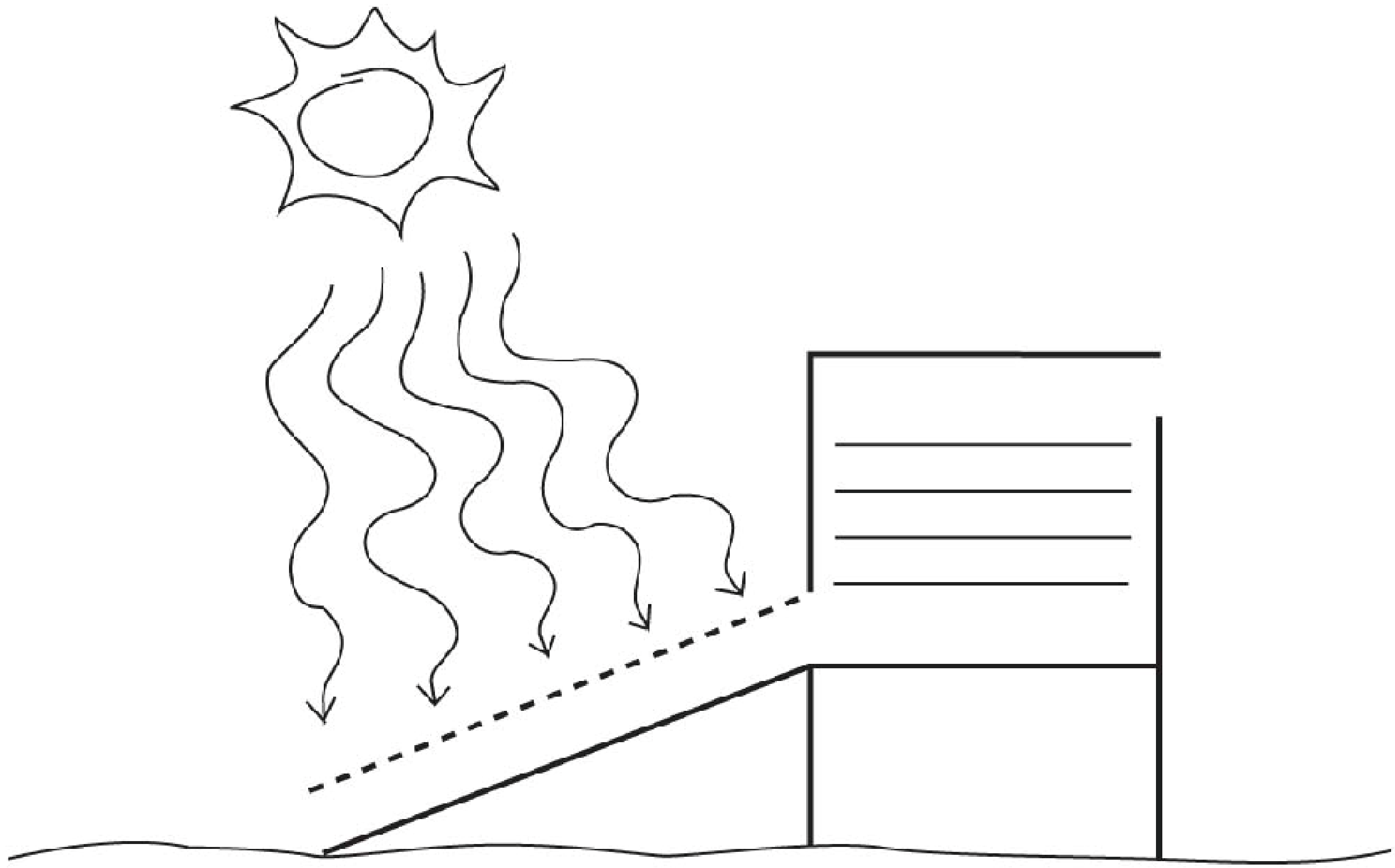
Potential for Food Management | When there is excess food during harvest seasons, it can be kept for later consumption. This is instead of selling the food or letting the food spoil. This also means that villagers can plan ahead to always have food stored. When they have extra harvests, they can store the food for the times when the crops are not producing. In addition, villagers can use any extra income they make to buy extra food. They would not be limited by time because they can dry and store this extra food to keep until it is needed. If the villagers have extra crops during a particular season, they can dry the food to eat later instead of selling it to buy other food. Currently, most families in the Ranobe area who have extra income use it all for food purchases. With a solar food dryer, excess crops that are harvested at certain times of the year can be stored, so that when there is not enough fresh food being produced, dried food can be eaten as a resource. Similarly, if food in the market is cheap because it is during the harvest season, extra food can be purchased and dried before it is needed. Since it can be stored, villagers will no longer be as strictly bound to price variation throughout the year.

Potential for Extra Income | As villagers become more accustomed to eating and making dried foods, they can also start to sell what extra food they generate. Dried fruits can be sold as snacks. These dried foods can be sold in local markets, and they can also be sold to nearby resorts and hotels (for example in Ambolimailaka, Mangily, Ankilimalinka, or Ankililoaka). The dried foods can be advertised for their ability to last for a long time while retaining their nutritional value. They also have their own unique taste. Finally, if people are interested enough in the dried foods and want to dry food themselves, it is possible to make and sell dryers to other villages or hotels too.

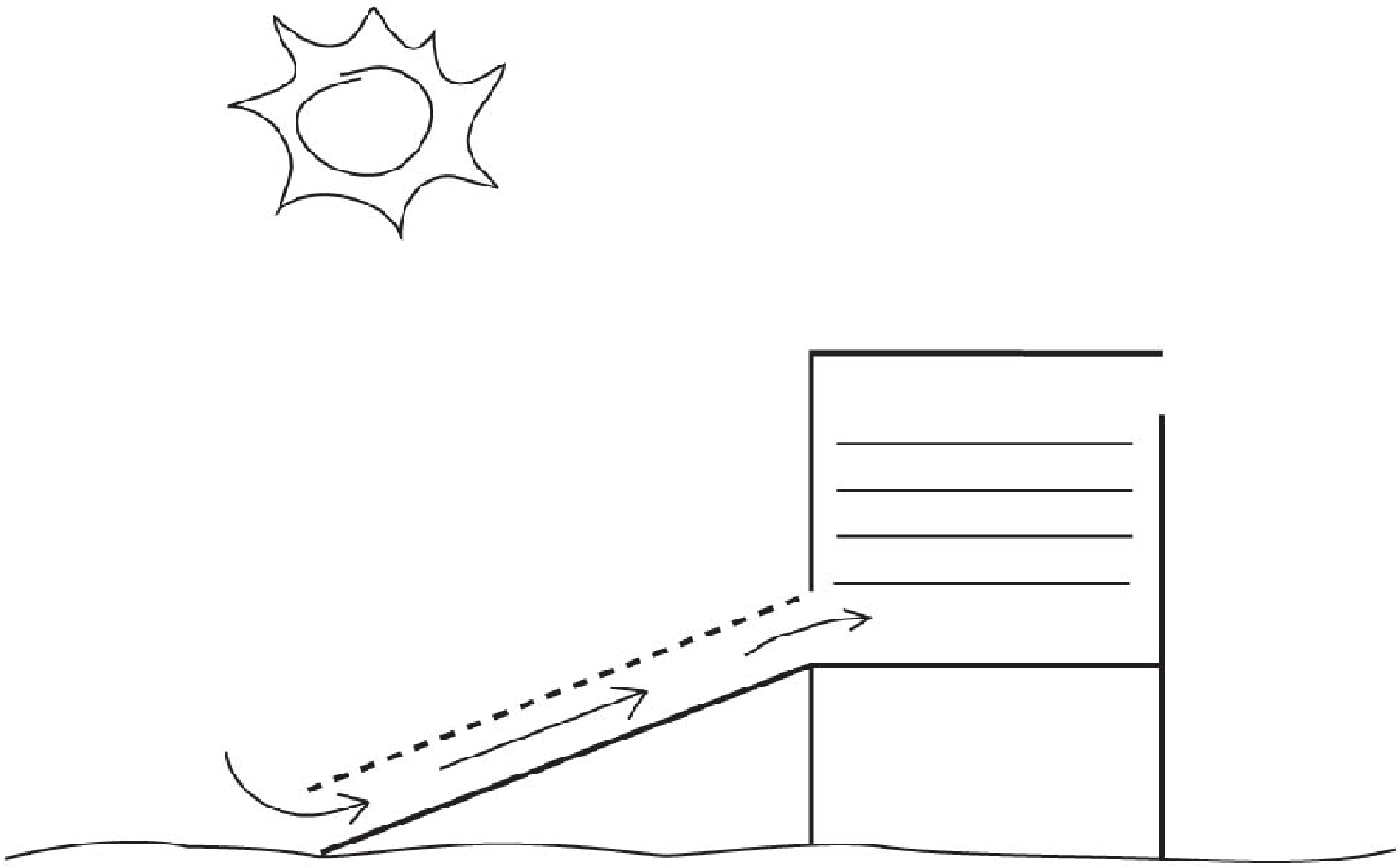
Potential for Creative Foods | While this guide gives some suggestions, villagers can experiment with different types of foods to dry. Different dried foods can be mixed and eaten together. They can also make recipes for when to use dried fruits in cooking. It is possible to rehydrate the foods that have been dried, using hot water, and then villagers can use the food in their normal cooking. However, villagers should be warned that rehydrated food should be eaten immediately. Once the food has been rehydrated, it cannot be stored anymore.

How Does it Work?

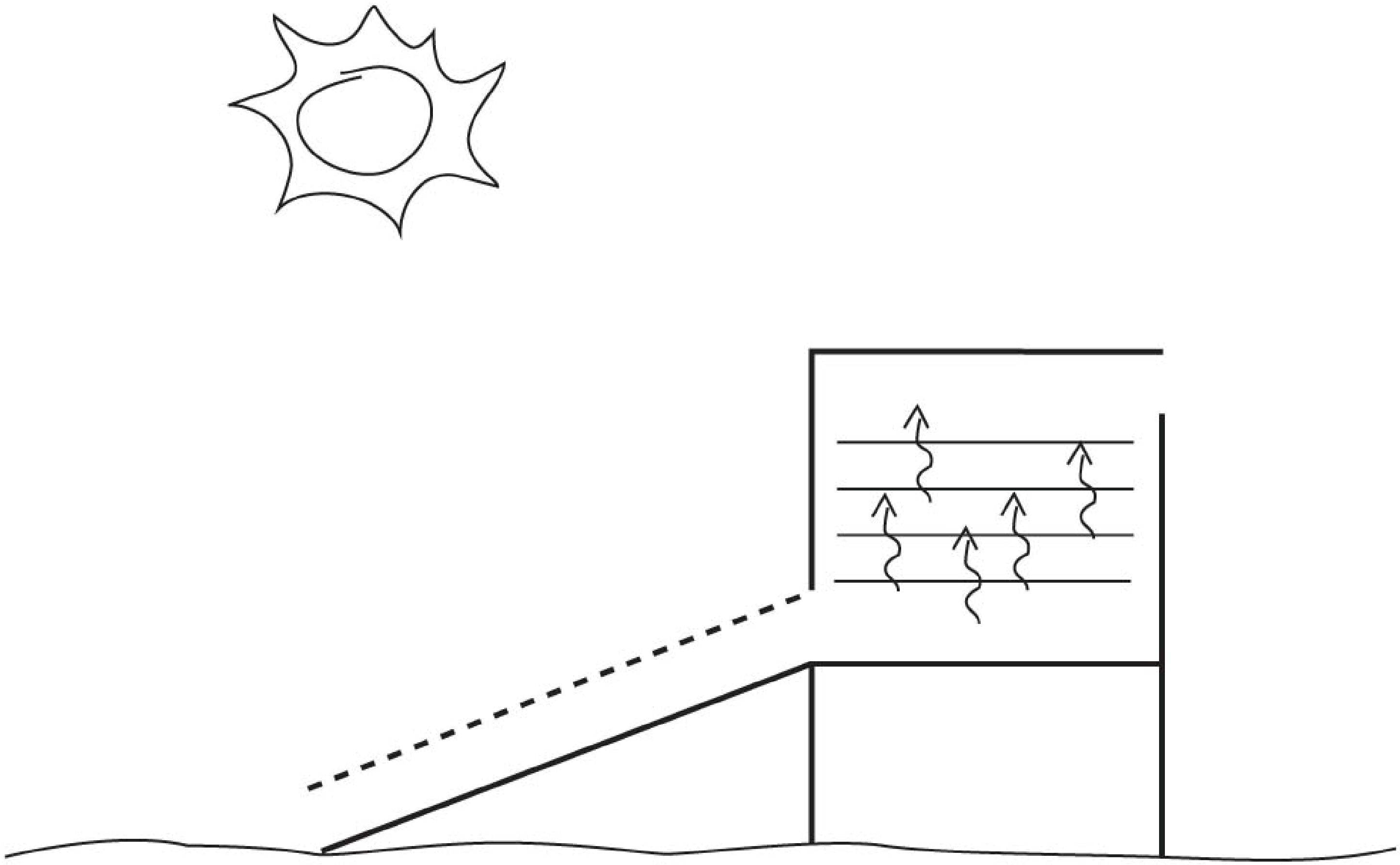
In general, air inside the dryer heats up from being in the sun. Dry air travels up from the bottom of the panel into the main part of the solar dryer containing the food. Warmer air has a higher capacity for moisture content, so it will evaporate water from the food in the dryer trays and absorb it. The hot moist air then escapes from the dryer through ventilation holes in the upper part of the dryer, and dry air replaces it from ventilation holes at the bottom of the dryer. This is shown step-by-step:



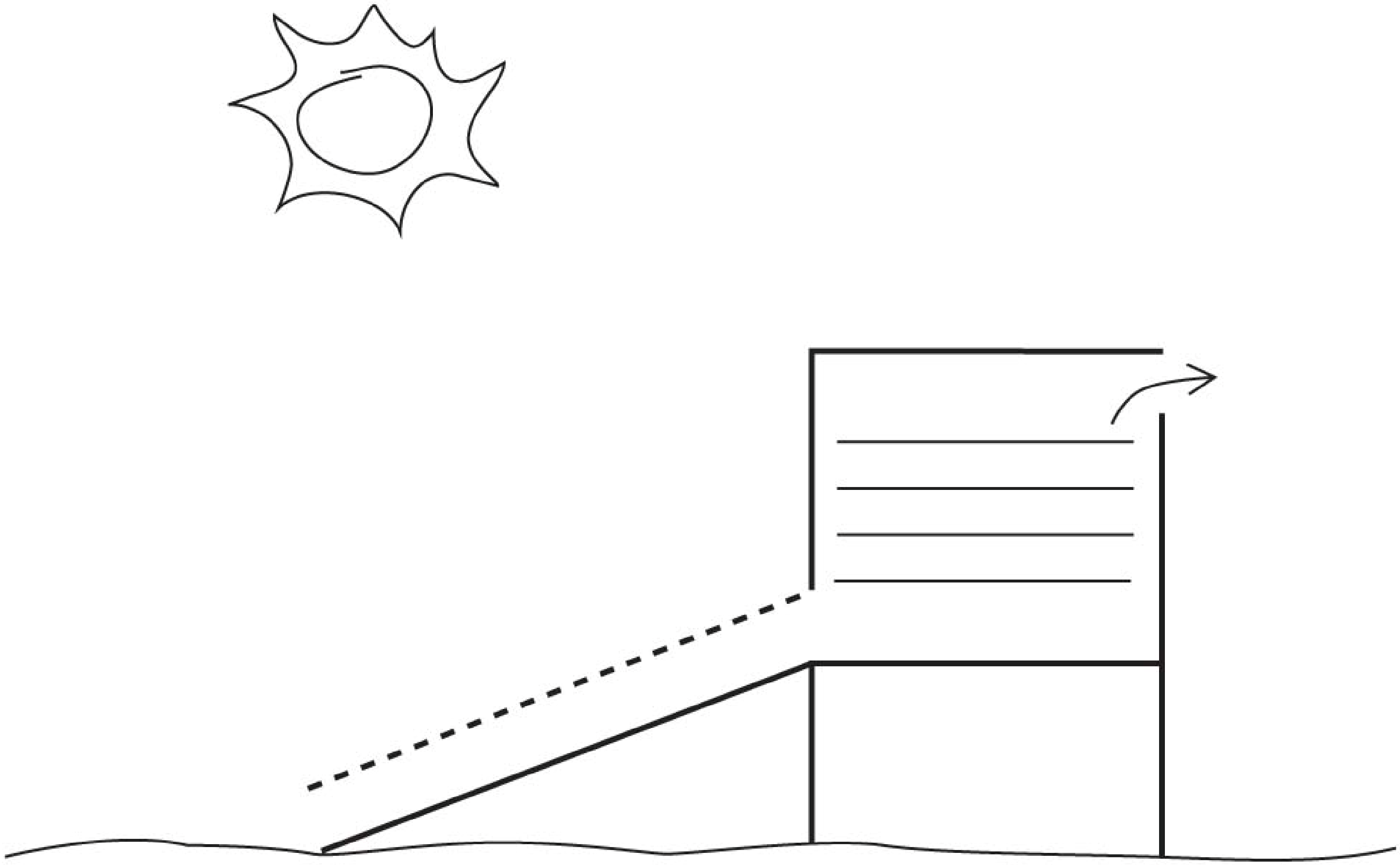
Step 1 | The air inside the dryer heats up from being in the sun. The sun heats the bottom part of the dryer first, and the glass cover traps the sun's heat within it. This part of the dryer also has a painted black interior, which will also help to absorb heat.



Step 2 | Dry air travels up from the bottom of the panel into the main part of the solar dryer containing the food. The air will be hot because it is being heated by the sun, as shown in Step 1. Warmer air rises.



Step 3 | Warmer air has a higher capacity for moisture content, so it will evaporate water from the food in the dryer and bring that moisture into the air. The air will rise through the layers of food, evaporating water from the food pieces along the way. Air can hold only a certain amount of water. When it reaches this capacity, it will not be able to absorb any more moisture from the food. It will need to be replaced with dry air to continue absorbing moisture from the food in the dryer.

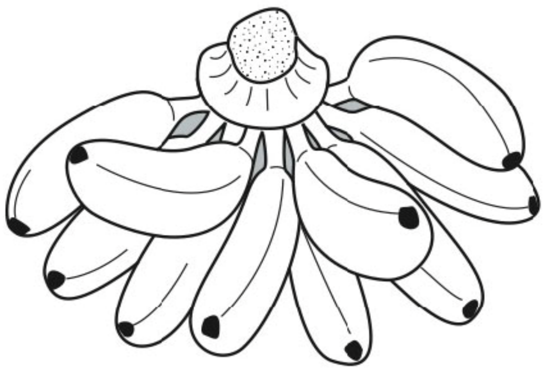


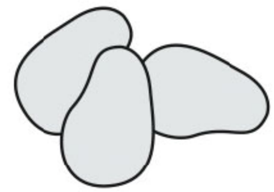
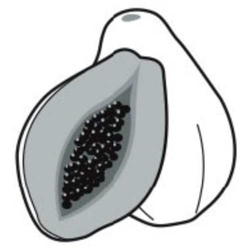
Step 4 | The hot moist air then escapes from the dryer through ventilation holes in the upper part of the dryer. Part of this effect is because warm air rises, and part of it is because there will be a pressure difference between the interior of the box and the outside air. When the temperature in the box rises, the air will expand and there will be higher pressure. To relieve this pressure, the air will want to escape through the ventilation holes. Air will replace it from the bottom and the cycle restarts from Step 2.

WHAT CAN YOU DRY?

The solar food dryer can be used to dry a variety of foods – almost anything that you and the villagers can think of! You and the villagers can add to this list as you find other foods that taste good when dried.

Fruits:
Bananas
Mangos
Papayas
Pineapples
Strawberries
Peaches
Pears
Apples

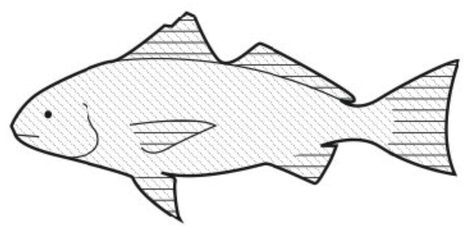
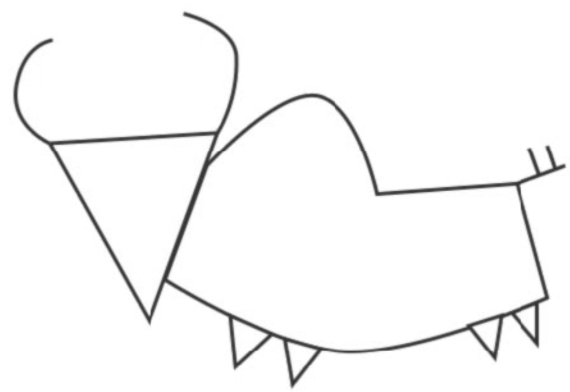


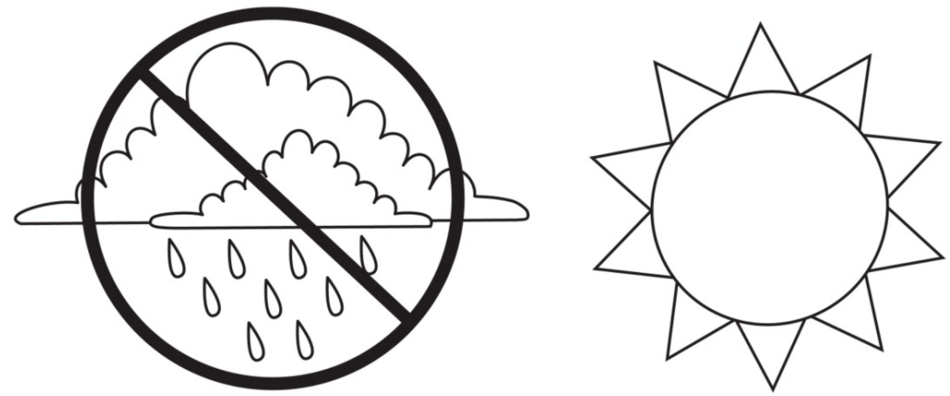
Vegetables/Herbs:
Beans
Peas
Onions
Carrots
Squash
Rosemary
Basil
Thyme

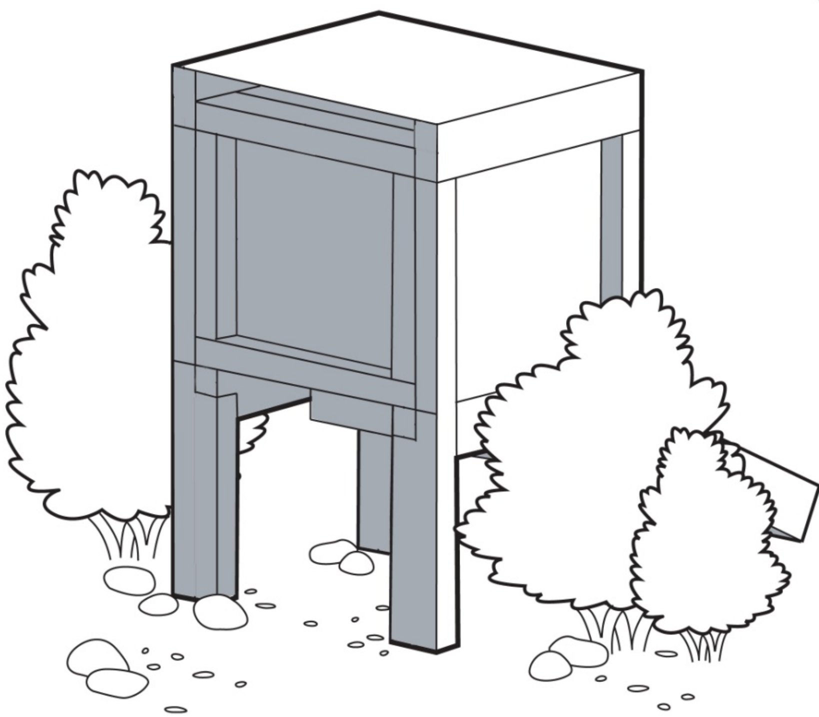


Meats:
Zebu
Fish

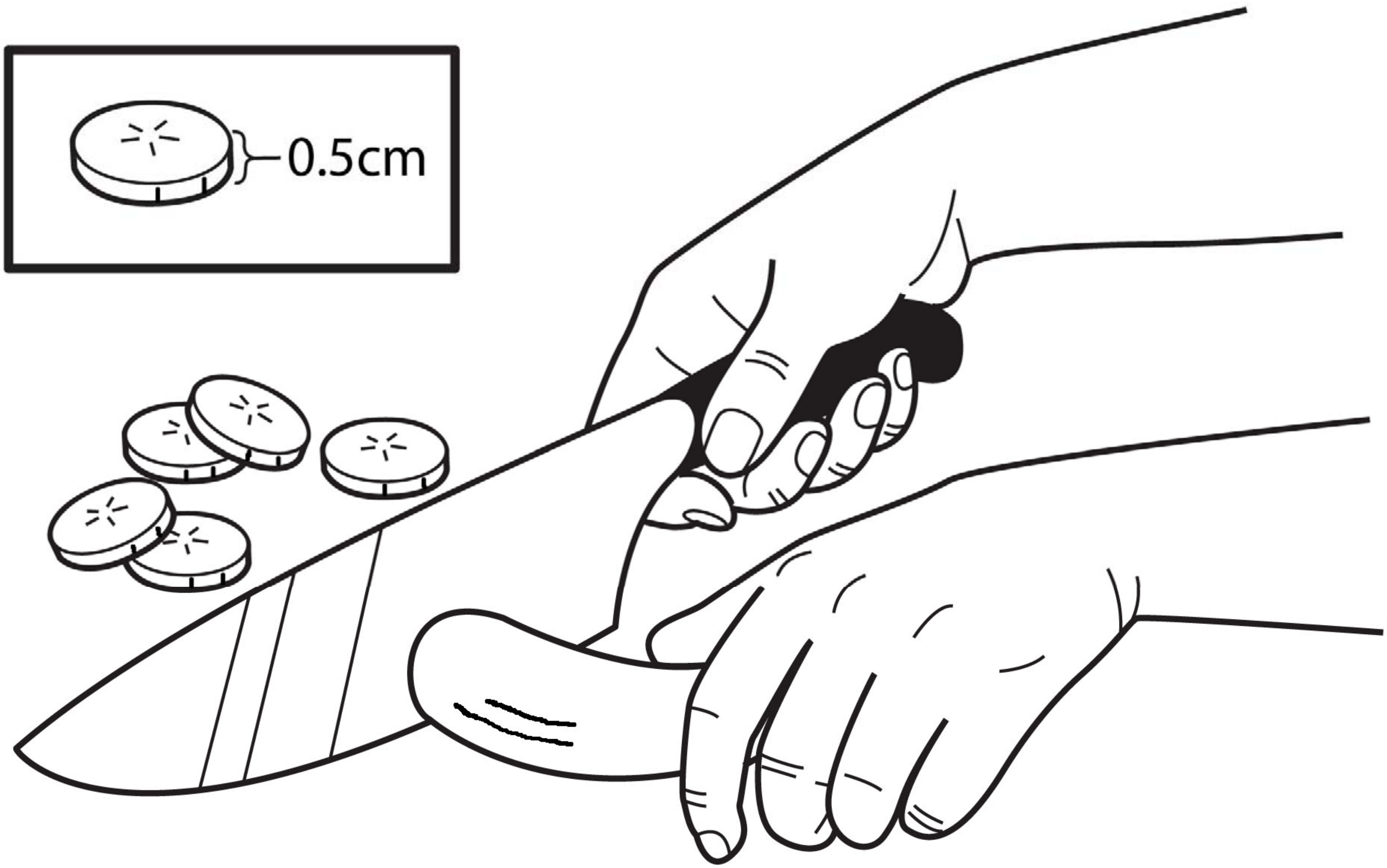



How do You Use the Solar Food Dryer?

