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Ecological panela production in Honduras: A lighter footprint for non-centrifugal sugar

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Abstract: Panela is a block sugar produced by small low-income farmers around the world. Evaporators used in the process are often inefficient and depend on firewood for fuel, which is costly and contributes to deforestation, This paper reports on the development of an evaporator in Honduras using a flue pan and improved oven that small-scale producers found lowered their fuelwood demand by 82% while reducing production time by 27% per day and 47% per unit of production. The evaporator can be built and maintained locally. Over 174 evaporators have been installed in Honduras since 2003, currently used by more than 2,000 small-scale producers. This study discusses the impact of the new evaporator based on a survey of 64 producers who have used the evaporator. The study found that fuel savings are sufficient to repay the cost of the evaporator, including interest, in 3 months of use. Panela projects using efficient evaporators can lower the environmental impact of small-scale sugarcane processing and increase rural incomes in many countries facing these challenges. Recommendations on how to structure and expand similar block sugar projects to increase sustainability close the paper.

Subjects: Environment & Agriculture; Social Sciences; Development Studies

Keywords: panela; low external input technology; Honduras; rural development; non-centrifugal sugar

ABOUT THE AUTHOR

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He is currently conducting food systems research in the Cusco region in Peru. His work also includes rural development in Vermont, including research with dairy farmers and Latino migrant workers, as well as affordable housing and disaster resilience for low-income communities.

Daniel Baker earned his PhD in Natural Resources from the University of Vermont with a certificate in Ecological Economics. He has received awards for land conservation from the Vermont Land Trust, several teaching awards, and the Vermont Campus Compact's Community Partnership Award. He lives in Starksboro, Vermont where he runs a maple sugaring business with his family and friends.

PUBLIC INTEREST STATEMENT

Small farmers around the world produce a hard brown block sugar known as panela in Latin America and jaggery in India. Traditional production involves inefficient evaporators that consume large amounts of fuel and labor. Many panela producers are poor, small-scale farmers living in regions with significant deforestation and related environmental issues. Addressing the need for improved evaporator technology that reduces environmental impact and increases incomes is an important goal in regions with small-scale sugarcane production. An improved evaporator was introduced in Honduras that can be built with local skills, technology and labor, and that reduces fuelwood demand by 82% while shortening production time by 27% per day. Fuel savings can repay the cost of the evaporator in one season. More than 2,000 producers are using these evaporators in Honduras. This technology can help small sugarcane farmers around the world increase income and reduce the environmental impact of artisan sugar.

1. Introduction

In recent years, Honduras has been rocked by political upheaval, extremely high homicide rates, the increasing influence of narco-trafficking, a coup, and emigration (Freedom House, 2016). Coffee farmers have had to replant crops devastated by coffee rust disease, *la roya,* and contend with a regional drought (Famine Early Warning Systems Network, 2015). Chronic rural poverty has led many to leave the countryside for the city, while at the same time crime and urban violence, exacerbated by limited job prospects, has led many to leave the country in search of better opportunities internationally.

Poverty in Honduras is both “pervasive and severe” (World Bank, 2015). Nationally, more than two-thirds of Hondurans live in poverty, and 42.6% live in extreme poverty, with higher rates in the country’s rural areas (World Bank, 2015). Rural populations in Honduras sustain themselves largely through agriculture (World Bank, 2015). Small-scale producers often depend on low-levels of agricultural technology, farm marginal land, and rely on firewood for fuel contributing to widespread deforestation (Rainforest Alliance, 2014; United States Agency for International Development, 2013). Technologies that increase rural employment through sustainable agriculture and conserve natural resources and reduce carbon emissions through value-added production promote rural development in Honduras and contribute to meeting the UN Sustainable Development Goals (United Nations, 2016).

Panela, a non-centrifugal sugar, is produced by small farmers around the world and offers great opportunities for innovation, yet research and investment in this sector has been lacking (Jaffé, 2014). The technology used to produce *panela* has changed little over generations and inefficient production methods cost *panela* producers substantial investments in firewood, labor costs and time. Traditional production systems also generate impacts that extend far beyond the farmer’s fields and are a concern for local, national and international communities regarding carbon emissions, biodiversity, air and water quality, and rural poverty (Rodriguez, Garcia, Diaz, & Santacoloma, 2007).