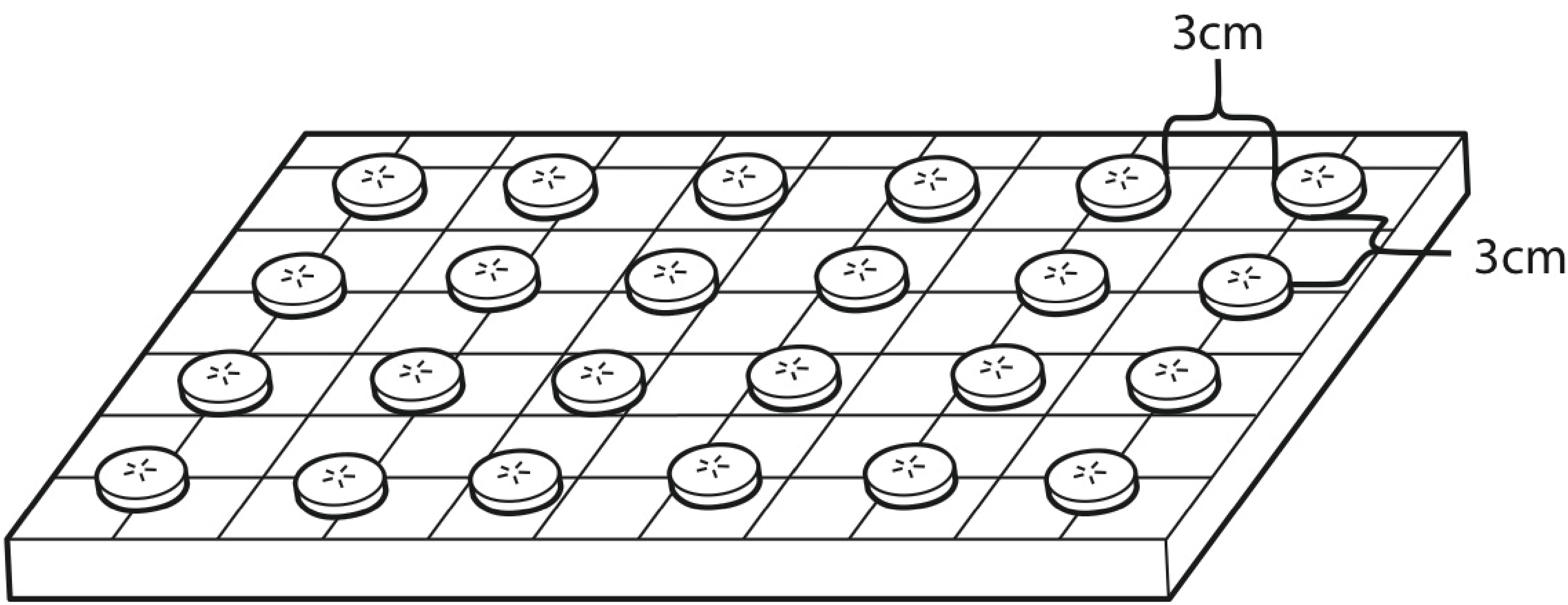




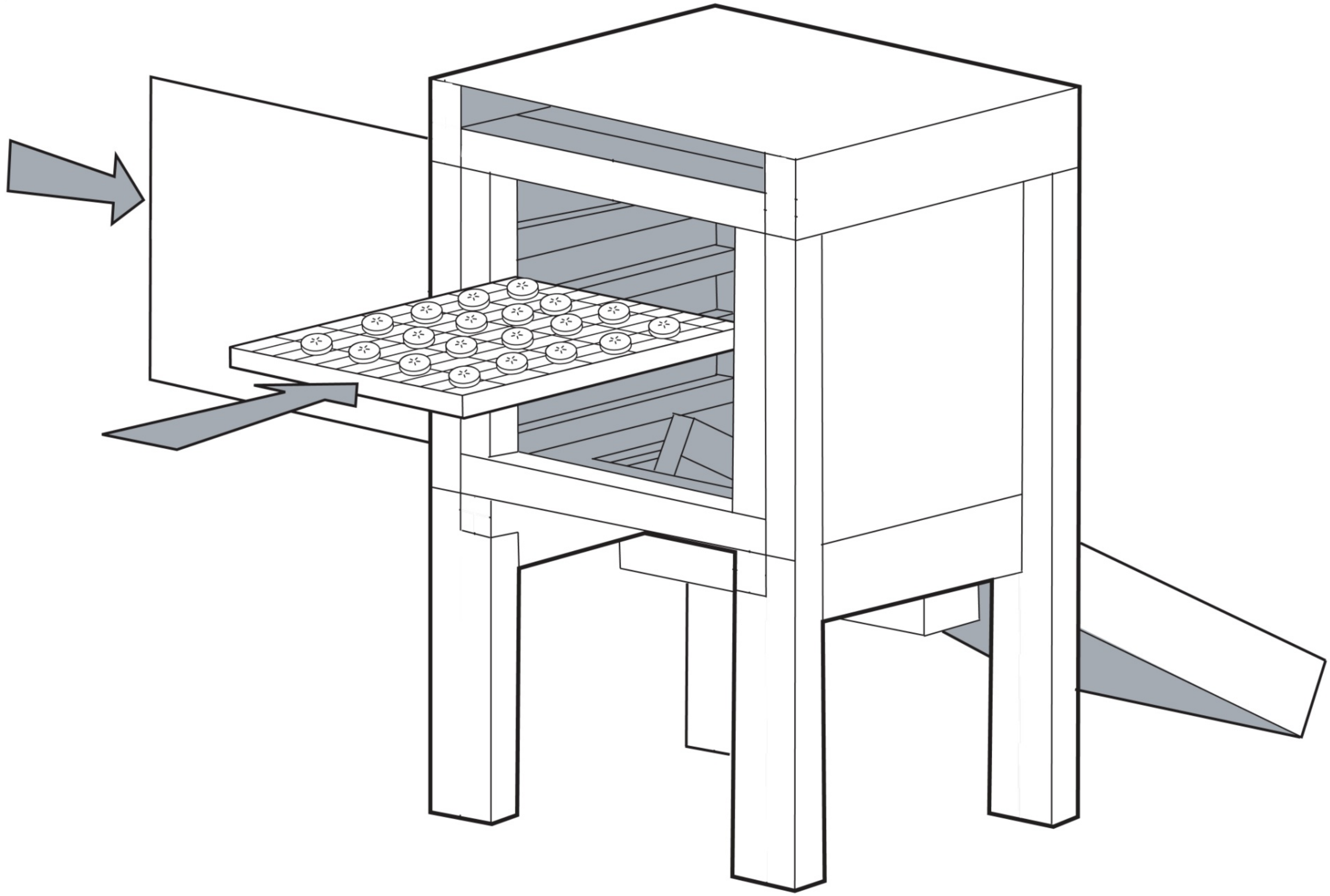
Step 1 | Choose a dry sunny day to dry. Choose a spot that is clear of any tall trees or other obstacles nearby. Ideal drying conditions are when the temperature is hot and the air is dry. You'll want to put the solar dryer in a spot where there is a lot of sun. It can also be helpful to put the dryer close to the field where crops are harvested, or close to the kitchen area where someone can regularly check on the food to see if it is dried. The dryer separates into two smaller components, which are easy to move around.



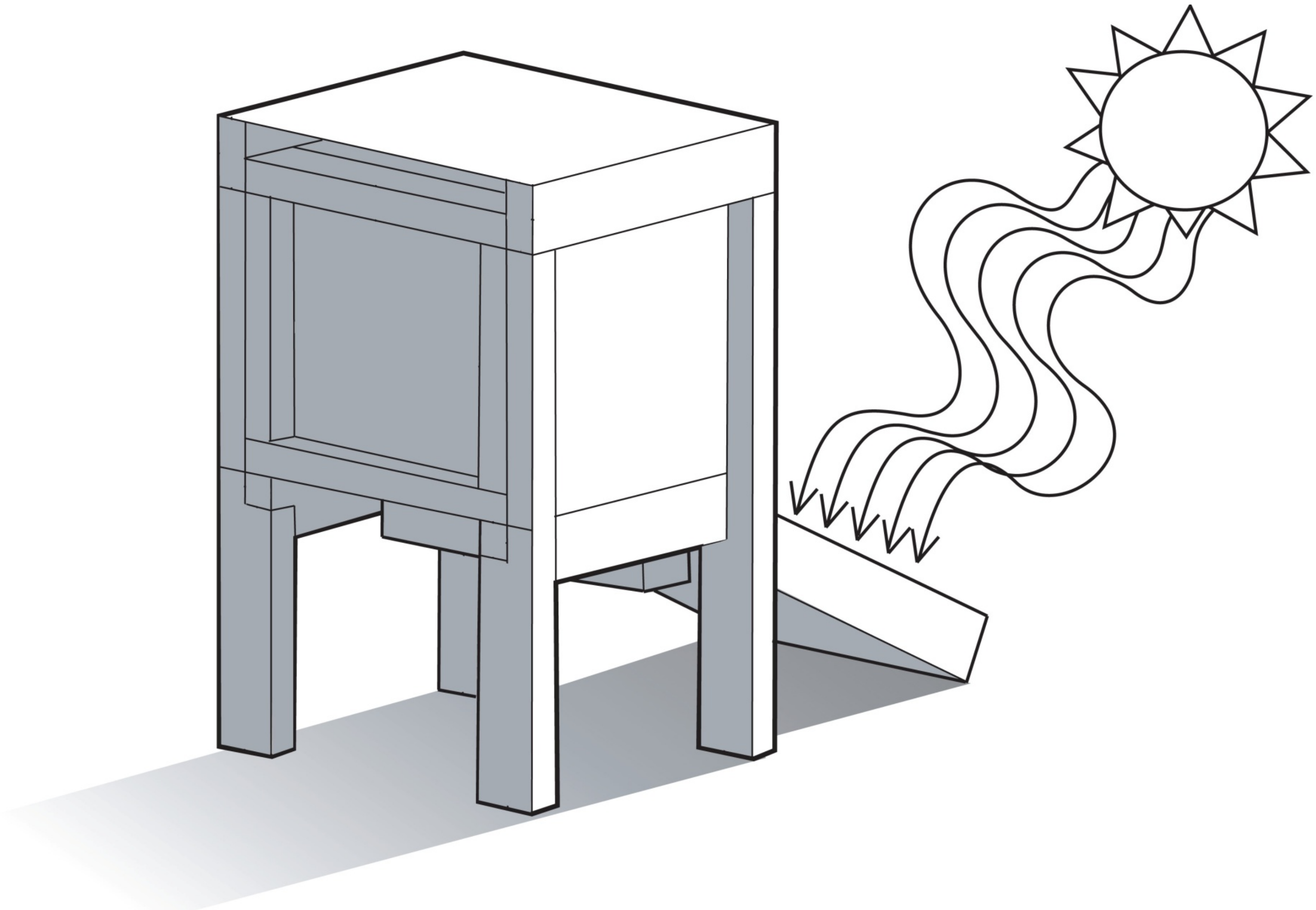
Step 2 | Slice up the food you will dry into thin pieces (about 0.5 cm thick). You can dry fruit, vegetables, herbs, and meat. Some ideas could be: onions, bananas, pineapples, mangos, or papayas. You can experiment with any other fruit that you have and see how it turns out. Similarly, you can also dry any type of meat. The thinner the slices, the faster the food can dry. However, you may still want some thickness so that there is some substance to the food. (If it is very thin it can turn into a chip - this is similar to the Malagasy kaka pigeon snack.) You can try out different thicknesses to see what you like.



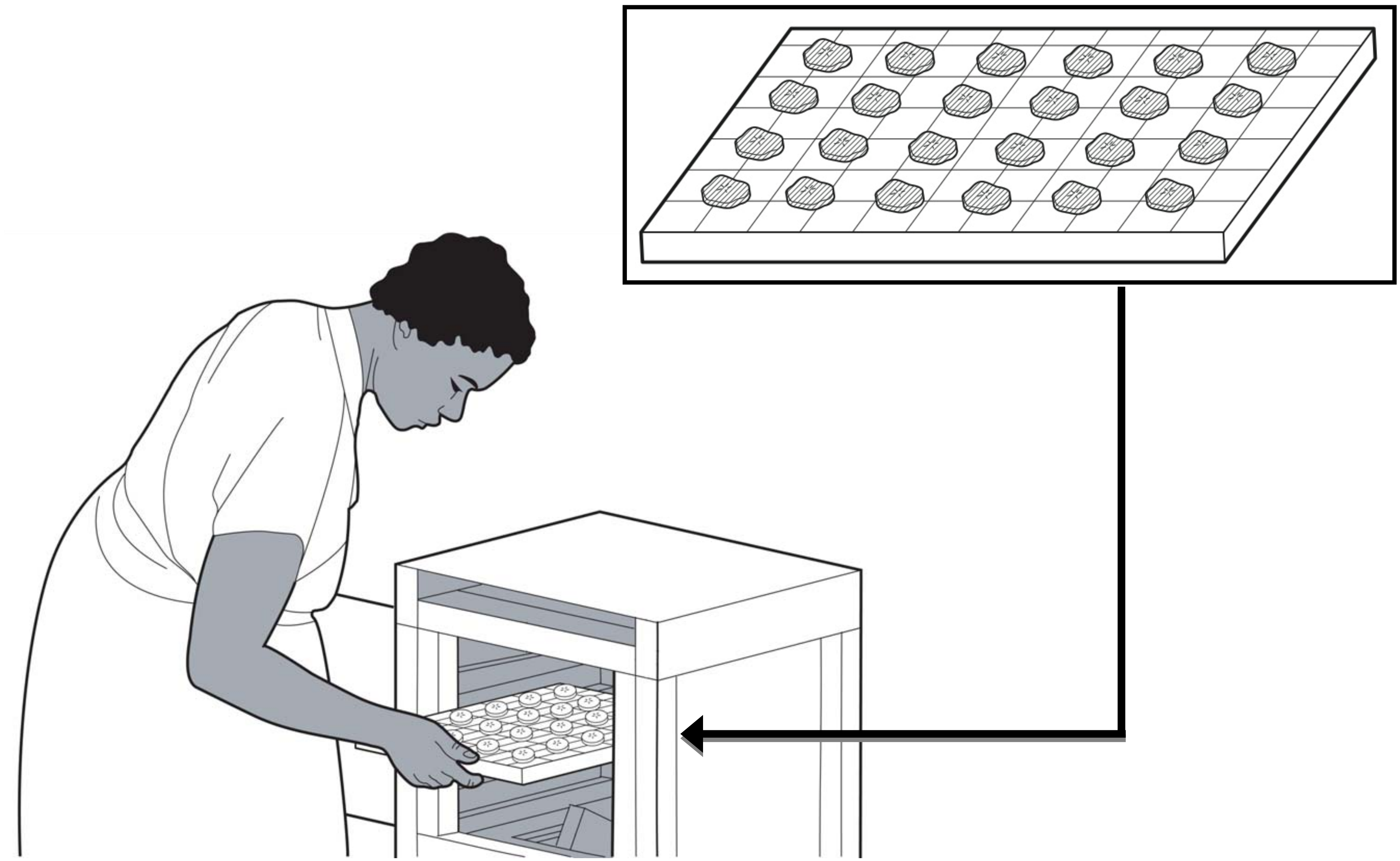
Step 3 | Lay food slices onto the tray(s) and leave spacing. The food should not touch other slices. Leave about 3 cm in between pieces. It takes about 2-3 bananas to fill a tray. The closer the food pieces are, the less airflow there will be through the interior part of the dryer and the less effective the dryer will be. The dryer will be slower and also will not work as well.



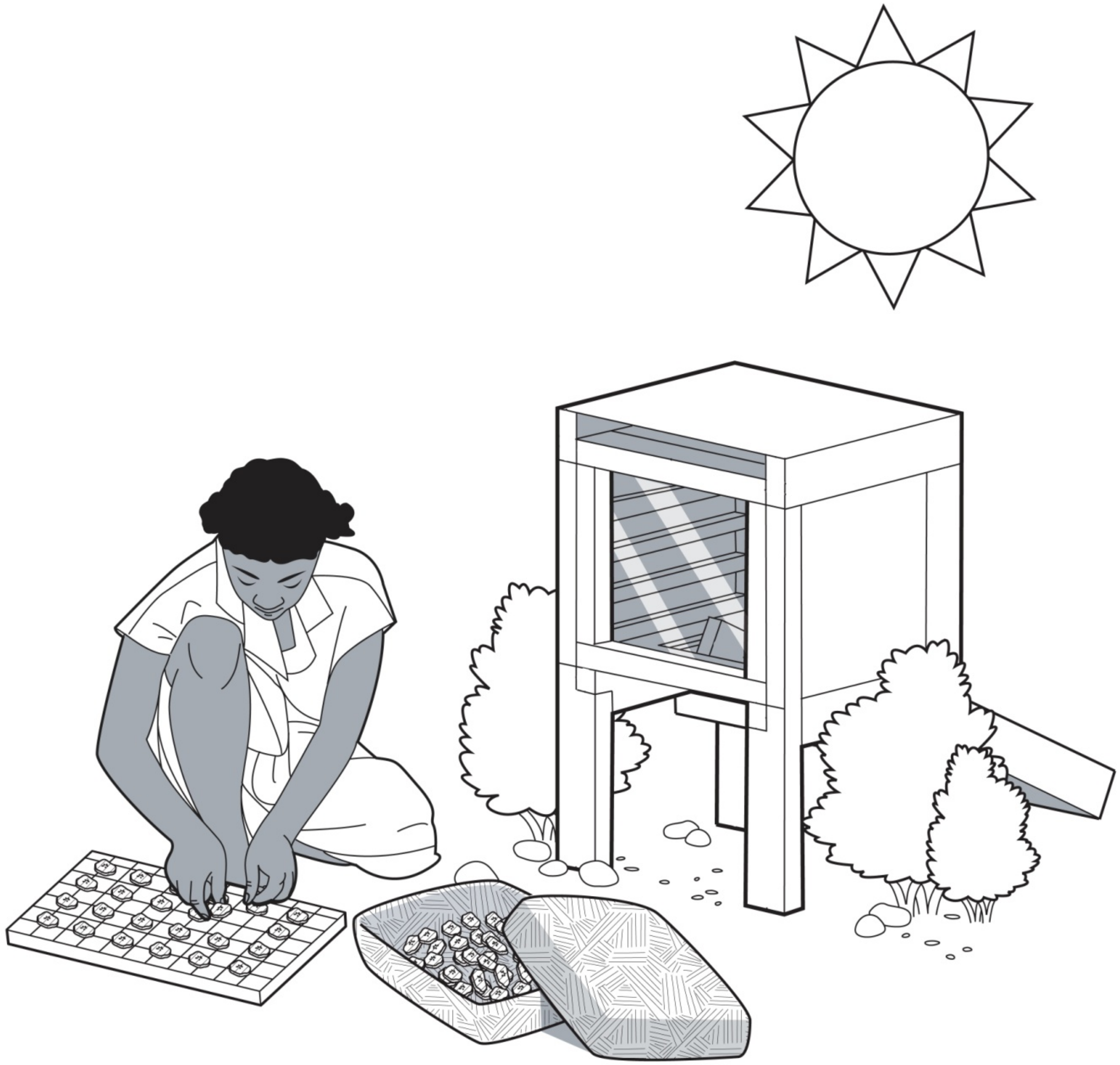
Step 4 | Put the tray(s) into the dryer. Trays will slide on the built-in racks in the dryer. You can fit a maximum of four standard trays. The trays are easy to customize, so for example, you can also fit more trays of different types of food if you make each tray smaller. **Close the sliding door when all the food has been put into the dryer.**



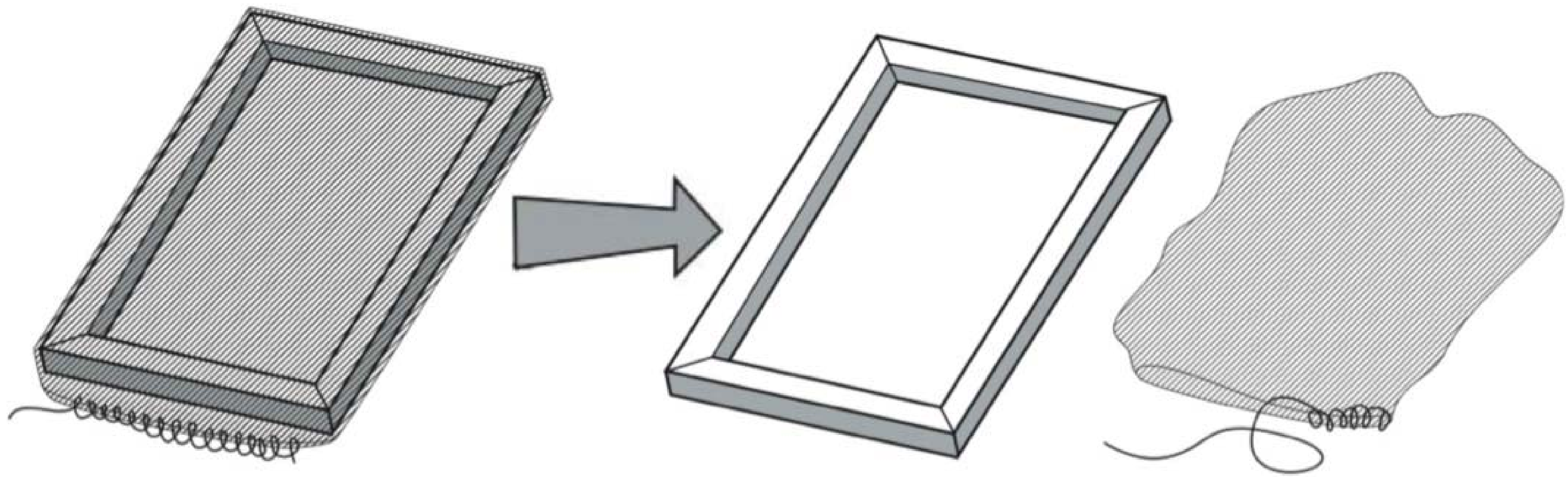
Step 5 | Let the dryer sit in the sun. The length of time will vary based on the food you're drying, outside temperature, and level of sun. In general, meat will take longer than vegetables or fruit. Food will dry faster in hotter temperatures, and the more food you are drying at the same time, the longer it will take.



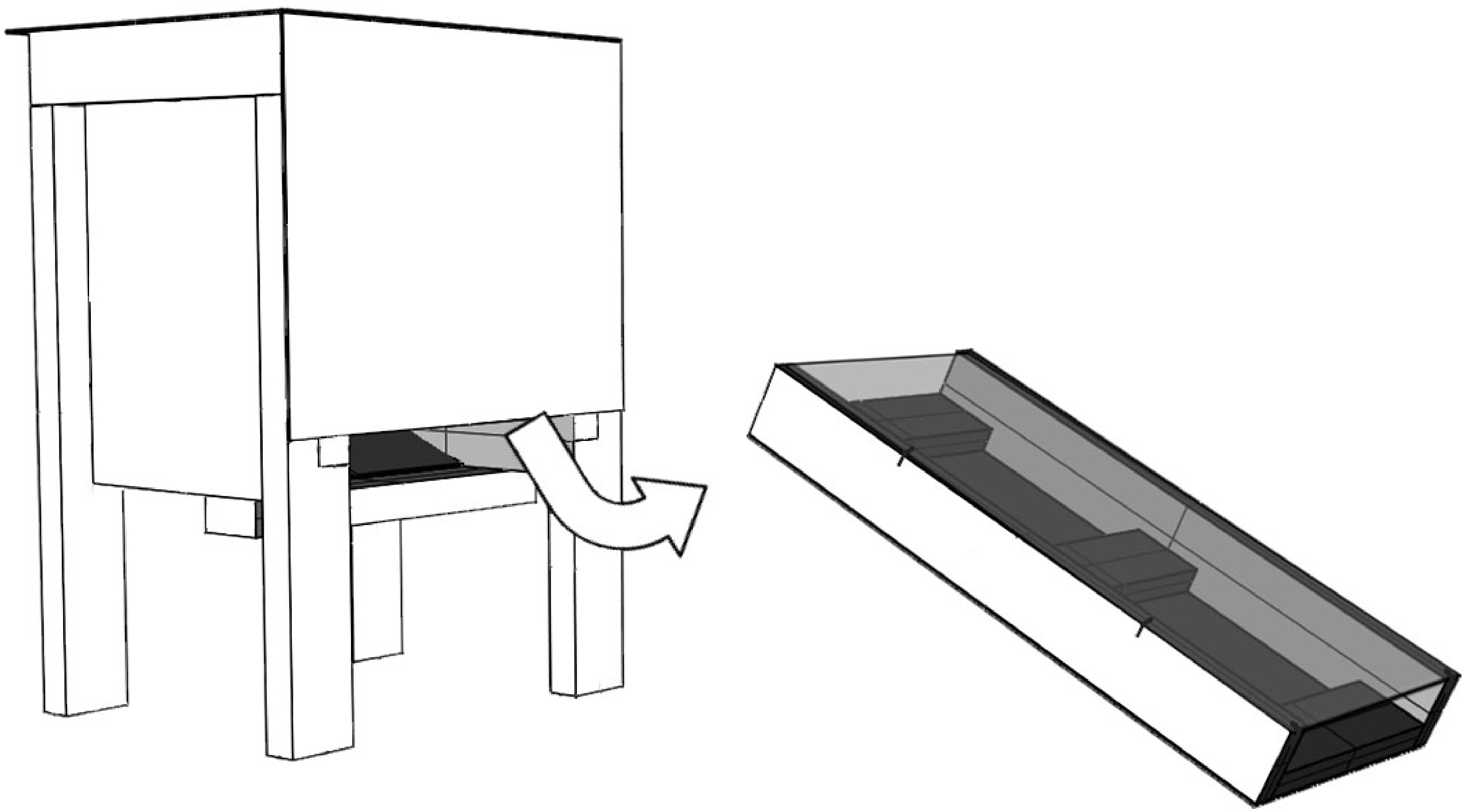
Step 6 | Check the food in the dryer after an hour (or a few hours, if it is meat), and take out if finished. After the given amount of time, check the dryer to see how the food is doing. The food is done when it has turned dry and crisp on the outside and inside. If the food is not done, leave it in for longer and check again.



Step 7 | Remove the food from the trays and place it into a sealable container. The best containers to use would be jars or other closed containers. However, a basket with a top on it will also work. The main intent is to keep insects and moisture away from the food, until you are ready to eat it.



Step 8 | Once you've removed the food from the trays, wash the trays to remove food residue. To make cleaning more effective, you can remove the mosquito netting from the tray frame. Washing the trays will help maintain sanitation of the food dryer, and will also prevent food tastes from contaminating other food that you're drying. Washing is recommended after every use. This will also help decrease the number of trays needed to do the drying. The fewer trays you build, the less wood and resources you'll be using.



Step 9 | When you need the solar dryer somewhere else, simply separate the two pieces so that it is easier to manage and take it to where you want it to be. It will dry food best in sunlight, but when it is not in use you can keep it in shade or inside a building. It will be most convenient for you to have it close to the kitchen area, so that you can frequently monitor it. The dryer can also be moved closer to crop fields for convenience if there are a lot of excess crops to dry.

WHAT TO DO WITH DRIED FOOD

After the villagers have finished drying the food, it will be easier to store it. It would be ideal to store it in a sealed closed container, but since it is dried, it will still last longer than your normal fresh food, even if you just put it in a basket. The important thing is to keep it away from direct sunlight and moisture. Exposing the dried food to sunlight will expose it to harmful rays that eliminate the nutritional parts of the food. Exposing the dried food to moisture will begin the rehydration process and reverse the drying that was done.

Rehydration can be done right before cooking. To rehydrate the dried food, put the food in hot water and let it sit for 10-15 minutes. After that, the food can be cooked as normal.

TROUBLESHOOTING & OTHER CONSIDERATIONS

If you have dried food that is crusty on the outside but still moist on the inside… you may have gotten the dryer too hot, resulting in "case hardening". Getting the dryer too hot can lead to "case hardening" of the food, where the outside becomes hard and prevents the inner parts from drying properly. In addition, temperatures that are too high (over 43-50°C) in the dryer can mean loss of nutrients and vitamins from the food. You can prevent overheat by increasing airflow or lessening heat collection. This can be done either through increasing ventilation areas or moving the dryer to a cooler area.

If the food has a strange flavor in it… you may have used the same tray for multiple types of food without washing the tray. Keep separate trays, or wash the screens between different usages. Mixing trays for drying fruit, vegetables, and meat, will result in mixed tastes.

If the food has mold on it… do not eat it. Mold is fungus that has started growing on the food, and makes it dangerous for people to eat. If mold has started growing on your food it is no longer safe for you to eat.

Use as little wood as possible during the construction process. Less wood will mean a lighter product, and will also benefit the nearby forest. Deforestation negatively impacts the forest, and you should decrease your contribution to this impact. In the short term, you will only notice just that the forest retreats farther and farther back, but as time goes on, you will also notice the quality of the forest that is left degrading. This means there will be fewer trees, less tree re-growth, and less variety in plant and animal life. As this happens, the medicinal plants that you look for in the forest will soon disappear. You will also have to go farther into the forest to find firewood.

Do not cut down more trees to create more room to grow crops now that you have a way to store them, but instead try to grow more intensively on the lands you have. Another interesting technique that you can try is rotating your crops. You should always have a plot of empty land, and every season you should switch your crops so that different nutrients are used and replenished in the soils.

Malagasy-Tailored Manual

This manual was written and designed with the specific village (Ranobe, Madagascar) in mind as the primary audience. The non-profit Ho Avy has a hired Malagasy translator, who is university-educated in a nearby city, Tulear. He will be the one conveying the information in this manual to the local villagers. Specific Malagasy needs addressed through the manual:

- Repetition - it is ingrained in Malagasy culture to repeat things. Including repetition in the document will make it easier for the translator. It will also remind the translator of important points.
- Simple vocabulary and sentence structure - this will make for easier translation.
- Simple steps - these are emphasized in bold, and represent a good "summary sentence" of the step, but can be expanded upon as necessary using the provided descriptions.
- Images - the zebu line drawing is based off of sketches made by Malagasy children, and the women in the drawings are based off of Malagasy women from Ranobe.

Credits & Acknowledgments

How-to Guide Images: Carolyn Nowak (Art & Design BFA '11)
Other images: Patty Liao (SNRE and Mechanical Engineering MS/MSE '11)

Technical Renderings: Stephanie Starch (Art & Design BFA '10)
Refinement and Compilation: Brennan Madden (SNRE MS '11)

Special thanks to:

- Professors Steve Skerlos (Mechanical Engineering) and Joe Trumpey (Art & Design) for advice and support throughout the production of this document.
- Non-profit Ho Avy for feedback on guide instructions.

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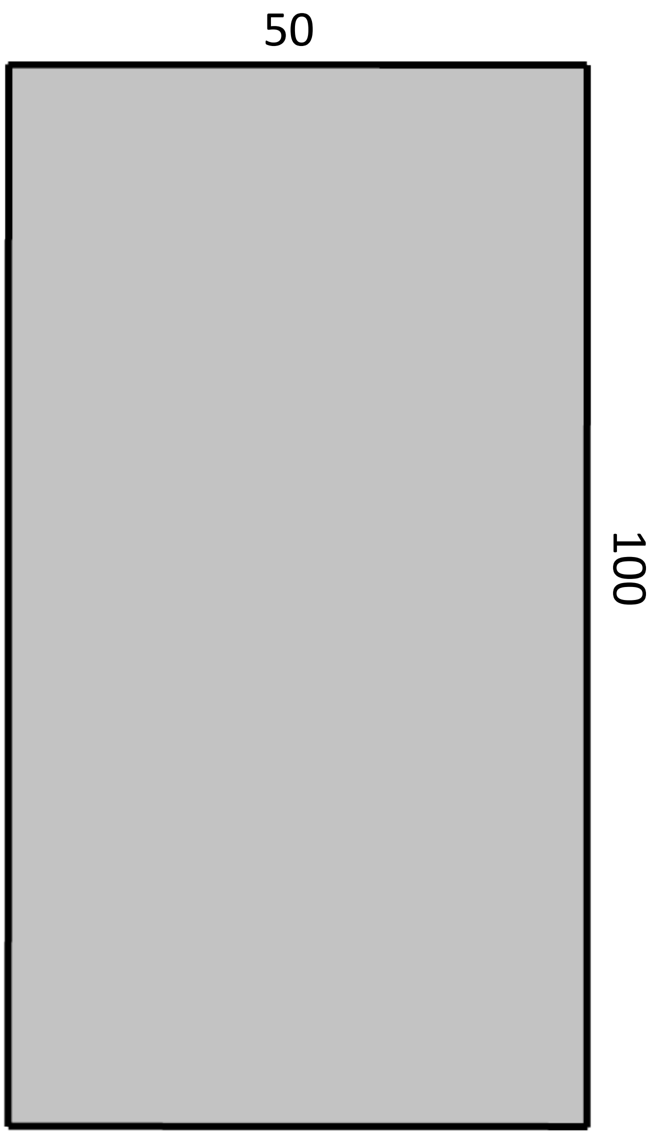
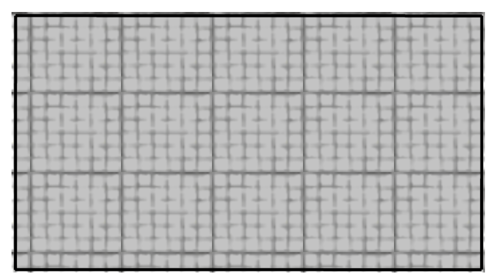
[7] Sharma, A., C.R. Chen, Nguyen V.L. (2009). Solar-energy drying systems: A review. Renewable and Sustainable Energy Reviews, 13, 1185–1210.

Materials Needed:



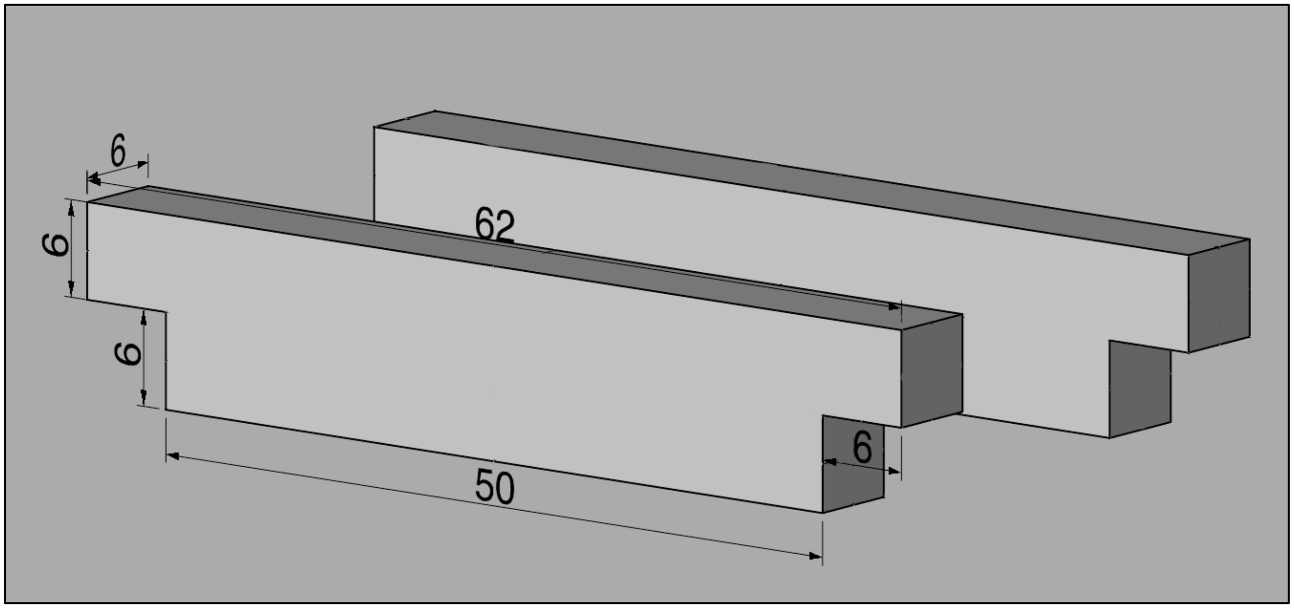
Glass 50cm x 100cm

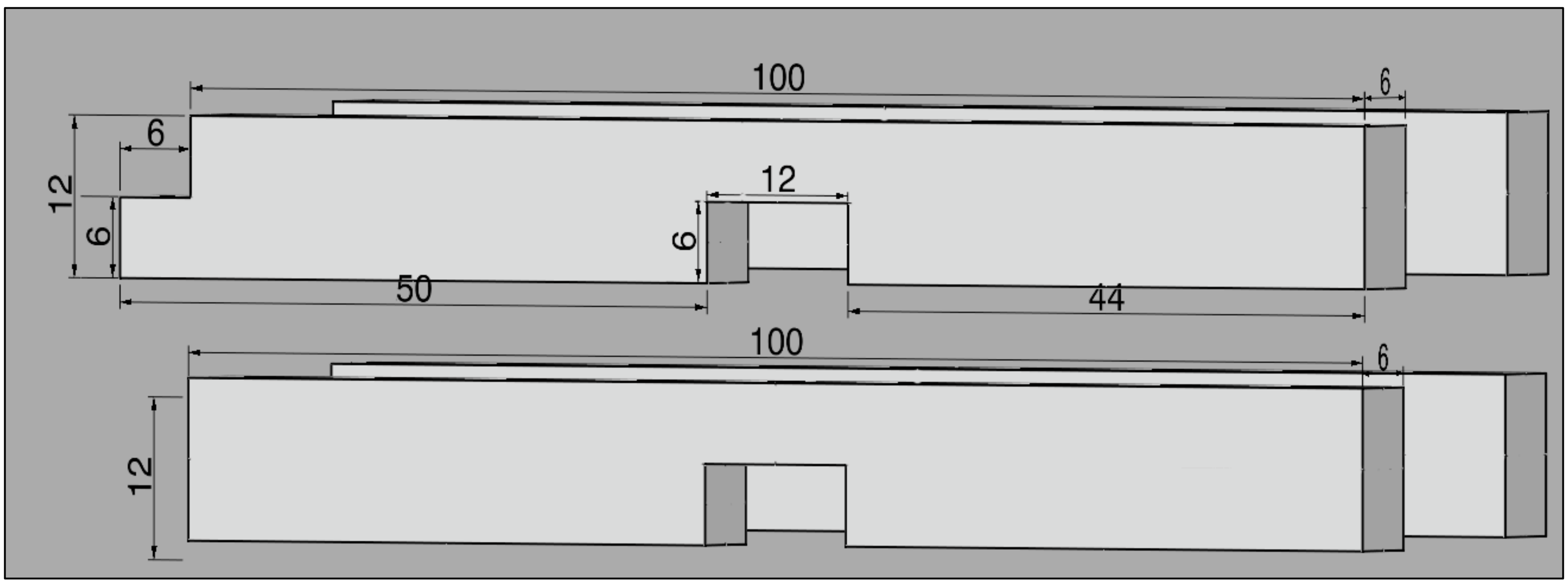
6 Angle
“L” Brackets



Untreated Mosquito Net (2m^2 + as needed)

Wooden Parts (all in centimeters):





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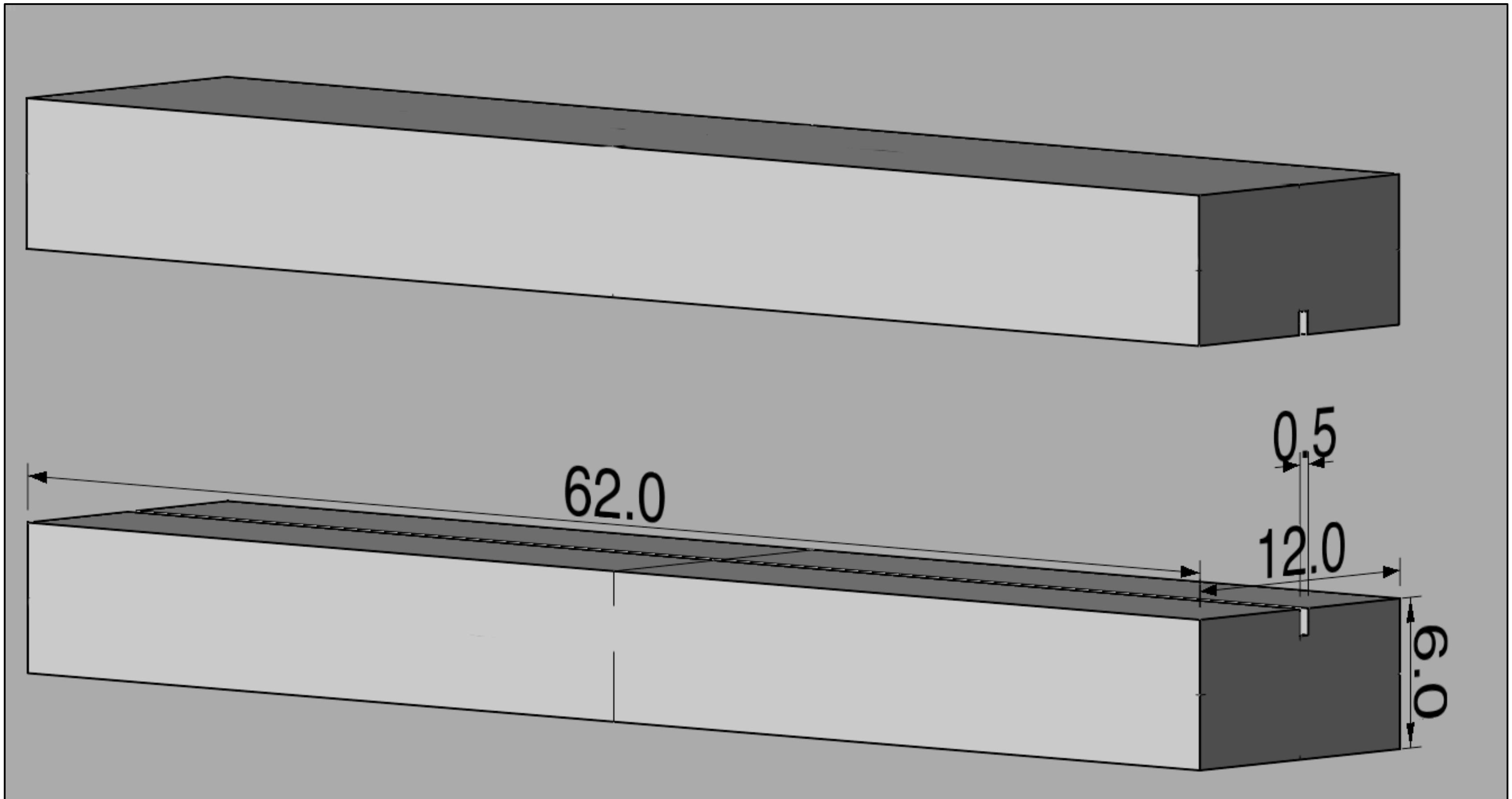
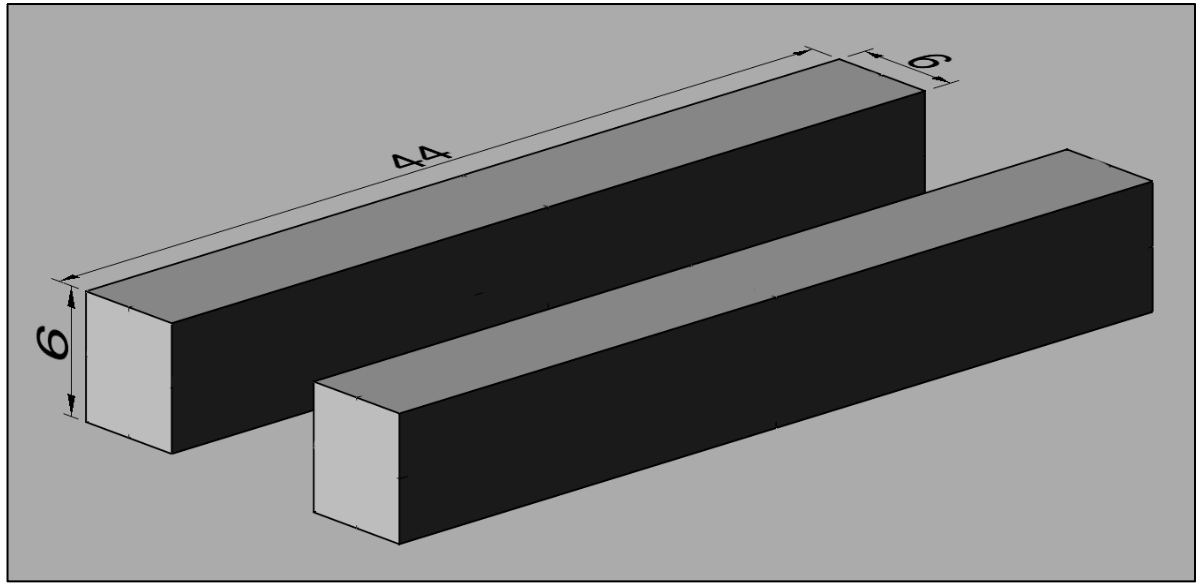
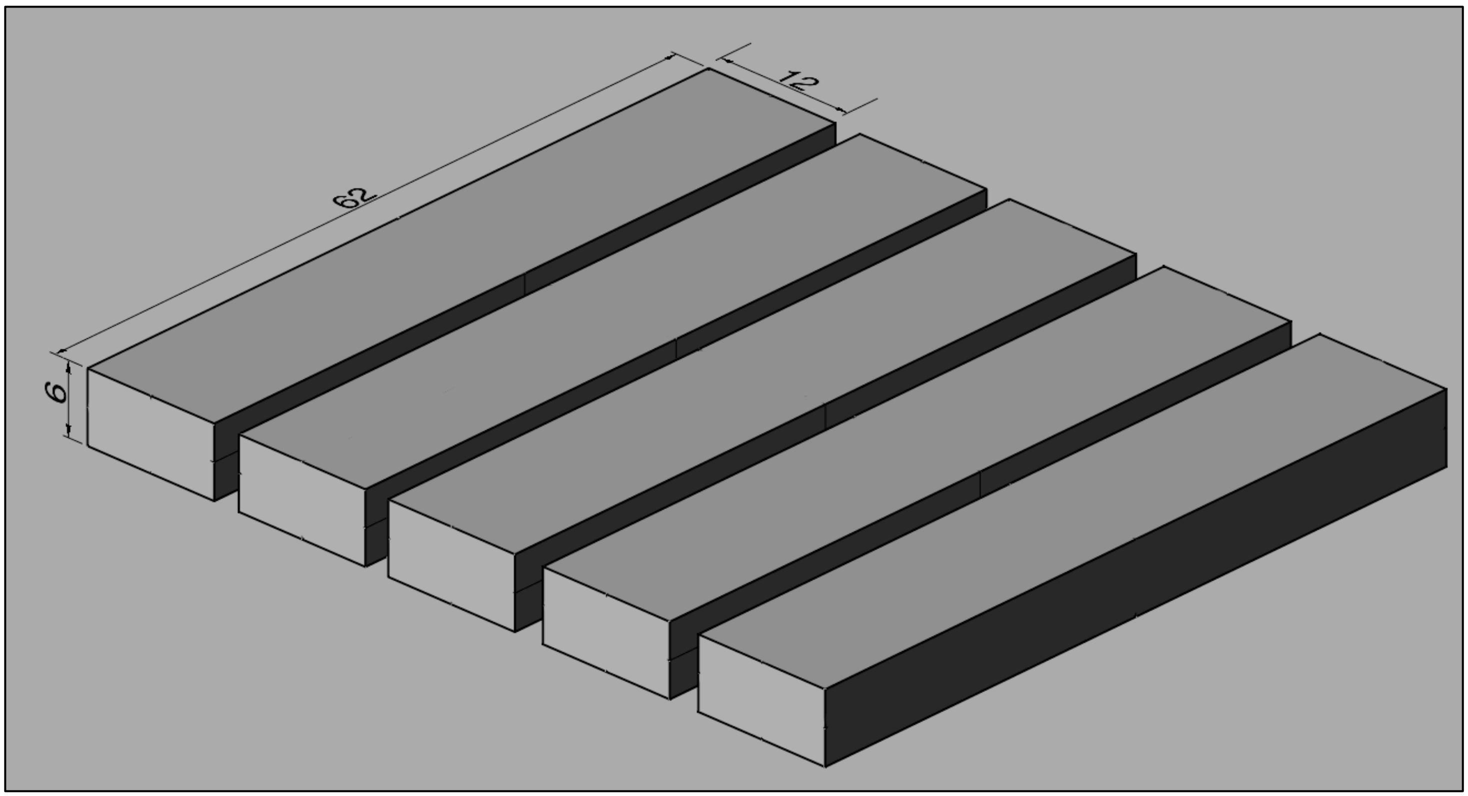


Two 62x12x6cm pieces require a cut down the middle for sliding door frame.