This article reports on the results of *panela* technology introduced and disseminated in Honduras that reduces environmental impacts, saves time, and increases incomes of small-scale rural farmers. With roots in North American maple syrup technology, this design was developed and disseminated in Honduras over the past decade. The evaporator can be built locally, is scale-matched to local conditions, and replaces firewood with bagasse fiber generated by the cane crushing operation.

This project was motivated by the hypothesis that accessible improvements in the design and hardware components of the evaporators used in *panela* production can substantially increase efficiency, lower costs, and reduce deforestation by lowering demand for firewood.

Research is based on observations and data from interviews with 64 individual producers at 34 small-scale production facilities *(moliendas)* collected between January 2010 and May 2014. The research analyzes the results of adoption on fuel use and income, and provides recommendations for the sustainable development of this technology.

1.1. Global non-centrifugal sugar production

Sugarcane has been grown in Central America since the earliest colonial times (Melgar, Meneses, Orozco, Pérez, & Espinosa, 2014; Tucker, 2008). With the advent of large-scale production, cane lands most suitable for industrial agriculture were applied to production of refined sugars, while small-scale producers on marginal sites continued to produce sugar in block form for local and regional consumption. *Panela* is a “non-centrifugal” sugar (NCS) that differs significantly from refined sugars in its production characteristics and nutritional value. While refined sugar now occupies a huge share of the market, *panela* can be found throughout Asia, Latin America, Africa, and the Pacific (De Maria, 2013). Known as *panela* or piloncillo in much of Latin America, NCS is referred to as jaggery, gur, rapadura, moscovado, or other local names in other regions (Rodriguez et al., 2007). While India and Colombia dominate global production, among countries producing NCS in 2011, Honduras was the world's 11th largest producer at 37,243 tonnes (Food and Agriculture Organization [FAO], 2016).

In contrast to refined sugar, producers of NCS are small farmers who grow sugarcane on very limited acreage, often on steep hillsides, using inefficient evaporators to produce a block sugar largely sold in local markets (Rodriguez et al., 2007)

Panela is consumed directly, and is also used as an ingredient in food preparation. It has a more pronounced flavor and is a significantly more nutritious food compared to white sugar, providing relatively high levels of minerals and nutrients (Guerra & Mujica, 2010; Pazos, Guzmán, & Bernal, 2004; Rodriguez et al., 2007; Singh, Solomon, & Kumar, 2013).

Despite its benefits, the global market for NCS has been declining, falling from 16% of global sweetener consumption in 1961 to just 3% in 2009 (Jaffé, 2014). In economic terms, *panela* is an "inferior" good with demand falling as income rises. Rodriguez et al. (2007), report income elasticity of demand for *panela* is −0.5, meaning that a 1% increase in consumer income results in a 0.5% decrease in demand for *panela*. Notwithstanding its economic characterization as an inferior good, Latin America has seen a small uptick in production in recent years following good price premiums. Some of this growth in demand is fueled by marketing *panela* as a natural and organic product (International Sugar Organization, 2013).

In *panela*-producing regions, locally owned manufacturers provide important regional employment (Haley, 2013; International Sugar Organization, 2013; Jaffé, 2014). *Panela* is produced by small-scale facilities employing local workers rather than large sugar factories supported by extensive plantations (Jaffé, 2014; Pazos et al., 2004; Rodriguez et al., 2007; Van Zantan, 1999). The majority of workers employed in the *panela* sector are men, but in some countries, such as Guatemala and Brazil, women participate in processing (Rodriguez et al., 2007).