Wooden Parts
(all in centimeters):





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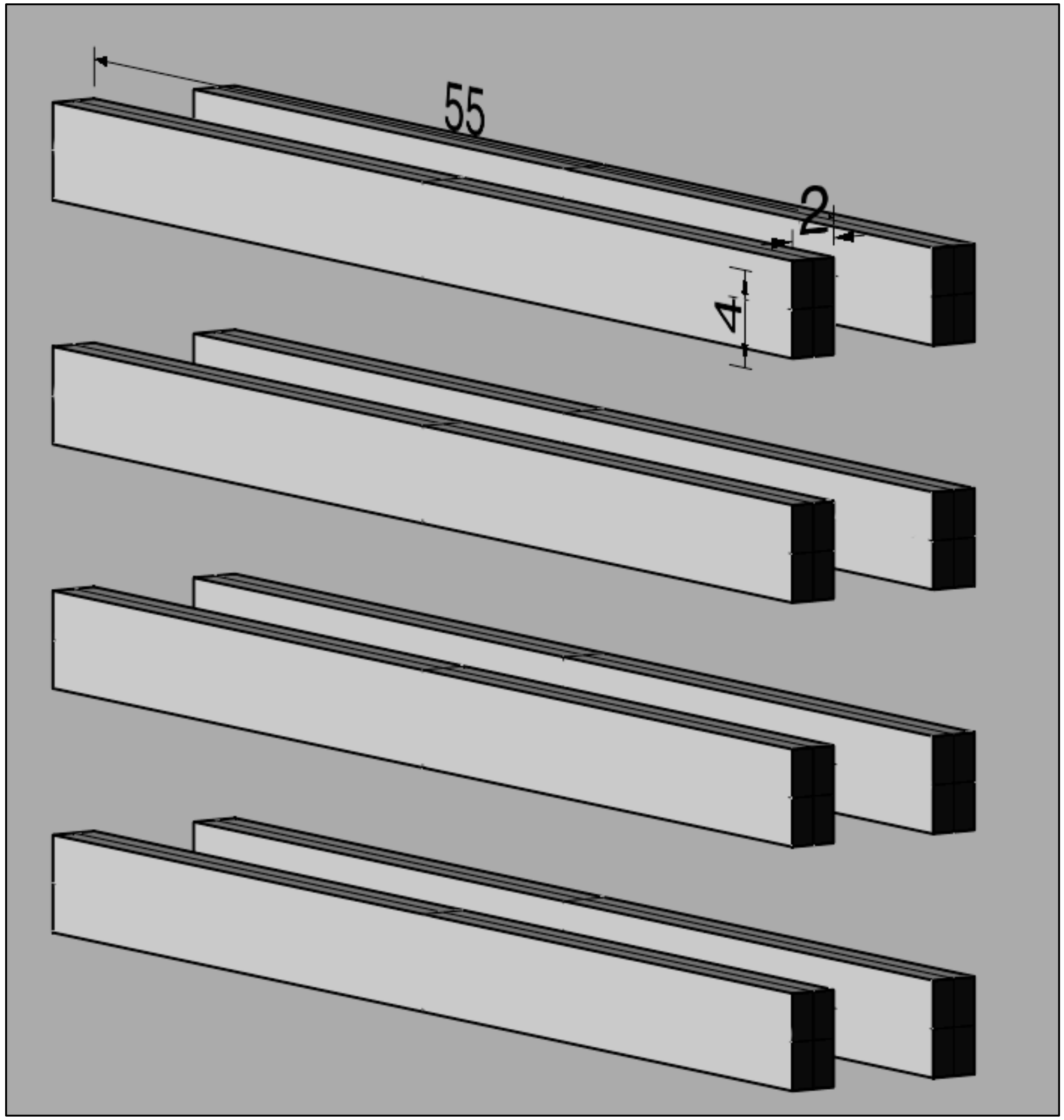
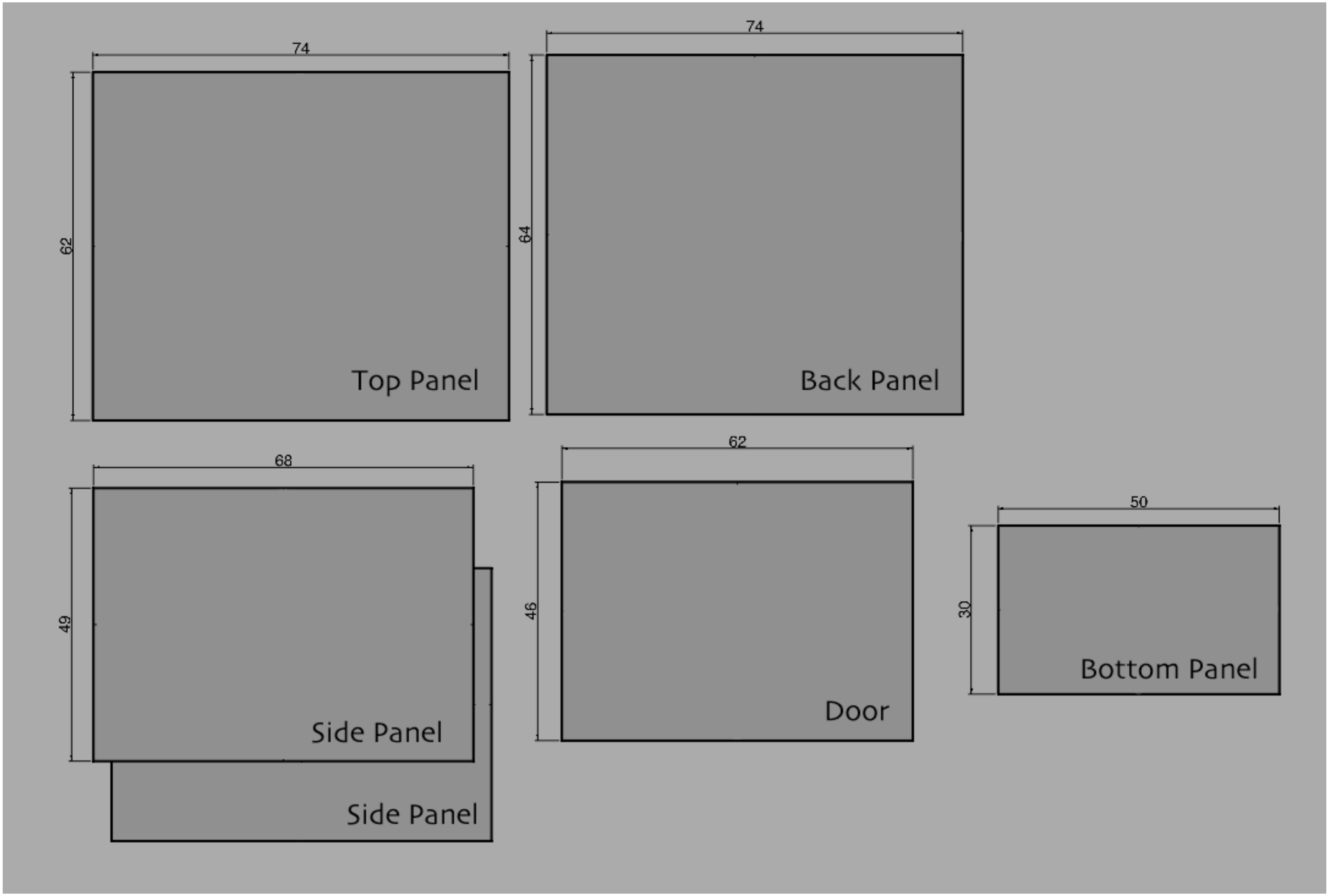


Ranobe Solar Dryer Tekniki Malagasy

Wooden Parts (all in centimeters):



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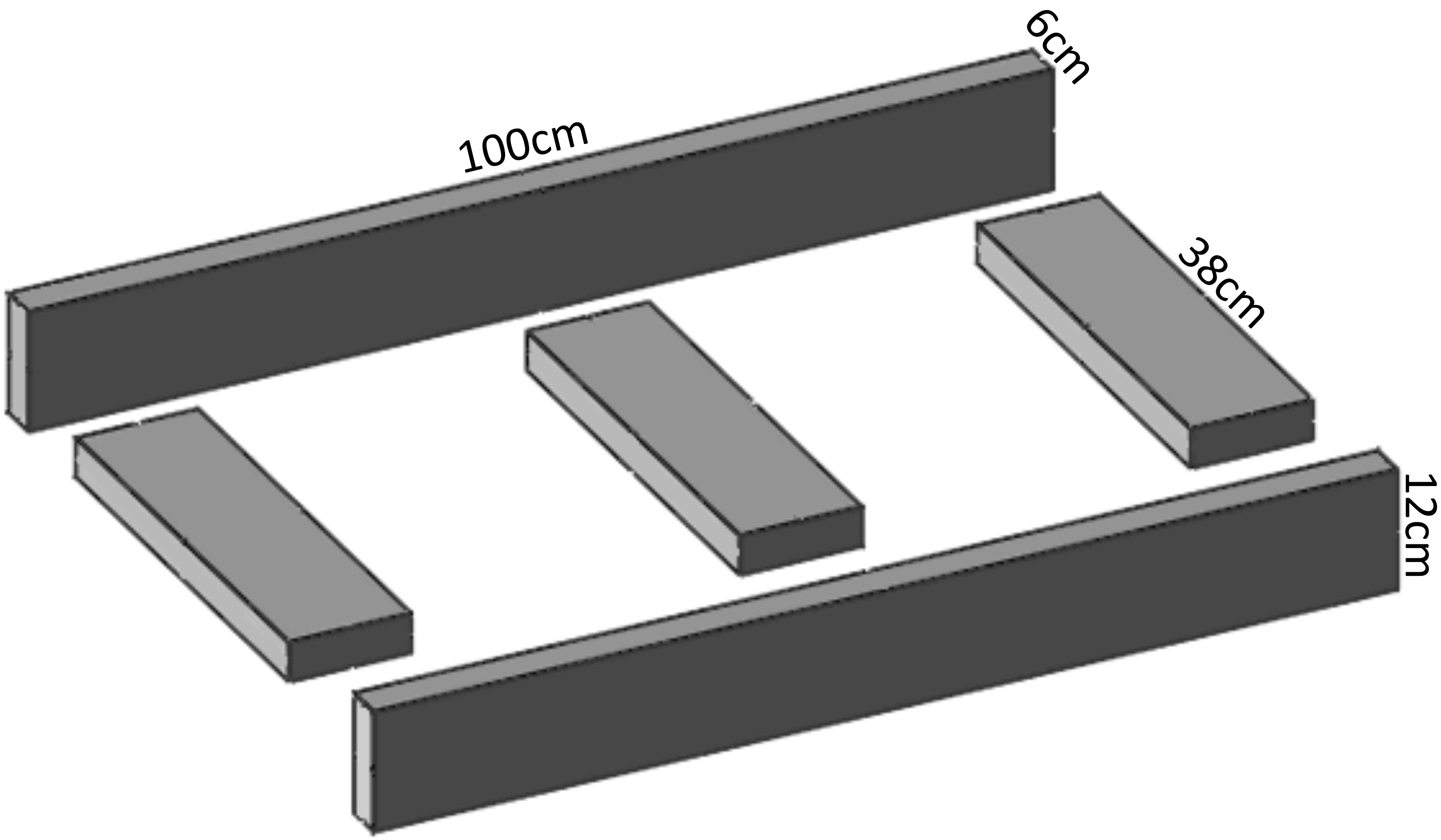
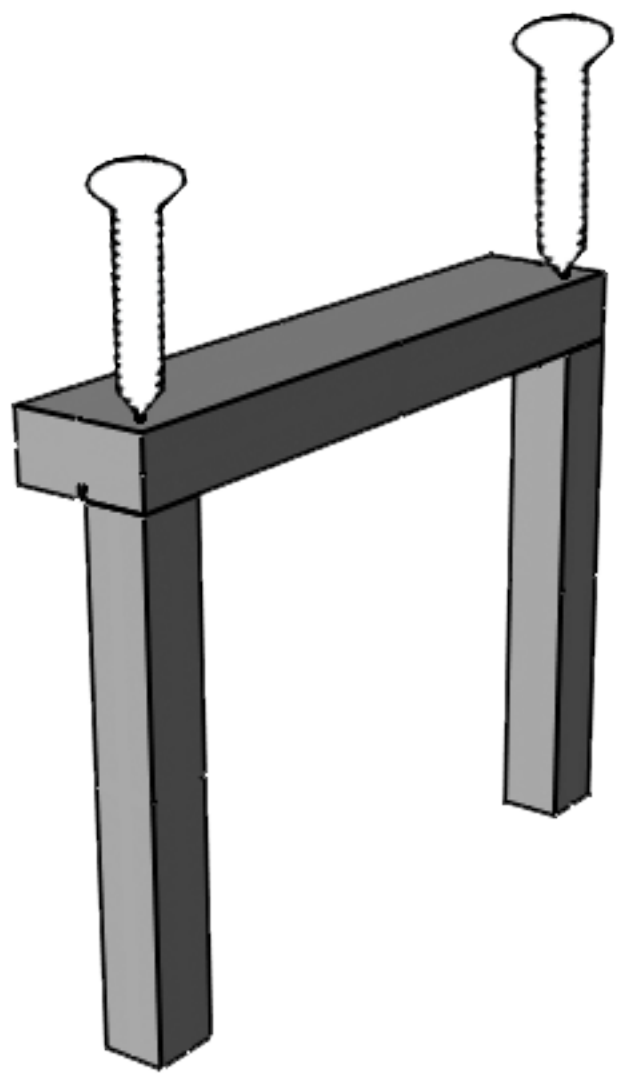


64 Needed

74 Needed

6 Needed

1



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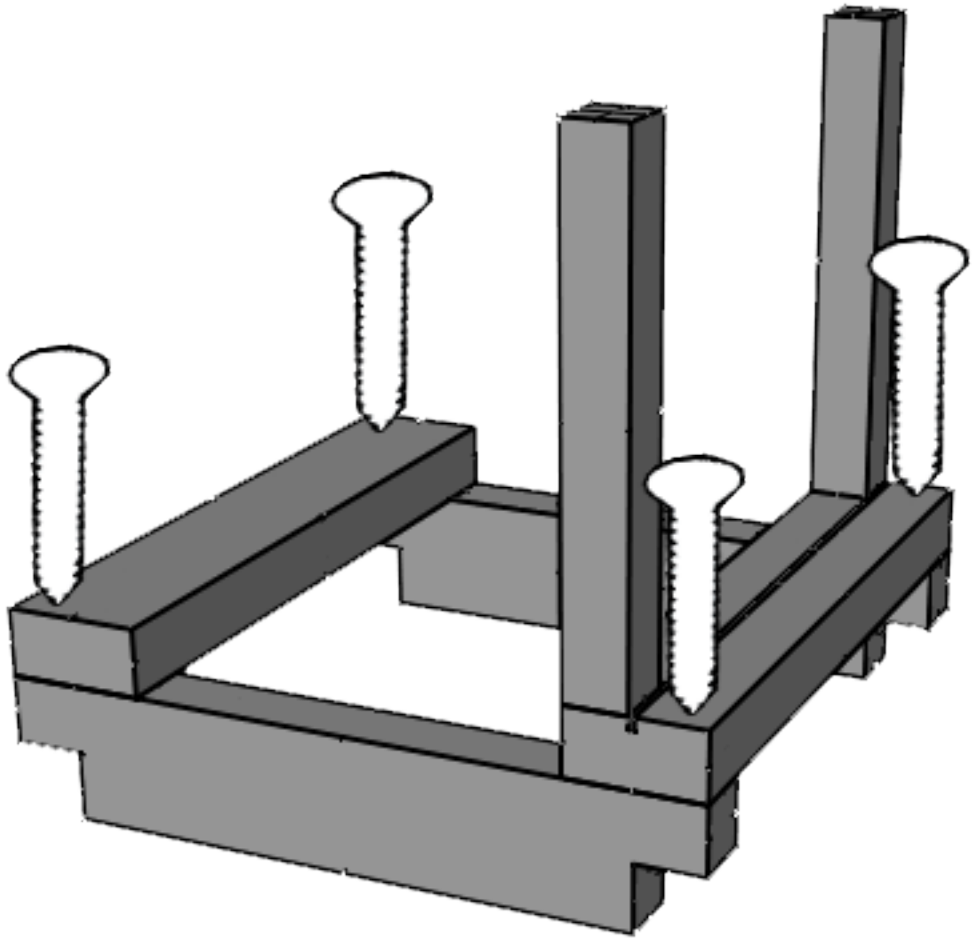

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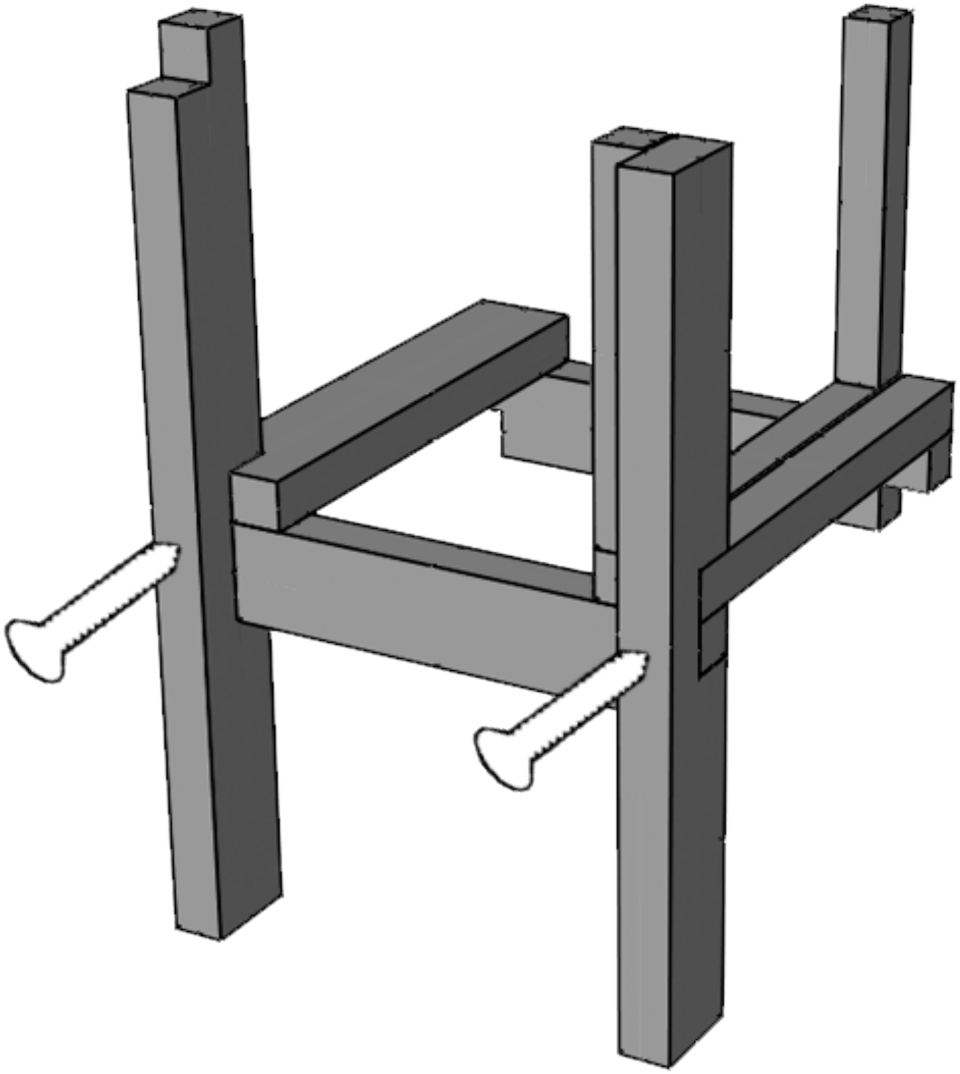

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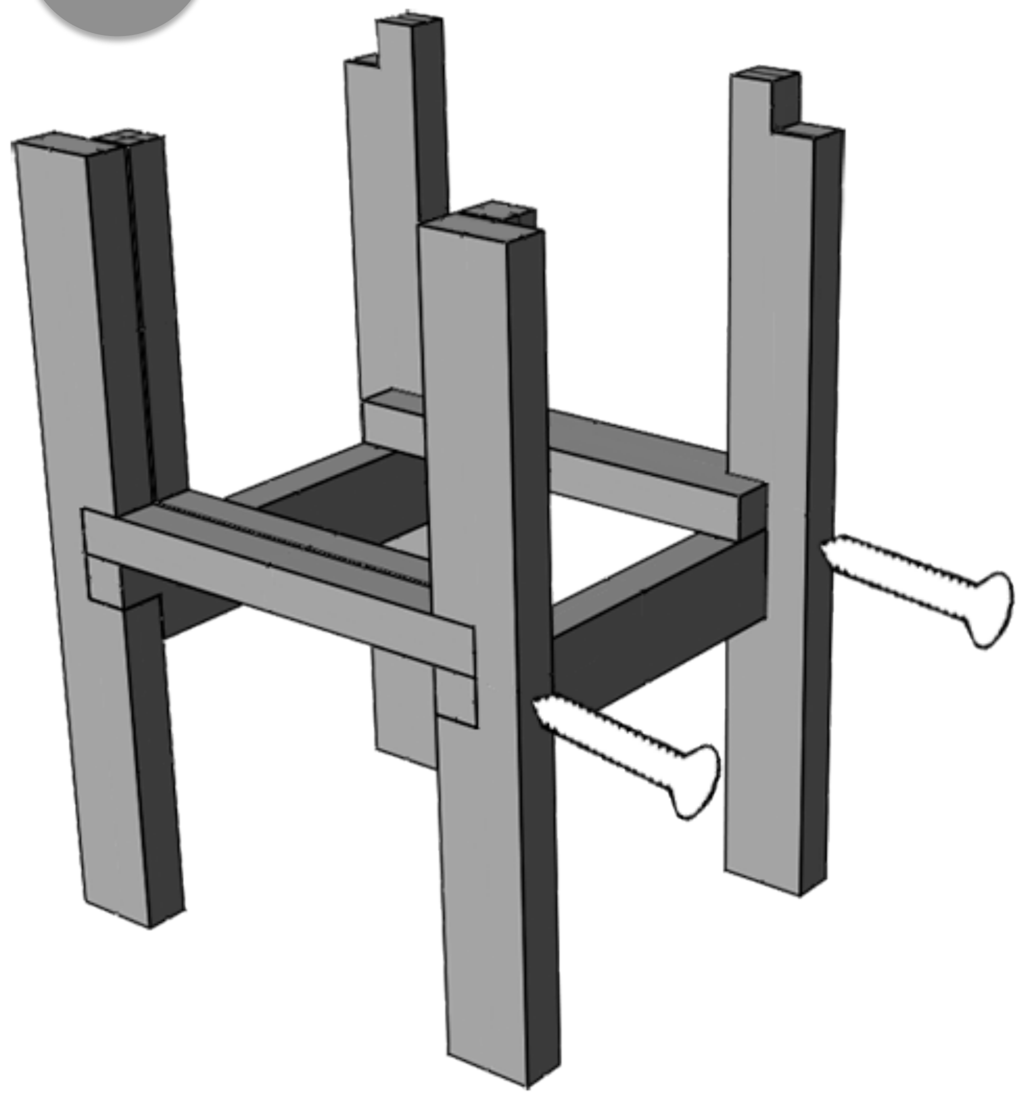

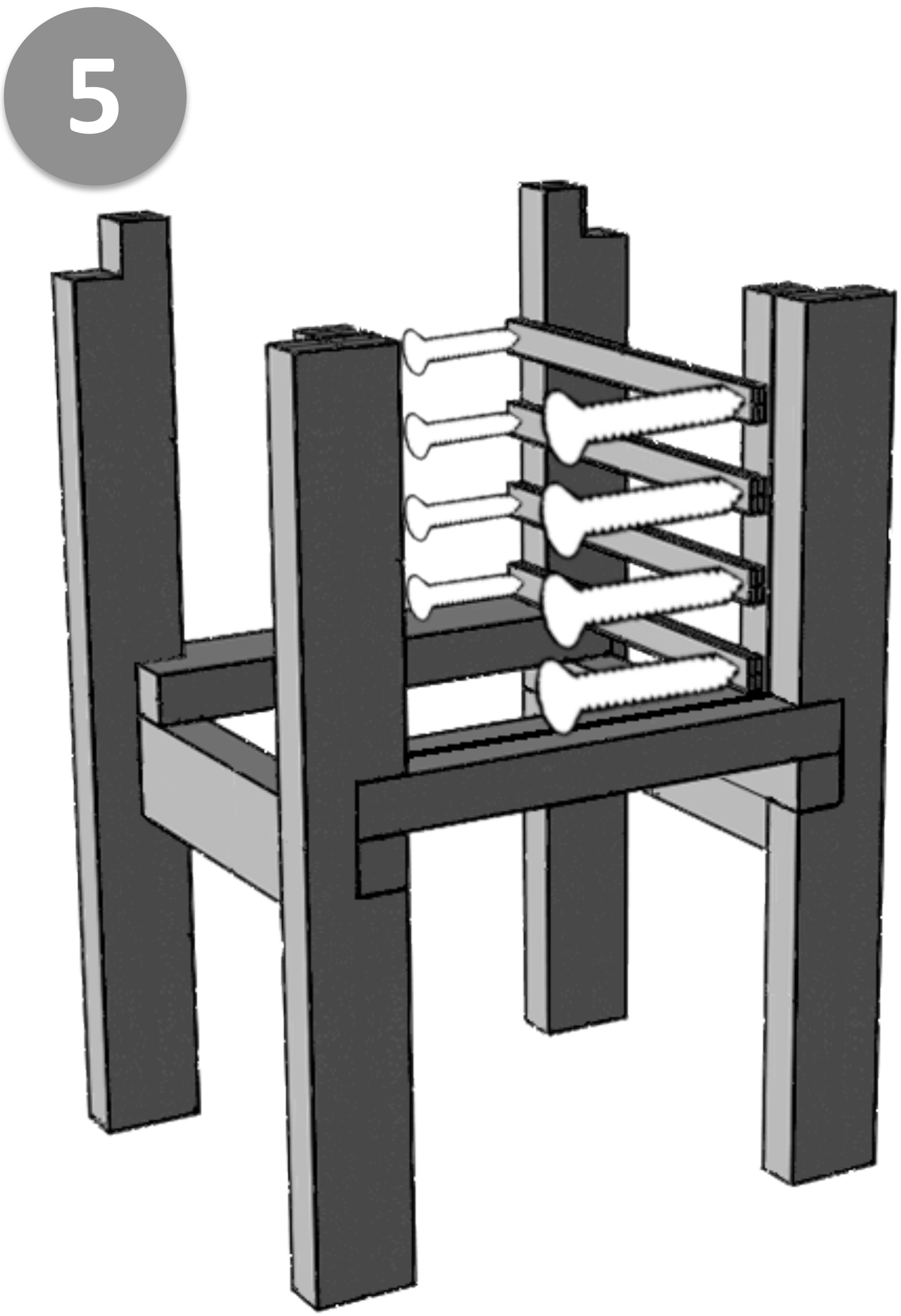
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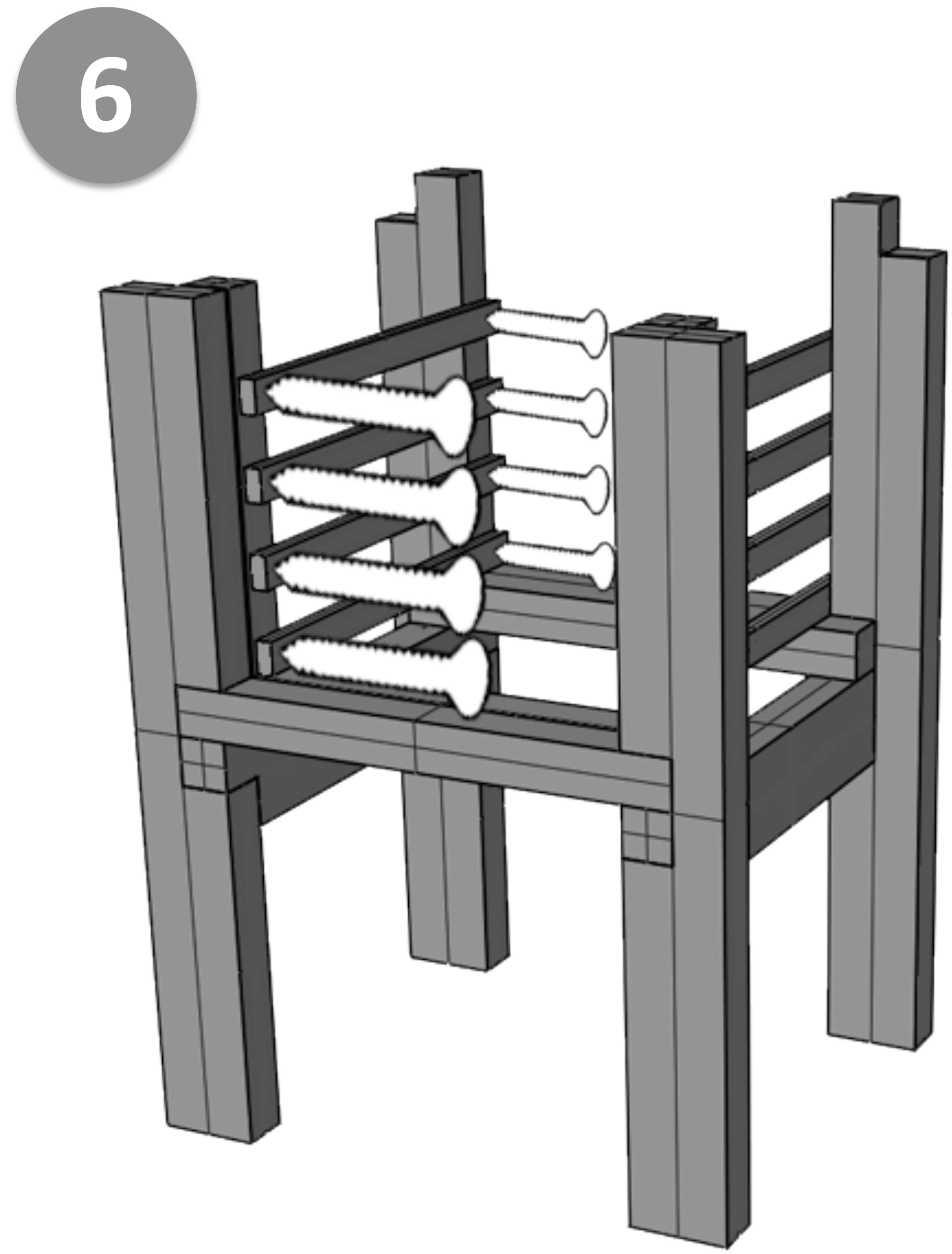
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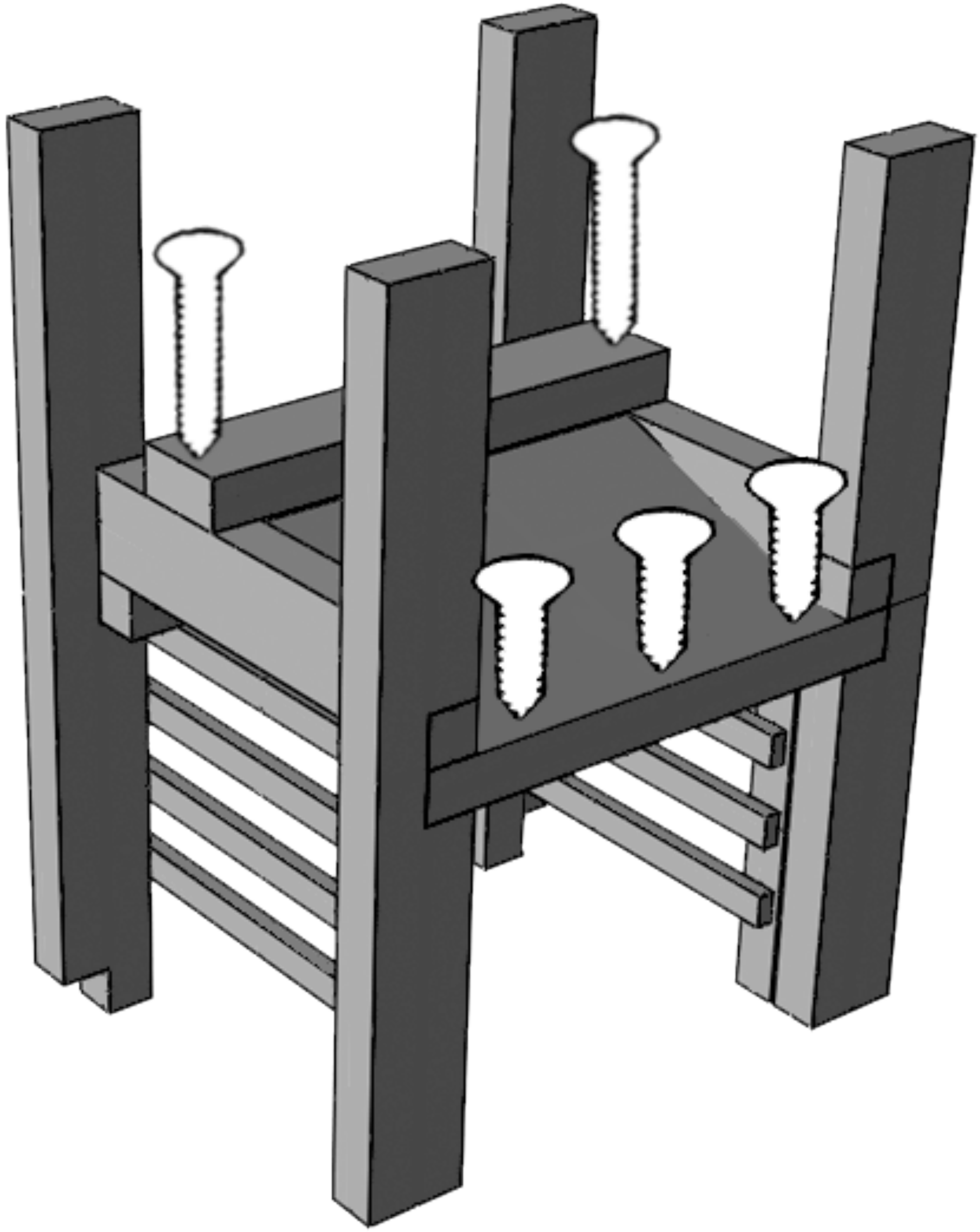

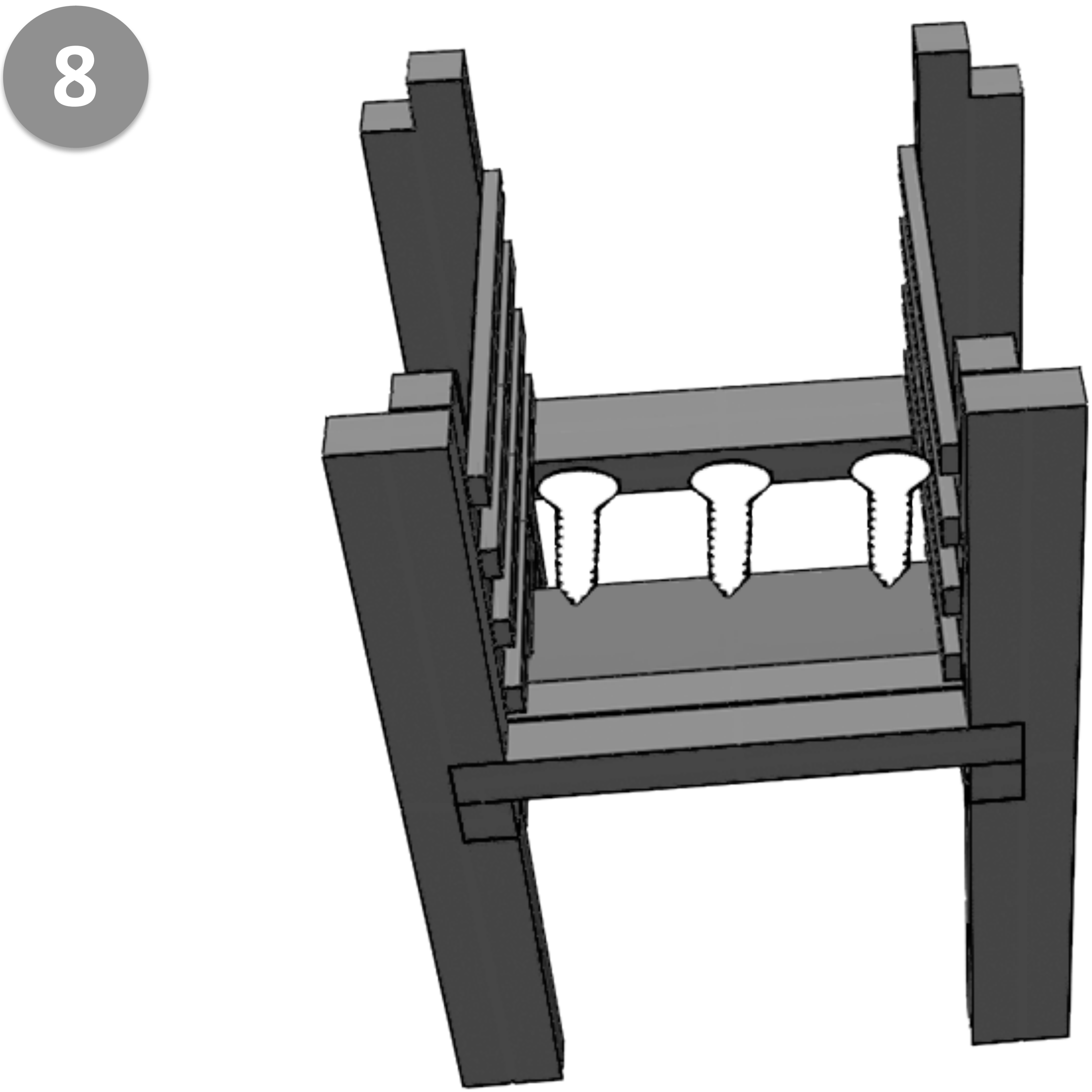
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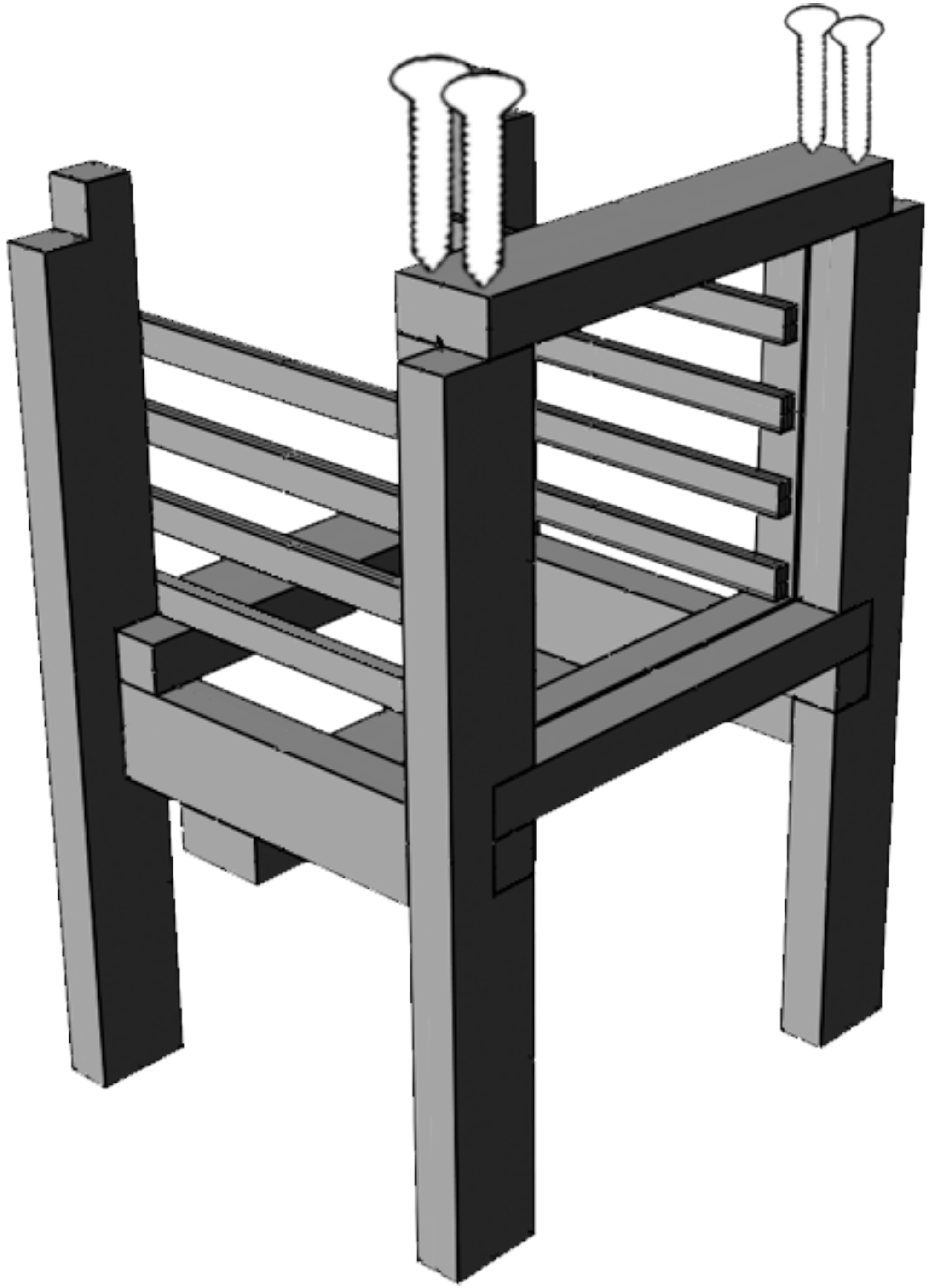

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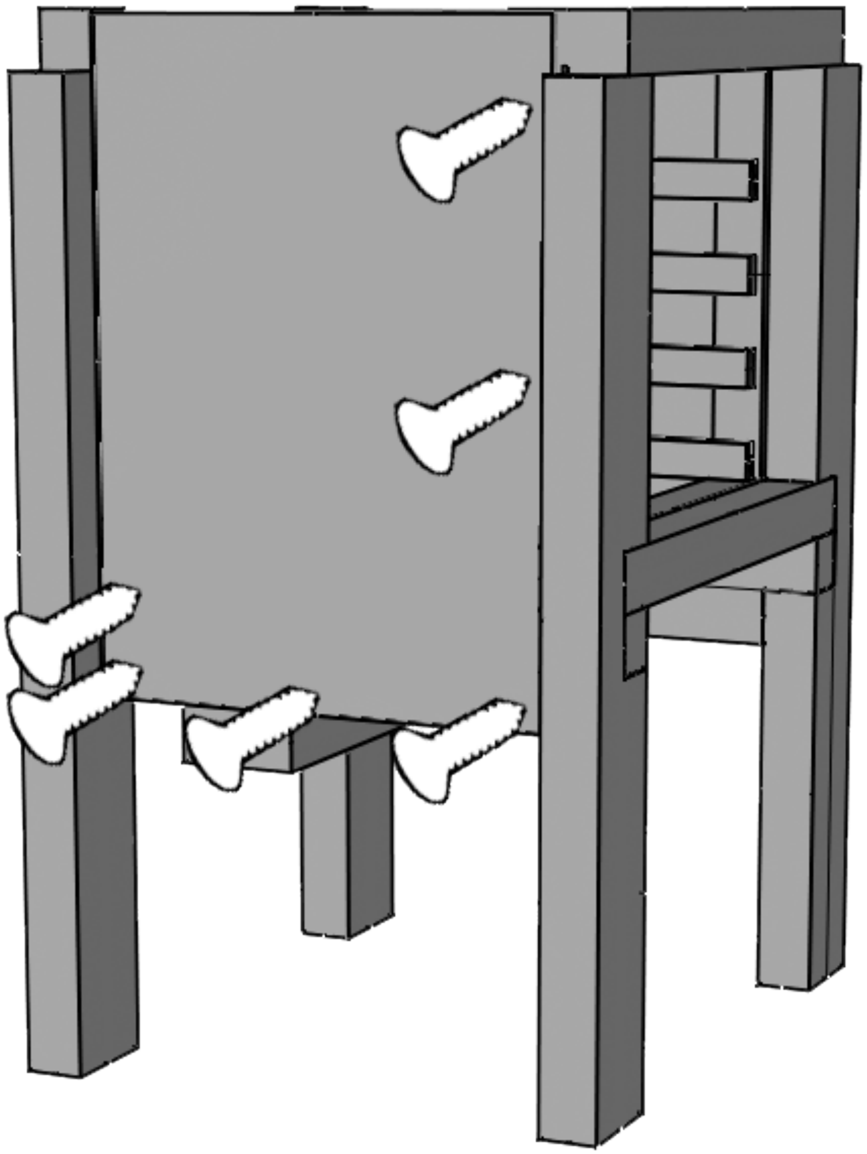