India, where *panela* is known as jaggery, is by far the world's largest producer of NCS, accounting for 64.5% of global production in 2003 and 56.1% in 2011 (FAO, 2016). Arya, Kumar, and Jaiswal (2013) estimates that nearly 50% of the sugarcane grown in India is used to produce jaggery, employing 2.5 million people. Similar to other countries, inefficient production technology in India has led NCS producers to burn rubber tires as fuel (Sharon, 2013). In response, several researchers have looked at alternatives designs, including modifications to the pan (Agalave, 2015) and improvements to the furnace and chimney (Arya et al., 2013).

Colombia, the world's second largest producer, contributed 13.4% of total p*anela* globally in 2003 and 14.1% in 2011 (FAO, 2016). Colombia also has the world's highest per capita consumption and the government provides robust institutional support for improved production (Gilbert & Pinzon, 2014; Rodriguez et al., 2007).

In Colombia, *panela* generates 120,000 permanent jobs and directly or indirectly involves 350,000 individuals throughout the supply chain (Rodriguez et al., 2007). In *panela* producing regions, the industry is a major source of income, supporting more than 70,000 families in the Colombian Andes (Gilbert & Pinzon, 2014; Rodriguez et al., 2007; USDA, Foreign Agricultural Service, 2015). In Guatemala, *panela* is a main source of income for rural families in six rural departments (Rodriguez et al., 2007).

In Latin America, *panela* production is largely based on the use of traditional systems that are time-consuming and require large amounts of fuel (Rodriguez et al., 2007). Inefficient evaporation technology contributes to deforestation and the production of greenhouse gases (García Bernal & van Zanten, 2003; Rodriguez et al., 2007). A study in 1989 found that *panela* producers consumed

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more fuelwood than other small-scale agro-industries (Reiche, Romero, & Navarro, 1989). When firewood becomes scarce, producers in several countries have begun using rubber tires for fuel. Burning tiresresults in the release of numerous carcinogens (U.S. Environmental Protection Agency, 1997) and this practice has been observed in several countries, including Guatemala, Brazil, India, and Honduras (Rodriguez et al., 2007; Shiralkar, Kancharla, Shah, & Mahajani, 2014; Wakefield, 2004).

Despite its regional importance economically and impact environmentally, *panela* has received little government attention in most countries and, in some cases, discrimination in favor of white sugar. In Venezuela, the government intentionally sought to displace *panela* production in favor of white sugar (Ullrich, 1984). Rodriguez et al. (2007) noted that even though *panela* is an important source of income for rural areas in Guatemala, the government provided little to no support to this sector.

A notable exception is Colombia, where the government focused on the development of the *panela* sector as a rural development strategy. The Colombian government and the international agricultural research station, CGIAR, have made *panela* a priority in that country for decades (Borray & Gottret, 2000; Forero & Cortés, 1981). *Panela* production accounted for 5.8% of agricultural GDP in 1992 (Requier-Desjardins, Boucher, & Cerdan, 2003) and 6.7% in 2001 (Rodriguez et al., 2007). Colombian studies include cane production, *panela* production, development of efficient evaporators, testing of those evaporators for air pollution and carbon emissions, as well as studies on the socioeconomic impact of improvements in *panela* technology (Albarracín, Matta, & Gómez, 2004; Ferrucho, Medina, & Jiménez, 2004; Forero, 2004; García, 2004; Montoya, 2004; Pazos et al., 2004). Consequently, *panela* production has evolved at several scales in Colombia and is an important component of regional economies (Rodriguez et al., 2007).

In Honduras, deforestation is a major concern. The country's average annual deforestation rate of 2.5% was among the highest in Latin America between 1990 and 2005, and led to a 37% reduction in forest cover during that period (Rainforest Alliance, 2014; World Bank, 2009). Fuelwood supplies more than 40% of the national energy, and wood provides 86% of residential energy (Flores, Ojeda, Flores, & Rivas, 2011). *Panela* producers, who are largely small-scale and traditional, depend on fuelwood for production, contributing to deforestation. Despite being ranked 11th internationally in production (Rodriguez et al., 2007), until 2004 there was no significant government investment in the sector. However, in 2004, the Honduras government, supported by international agencies and non-governmental organizations, funded a pair of *panela* projects to train and disseminate new evaporator technology introduced by the author. Several variations on the flue pan-type evaporator designs were investigated. This paper reports on the design that has been the most successful and is currently in widest use.