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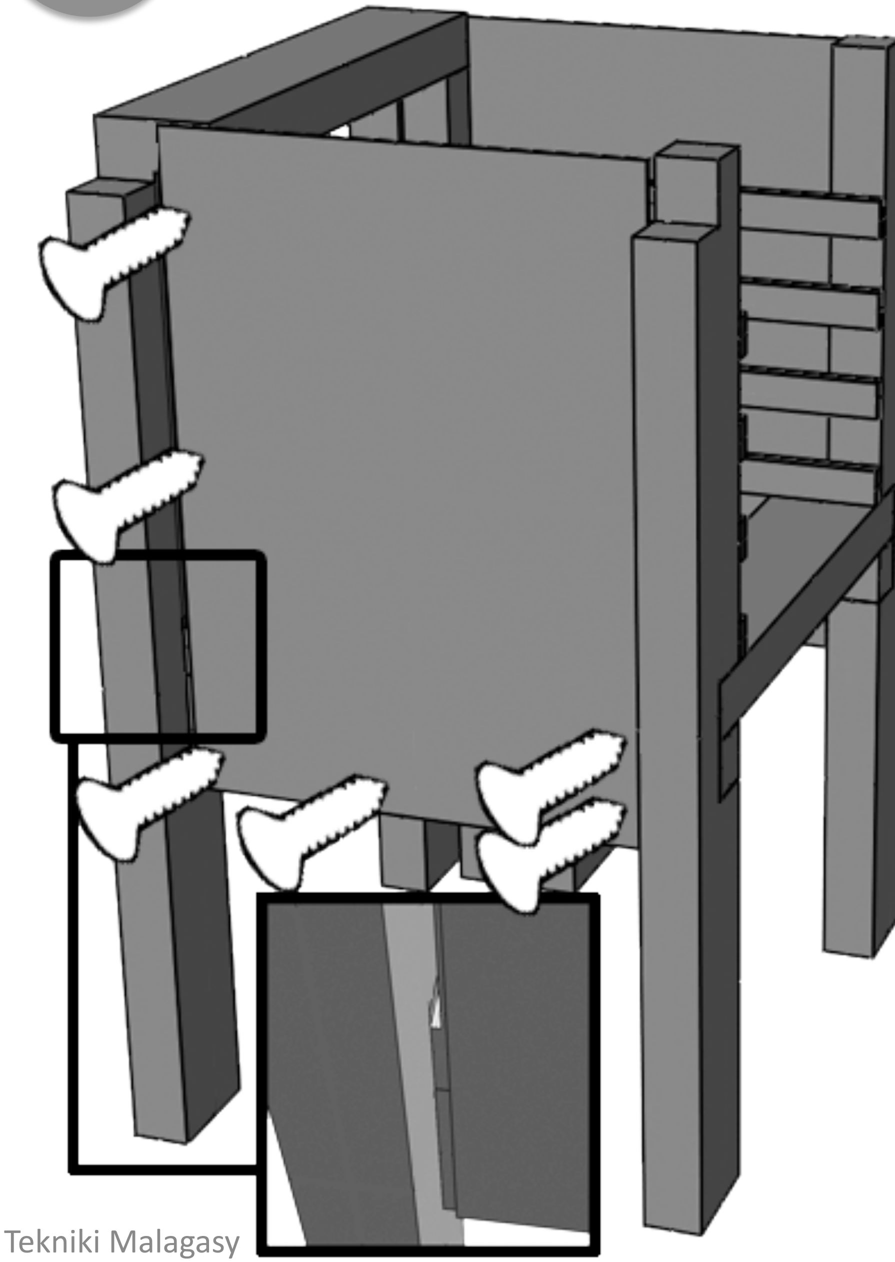

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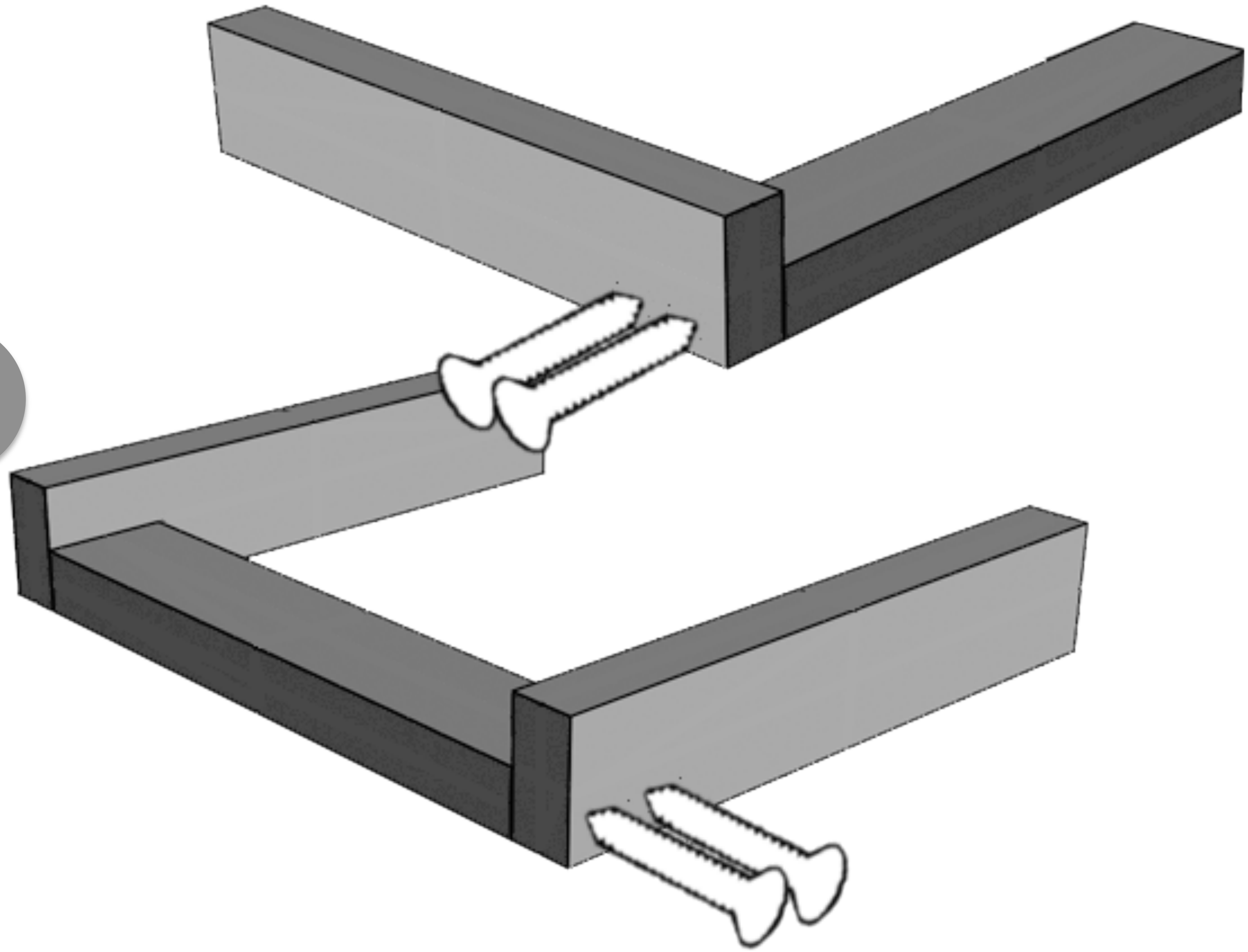

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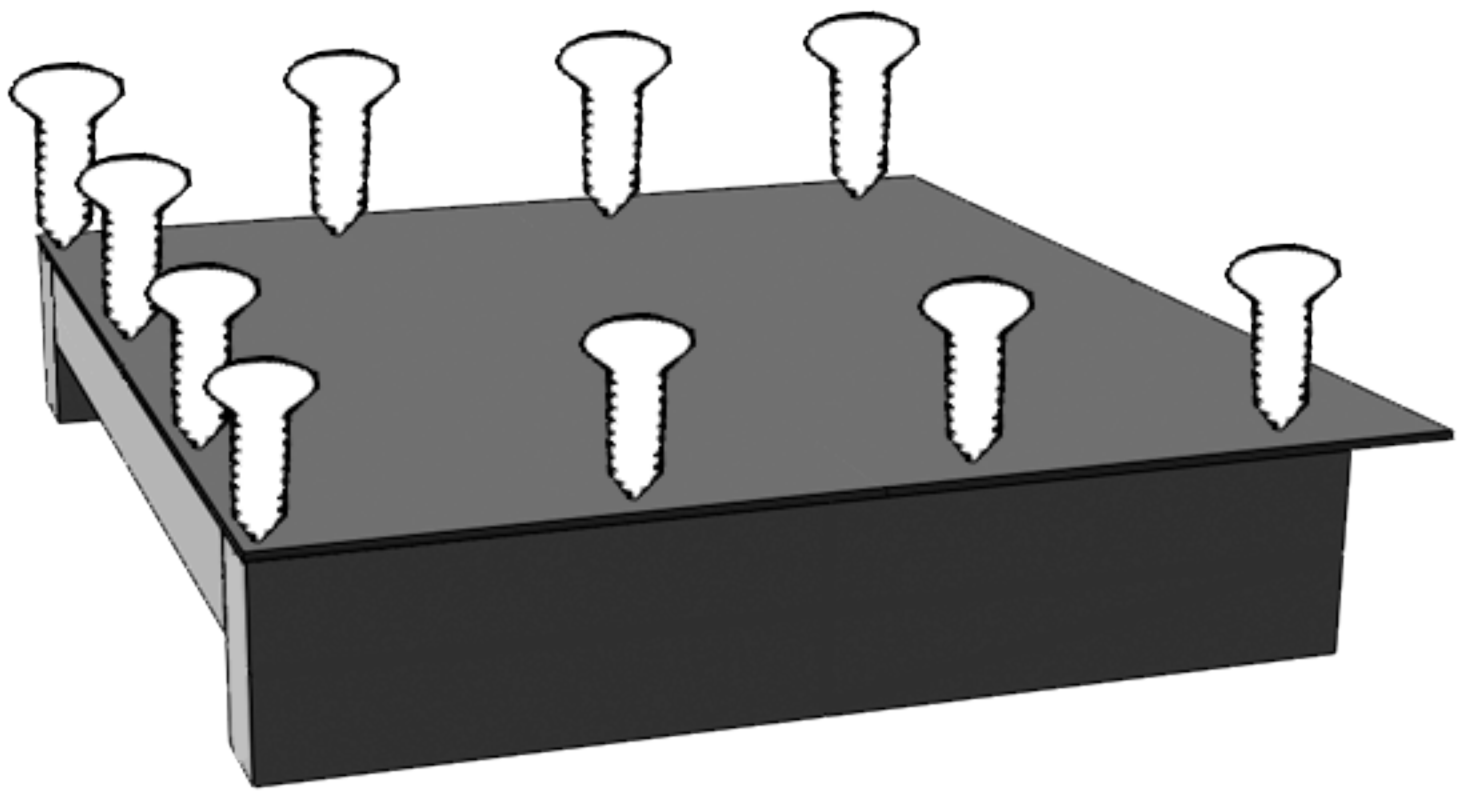

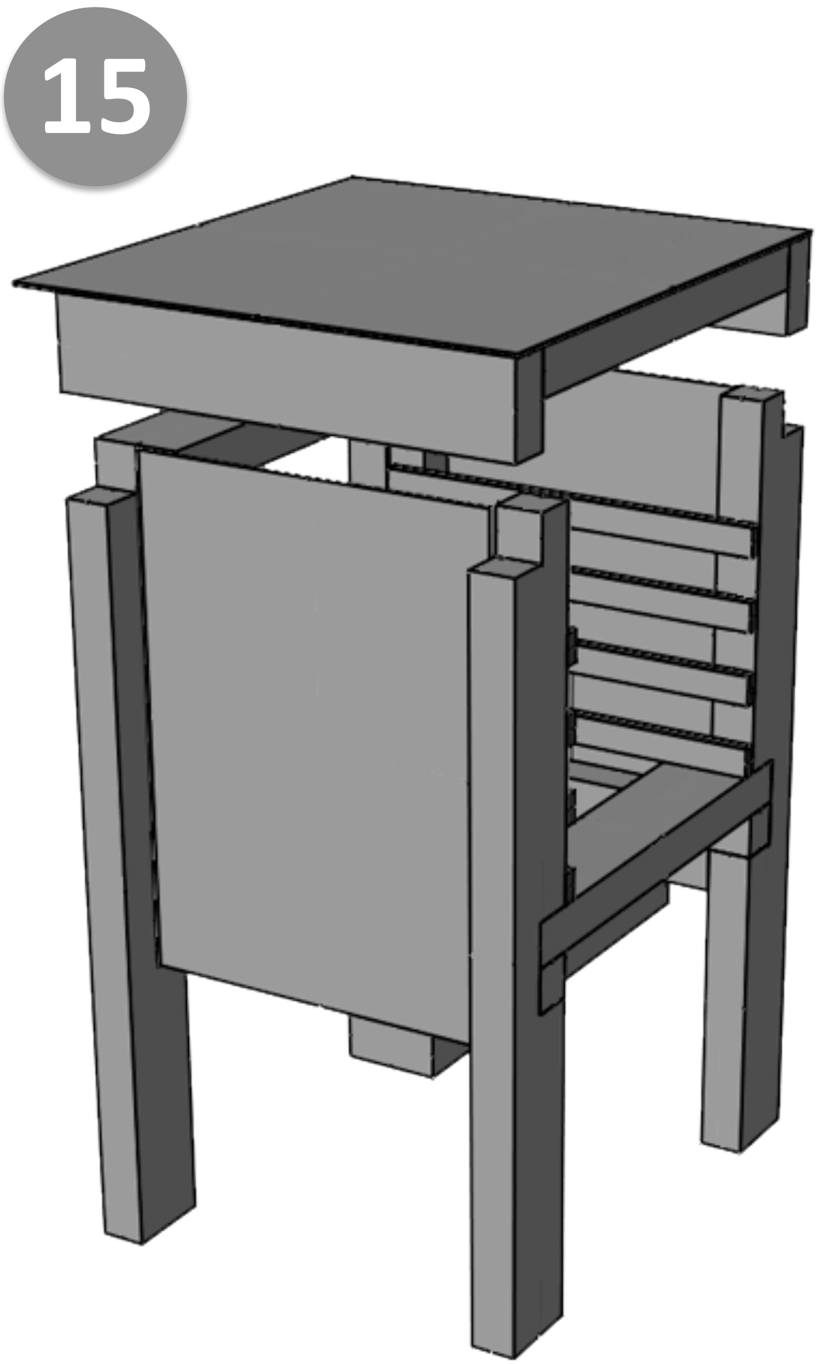
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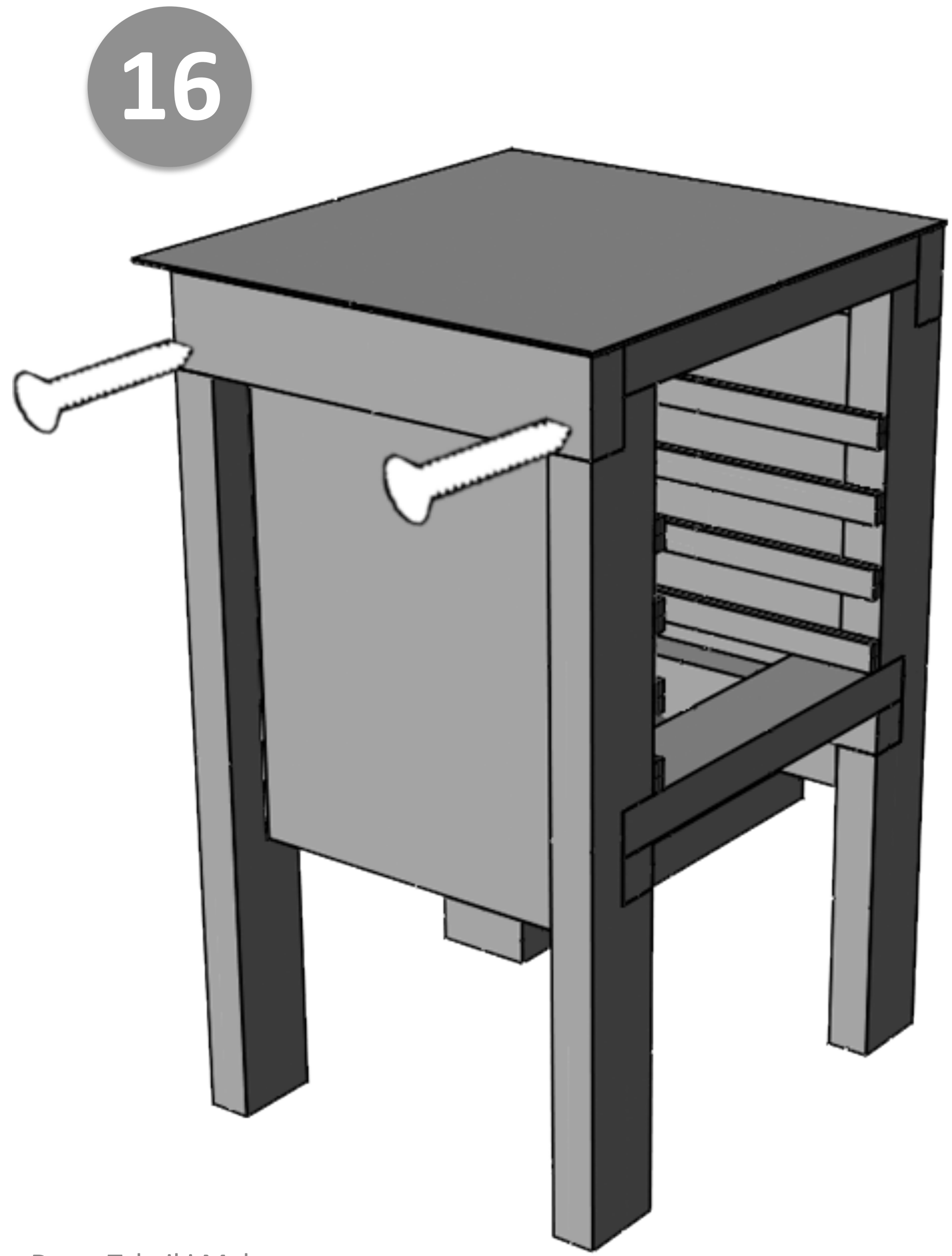
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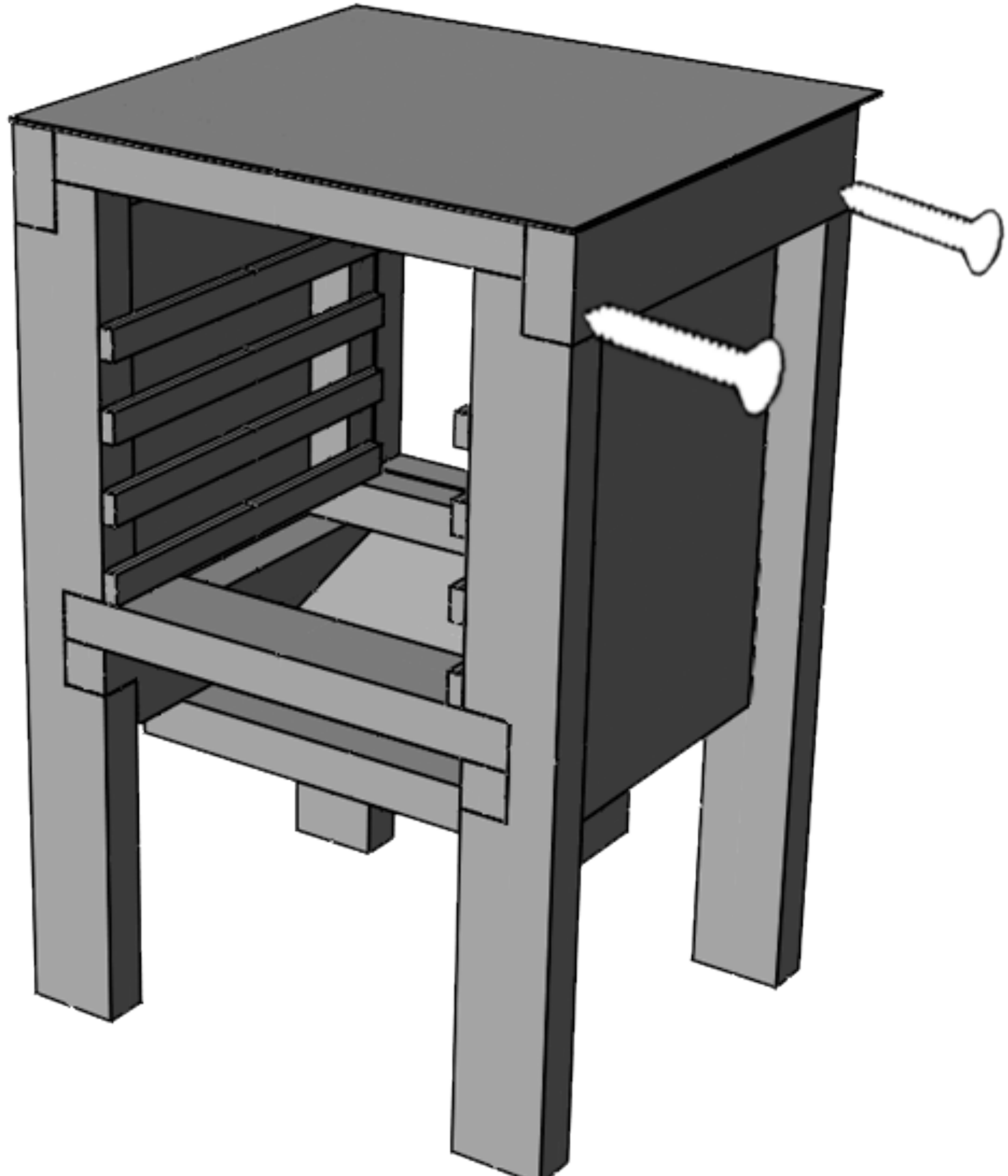

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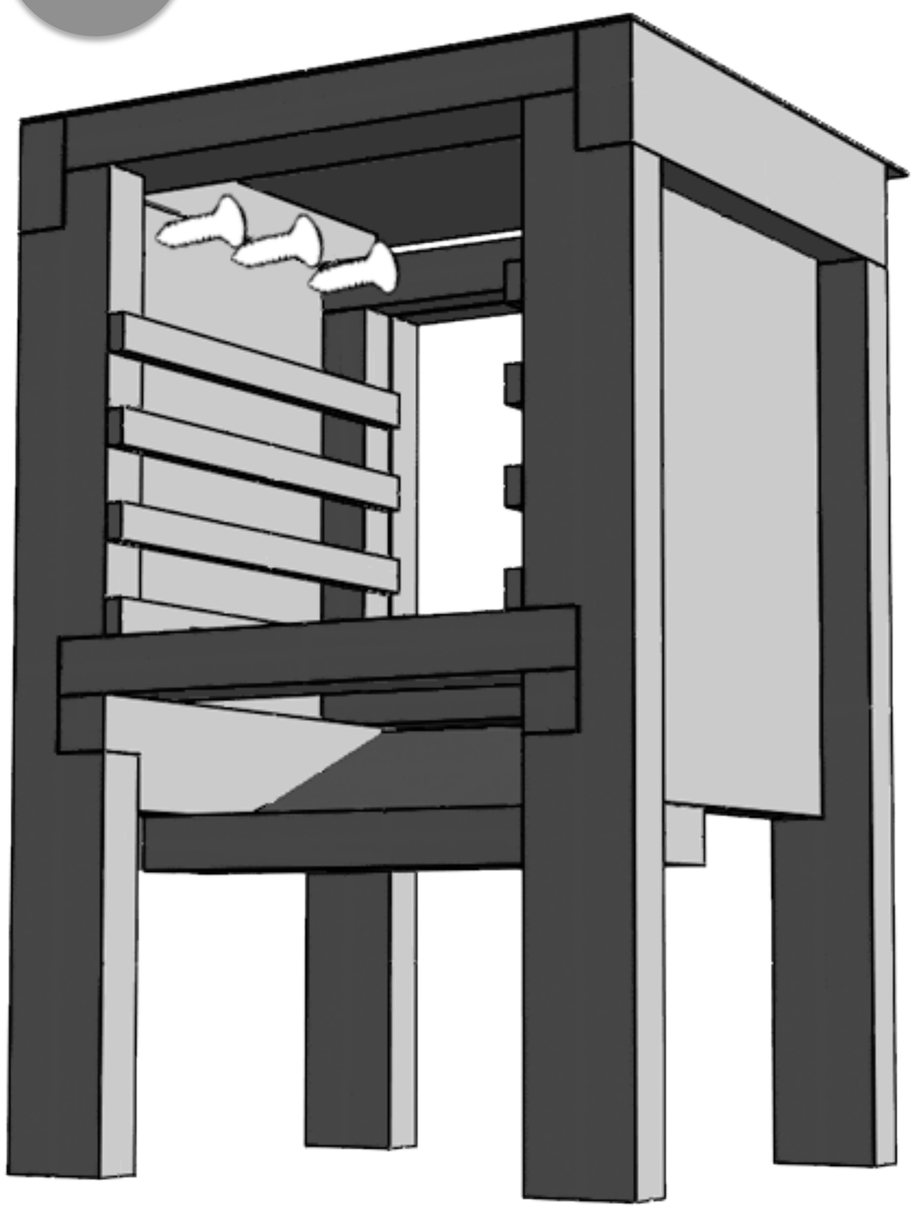

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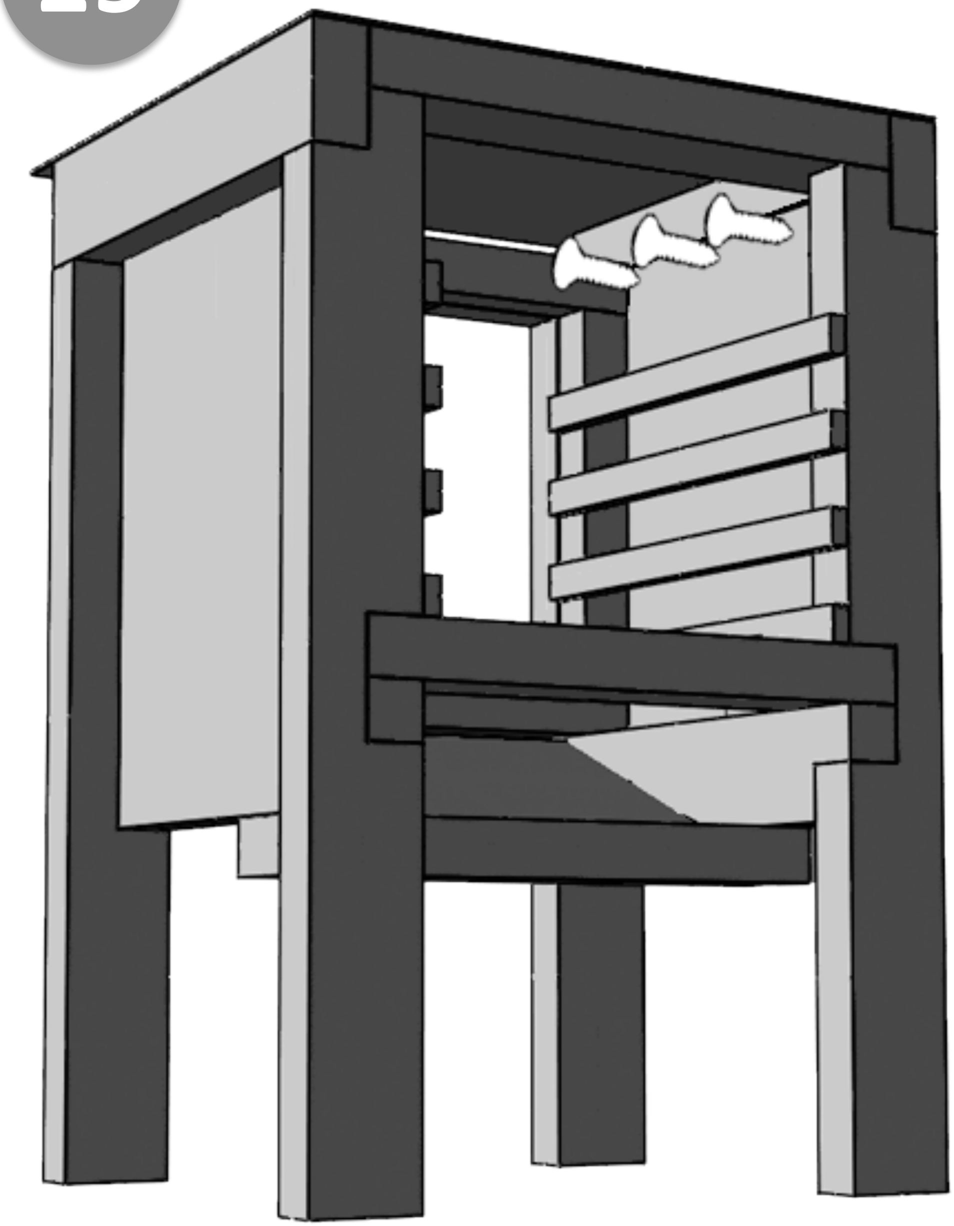

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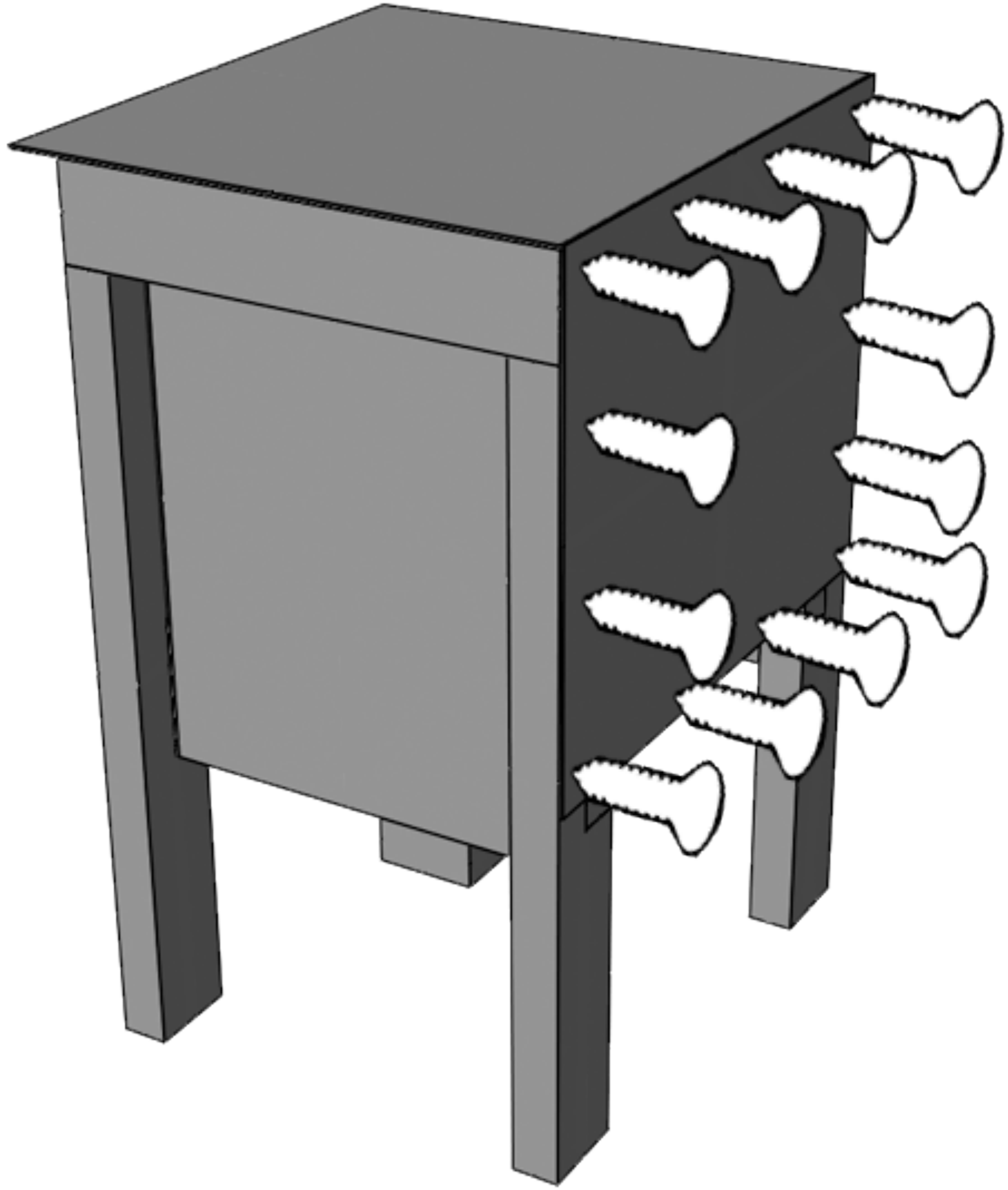

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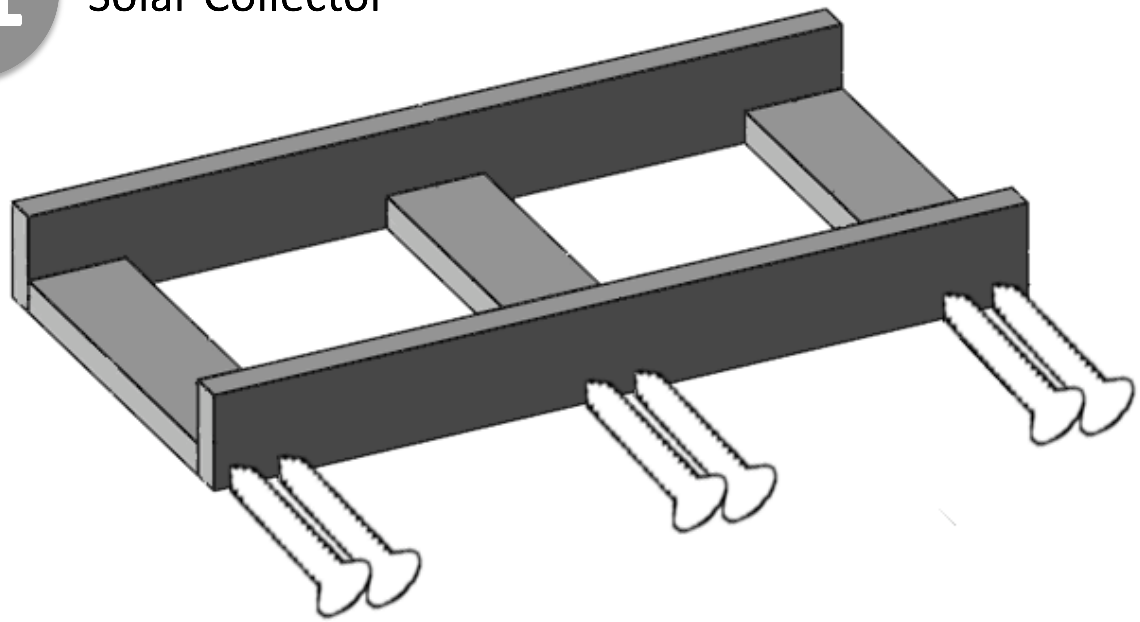

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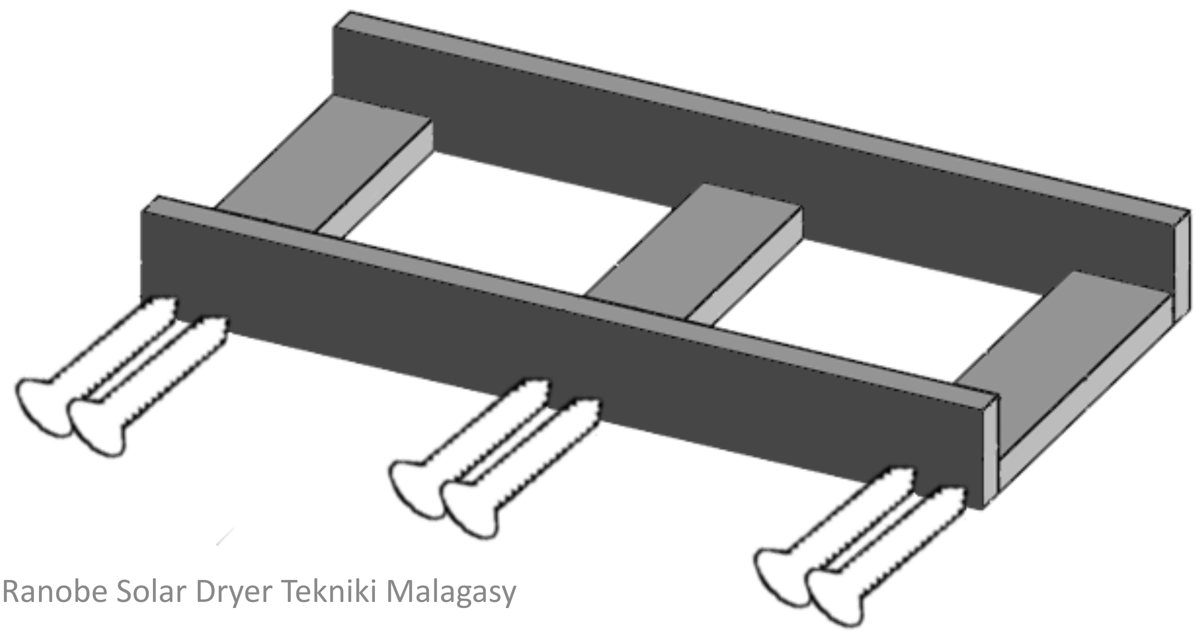

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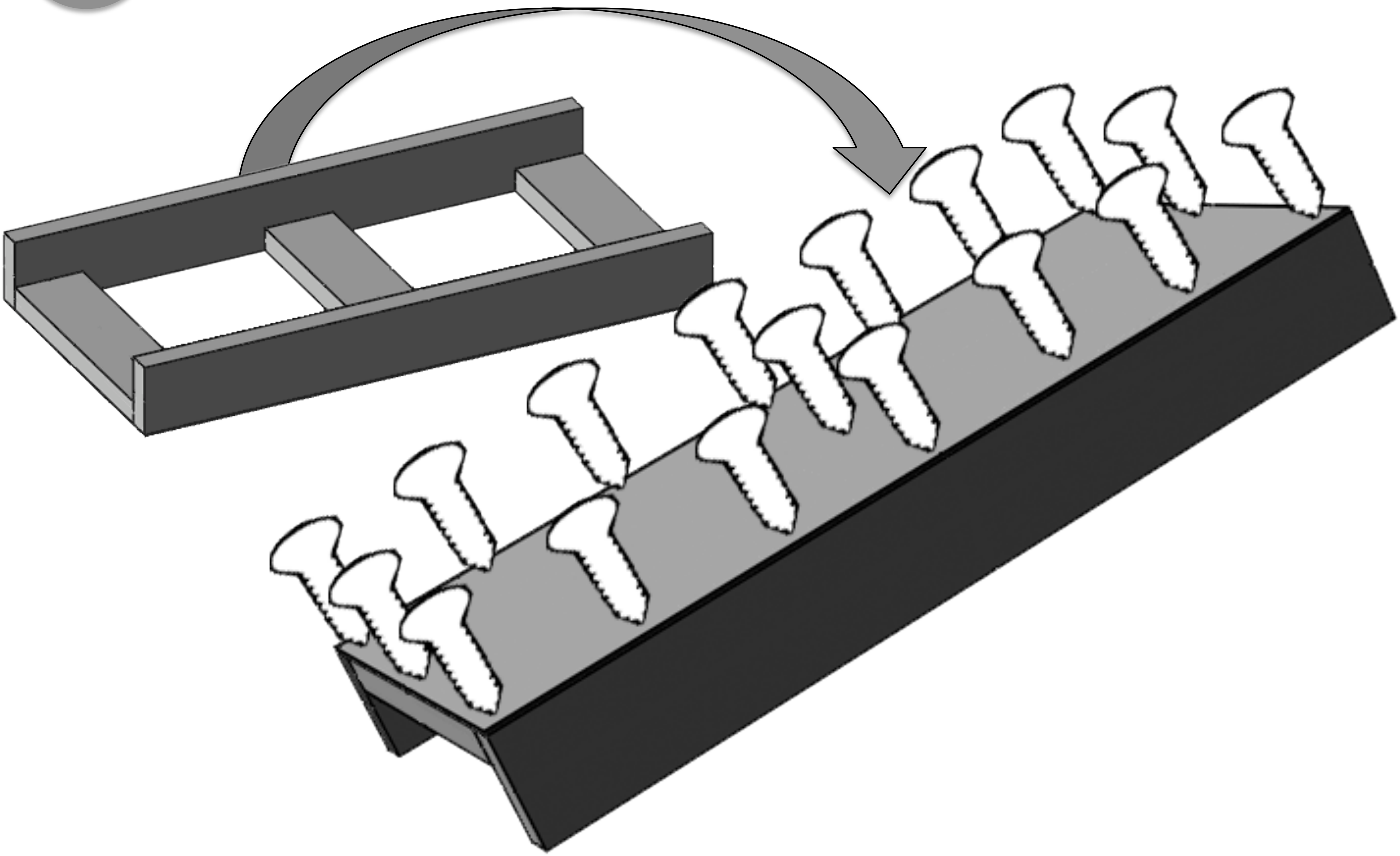

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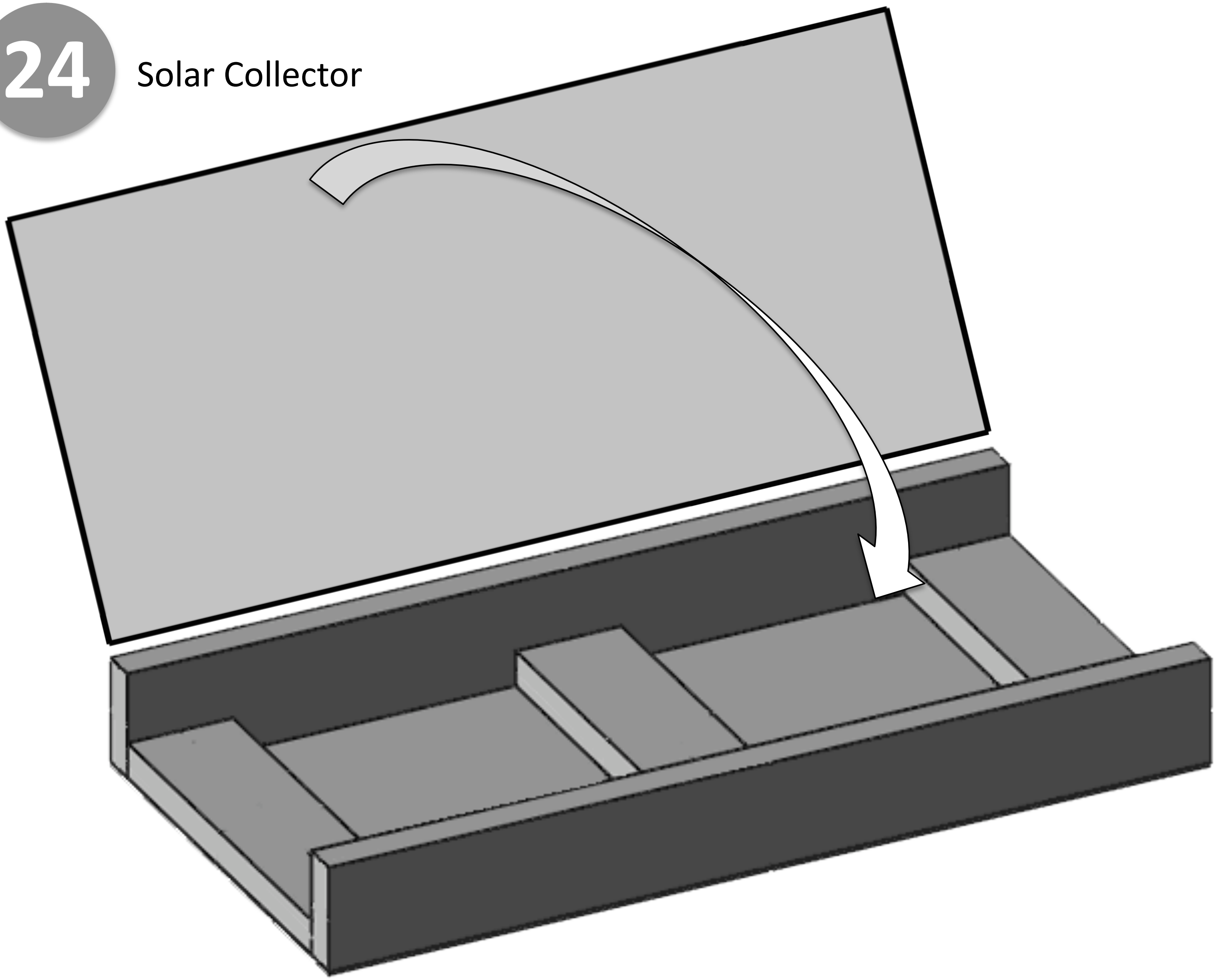

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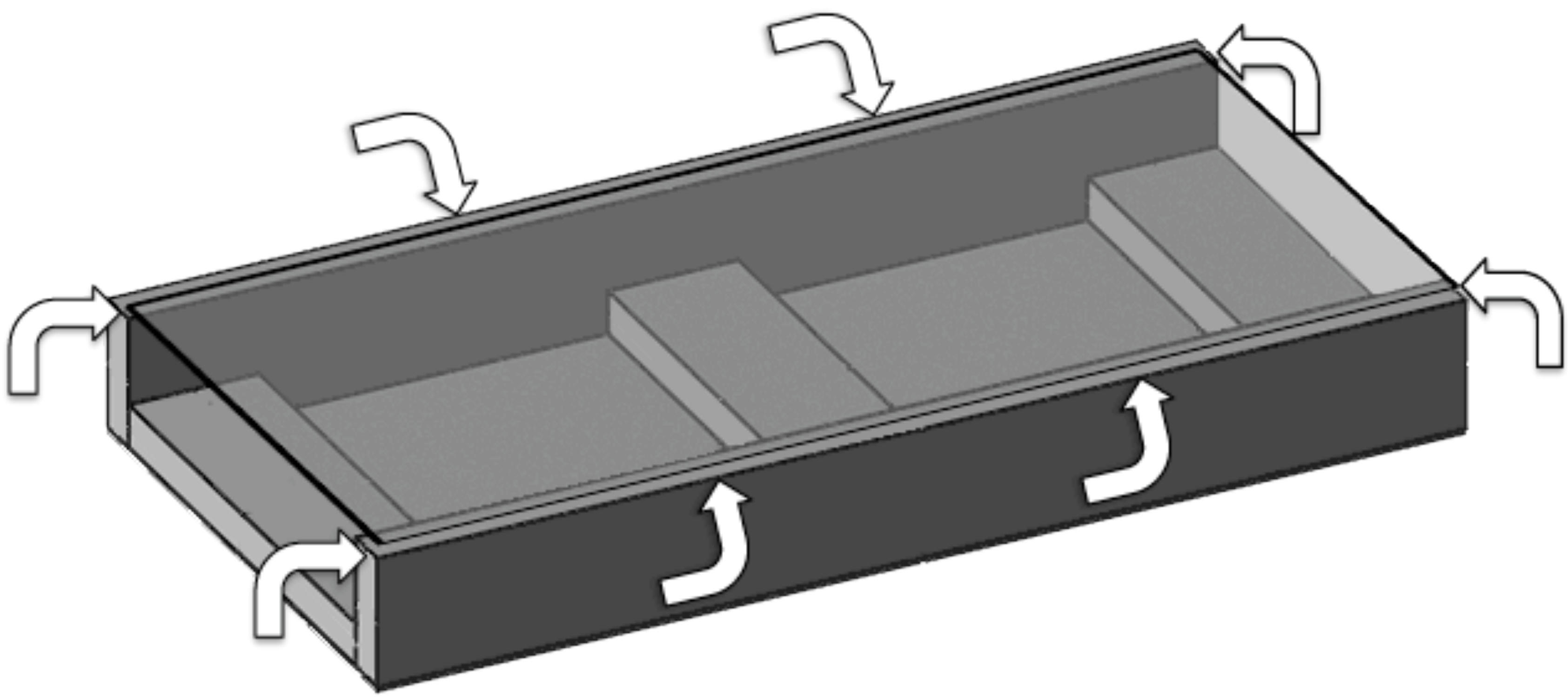

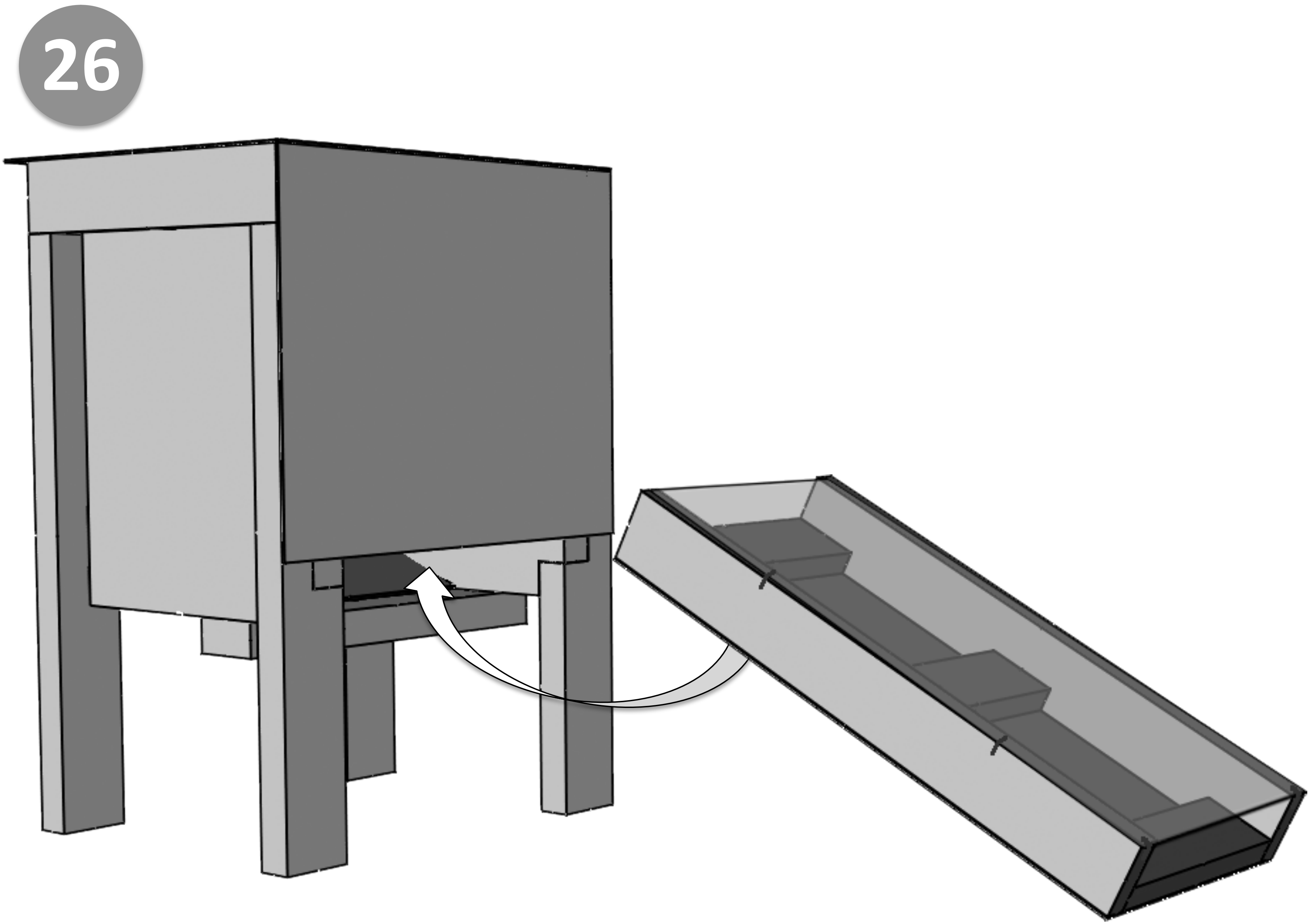
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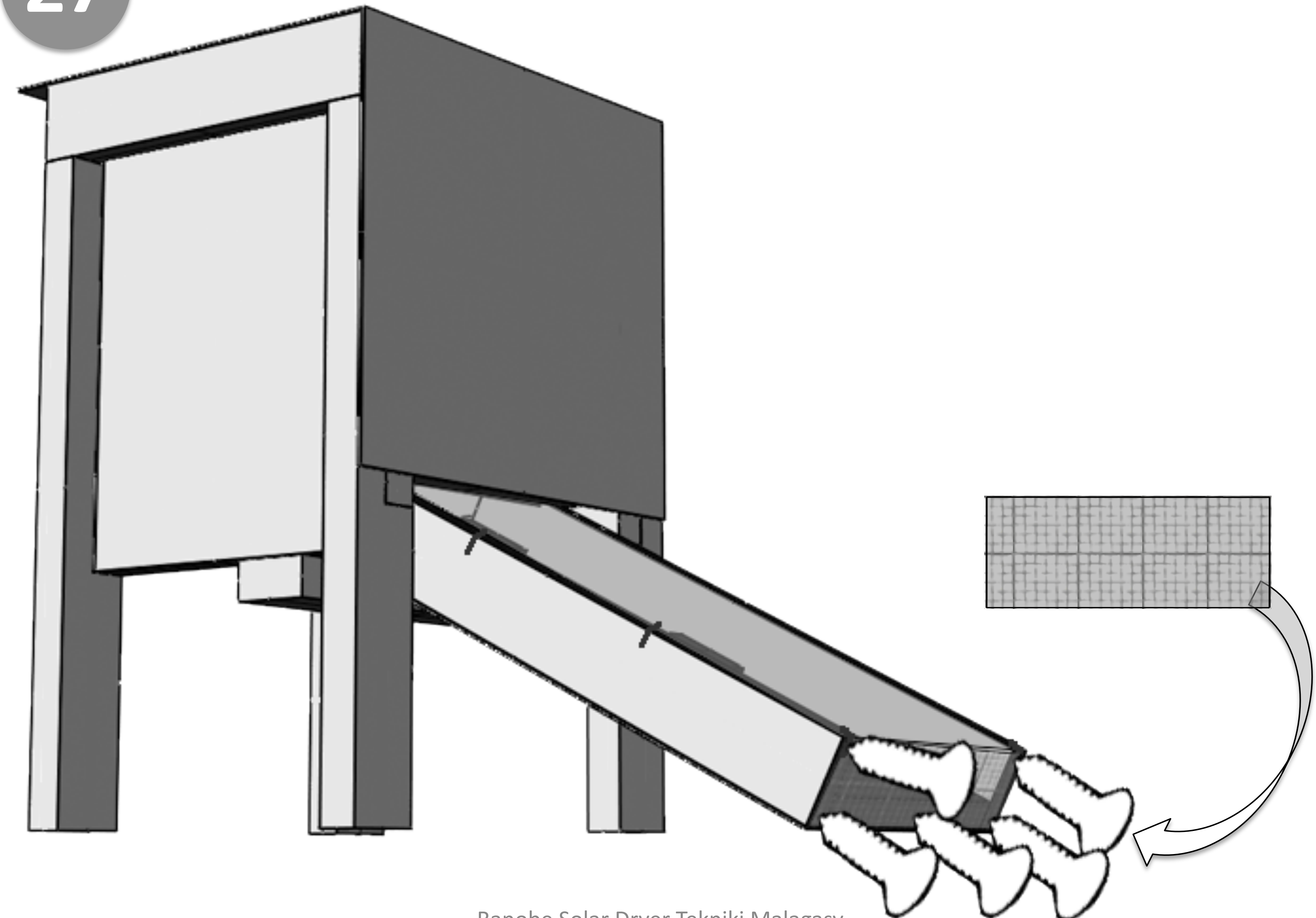

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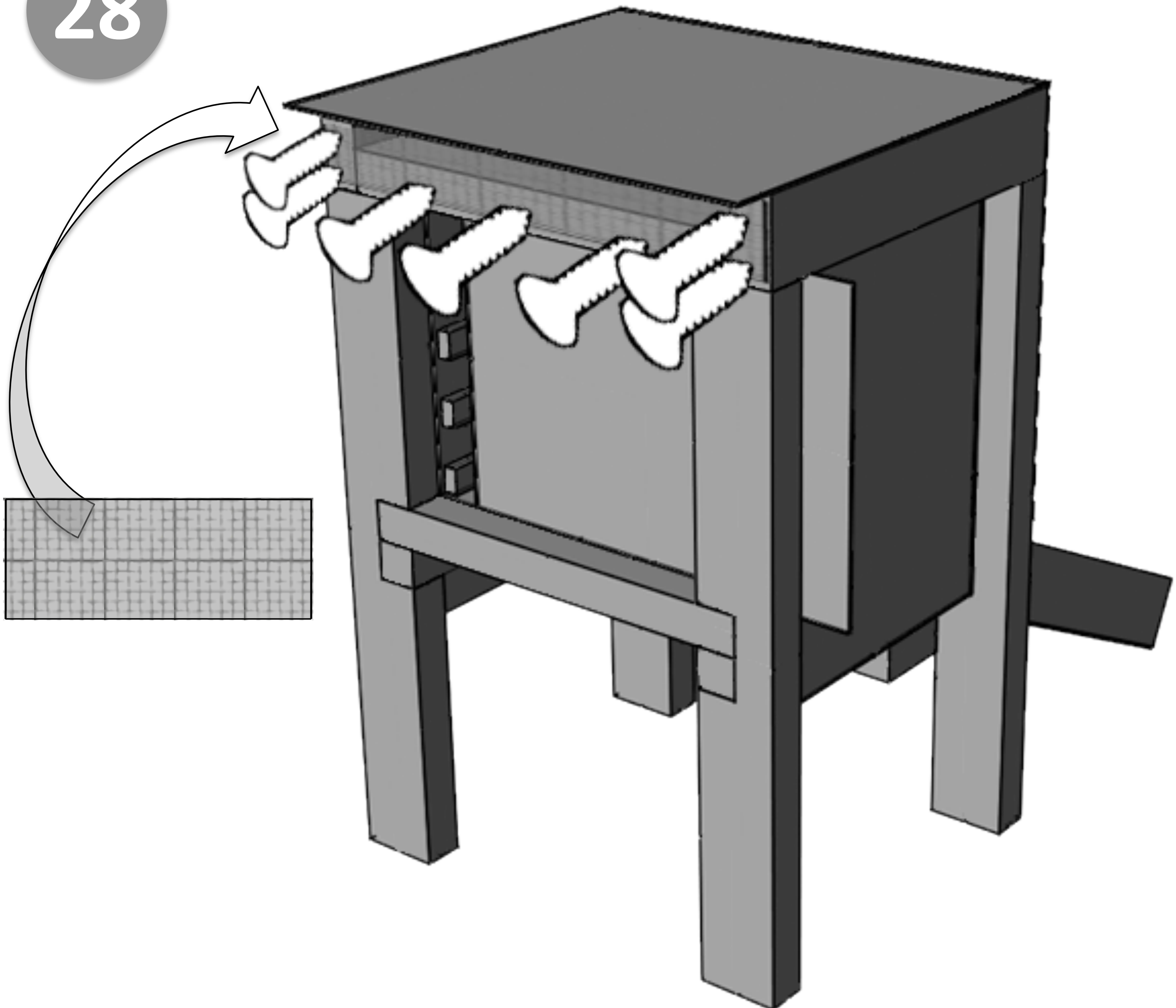
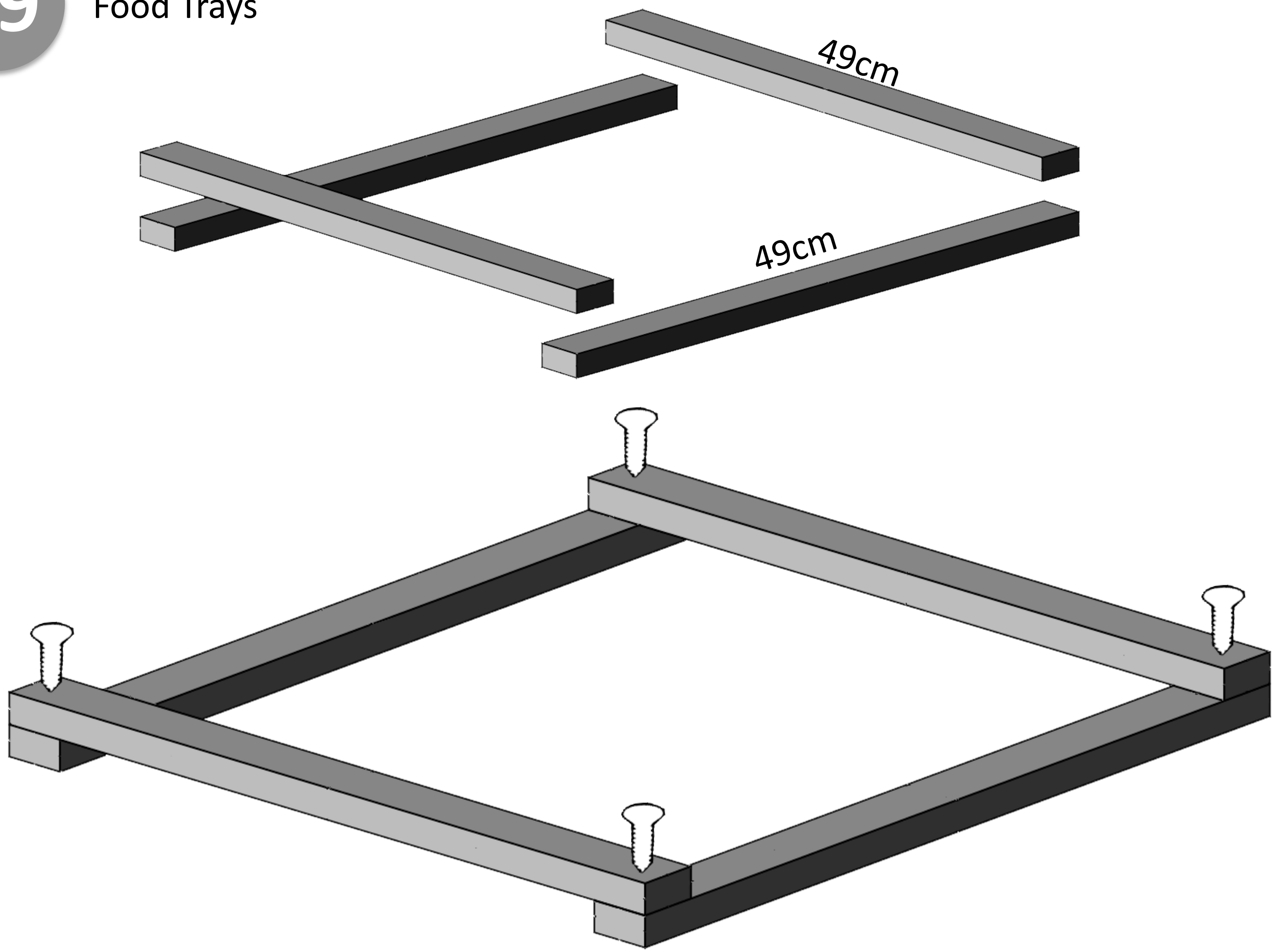
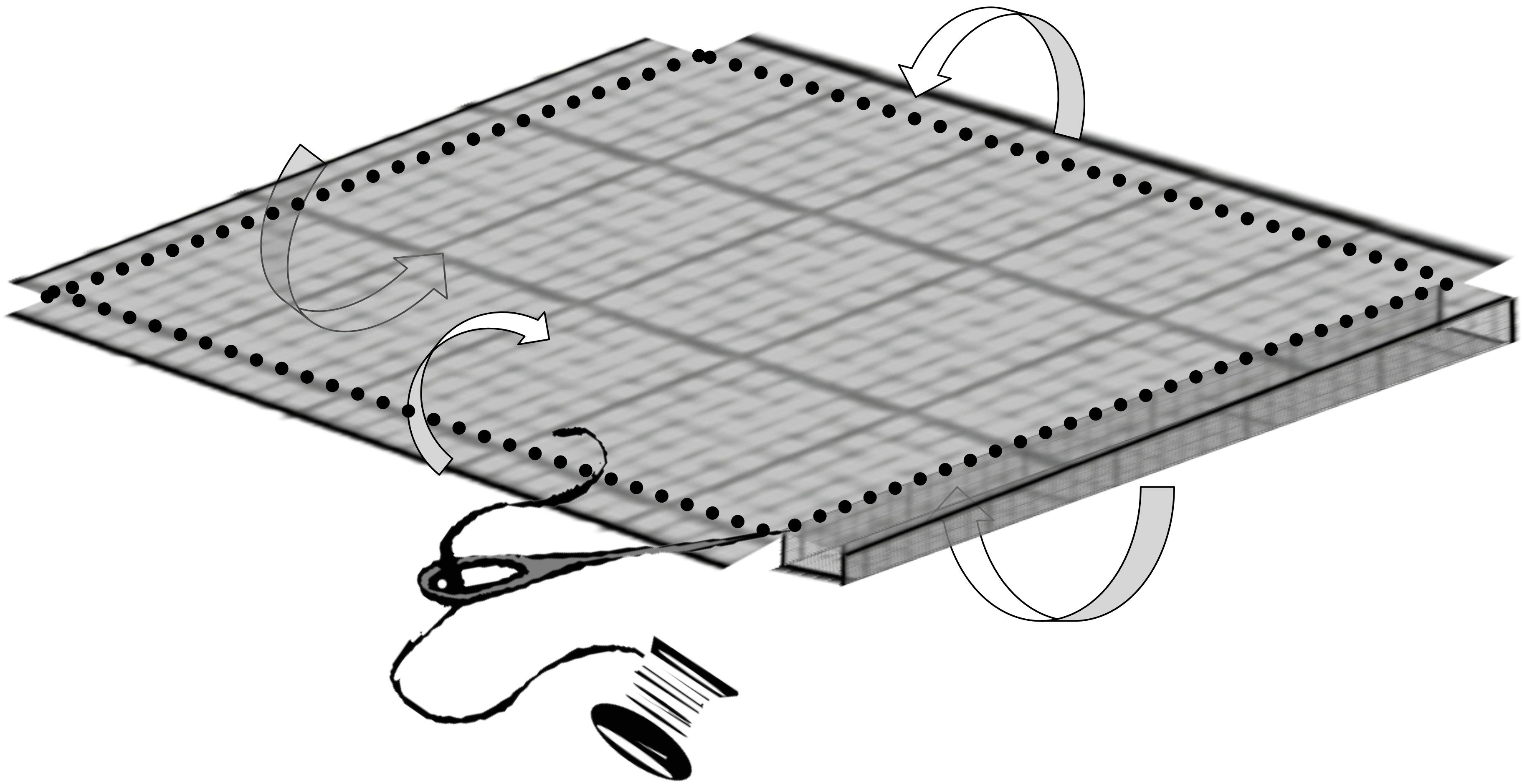


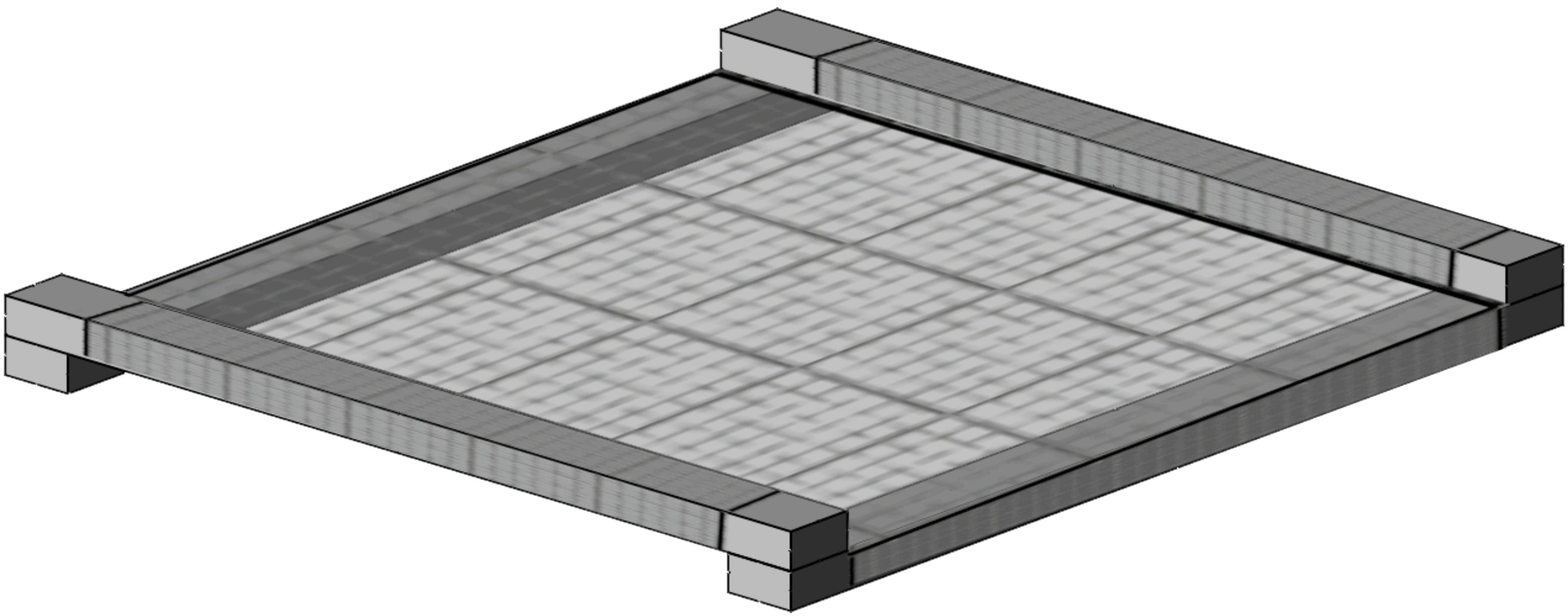
29 Food Trays



30 Food Trays



31 Food Trays



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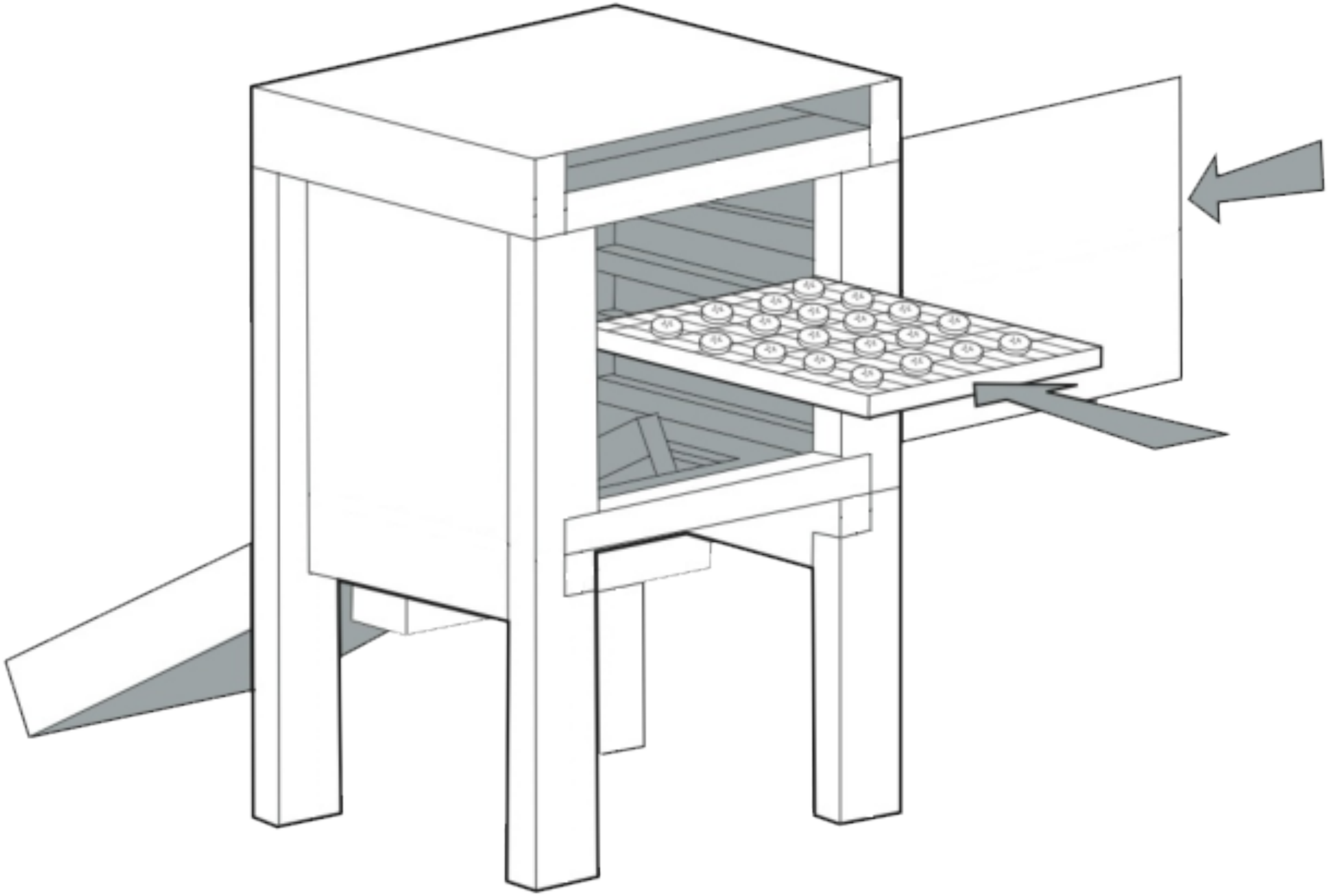

Appendix E:
Solar Oven Sugar Cookies

How to Satisfy Your Sweet Tooth in Madagascar:
A Sugar Cookie Recipe

What You Need:
1 egg
1 cup flour
1 tsp baking soda
pinch salt
3/4 cup sugar
1 tsp vanilla
1/3 cup oil
1 solar oven
a sweet tooth
4 hungry teammates

Baking Time:
09.20-12.00
in sunny, tropical winter weather

What To Do:
To start, preheat your solar oven to as hot a temperature as you can by adjusting the placement of the sun if possible. If the weather is not at your disposal, face your oven cavity toward the sun and use reflective materials to focus light and heat into the oven cavity.

 

Mix all ingredients together and stir into cookie dough using a camping mug as both a liquids and solids measure - being in the field makes these equivalent. Chatting with Malagasy ladies during this process is highly recommended as an inspiration for one or two unexpected and surprising ingredients (particularly if you don't know that they've been tossed in). Finally, pour the resulting batter into muffin tins or cookie sheets, ready for solar oven action!

When baking, try to rotate the solar oven every hour, or convince the local children that it is a game to get as much sun into the oven as possible. Bake until poking a stick in comes out clean.

<u>What Not to Do</u>:
When refilling your flour supply in the dark, try not to confuse flour with baking soda. When unsure, try testing with vinegar before taste-testing, no matter how good of an idea it may seem. You are forewarned!

Baking in cloudy or rainy weather will disappoint, even if you have all day - unless you are looking for PowerBar or half-baked consistencies, in which case such weather is ideal.

Do not expect consistent results. You are certain to get inconsistent ingredients from street vendors at least once a month due to language and gesturing miscommunications.

If you follow these steps, you'll be sure to have a delicious baking extravaganza to share in an amazing country! You might even develop your own endemic solar oven Malagasy recipe.