The central objectives of the Ecological Evaporator are to evaporate cane juice using only bagasse as fuel, and to do so at a production level and cost that provide substantial net benefits for both producers and workers. The evaporator was designed with the intention to be an "appropriate technology" that is "consistent with the cultural, social, economic and political institutions of the society in which it is used" (Hazeltine & Bull, 2003), and a Low External Input Technology (LEIT) (Tripp, 2005).

This paper reports on the progress of the new evaporator design. The paper concludes with recommendations for how projects are structured, with particular regard to funding that has profound impact on self-reliance and thus the sustainability and diffusion of this technology.

1.2. Project background

The Ecological Sugar Project began in 2000 with the aim of developing a more efficient evaporator system for small-scale sugarcane farmers. It was initiated by the author with funding from the US NGO Partners of the Americas and developed in partnership with a sugarcane producers cooperative in the department of Comayagua. Producers in that region had received technical assistance in the past, during which time they adopted the practice of substituting scarce firewood with used rubber tires. One sugarcane processing facility could burn up to 2,721 kg of tires per week (Baker, 2007). Other technologies transferred into this region were less environmentally damaging, and included the use of grates in the evaporator fireboxes and pre-filters for the cane juice. In 2000, however, producers were still using flat pan evaporators and short chimneys, and the author introduced the concept of a flue pan evaporator, used in maple-syrup producing regions in the United States and Canada for more than 100 years (Lawrence, Martin, & Boisvert, 1993). Over the course of several years, the author worked with the cooperative to redesign the flue pan so that it could be built locally, utilizing available technology and skills, and worked well with cane juice, which has a higher concentration of sugar compared to maple sap (Baker, 2006; United States Agency for International Development, 2013; Wakefield, 2004).

In 2004, with funding from the Partners of the Americas, the Honduras Ministry of Agriculture, and support from the University of Vermont, a training program was developed to demonstrate the technology. More than 200 farmers attended workshops over a two-year period, including producers from six Honduran departments, with the majority from the western region of Honduras.

During recruitment for the training program, it became clear that producers in the central department of Comayagua were atypical of *panela* producers nationally in that their land holdings, scale of production, and employment characteristics were significantly larger and more technically advanced than other *panela* producing regions in Honduras. In the other five departments sending producers to the training program, average producers had much smaller landholdings, often with too little production to support an individual *molienda.* In these areas, *moliendas* are often shared with other producers, and require less hired labor. The cane crushing *trapiche* is ox-powered and traditional evaporators have sheet metal bottom wooden pans, no grates and often horizontal-draft chimneys (Baker, 2007).

The finding that the majority of *panela* producers in Honduras were at a significantly smaller-scale of production compared to those in Comayagua led to a refinement of the evaporator design suited to this level of production. This smaller Ecological Evaporator design was more widely adopted between the two size options and is the subject of the research reported here.

Although the initial focus of the technology transfer was the flue pan, the very simple traditional evaporator systems required modifications in addition to the pans themselves. This led to a package of changes to evaporator systems in western Honduras, including building a firebox, adding grates, and building in a short vertical chimney. It is this group of changes that make up the technology transfer referred to as the “Ecological Evaporator” in this paper.

1.3. Overview of the production process

Panela is made from evaporated sugarcane juice. Sugarcane is harvested by hand from fields planted to the perennial crop. In contrast to the large sugarcane plantations that produce refined white sugar on large, flat fields, *panela* in Honduras is often grown on steep hillsides.

After cutting the cane and trimming leaves, it is generally transported by draft animals and either brought directly to the *molienda* or loaded onto trucks. At the *molienda,* the cane is crushed by a *trapiche*. Traditionally, these were powered by teams of oxen or occasionally horses. Larger *moliendas* in Comayagua have *trapiches* powered by diesel engines that require larger volumes of cane to be economically viable. Most *panela* producers in Honduras are at smaller scale and rely on traditional, animal-powered *trapiches*.

After crushing, the juice is generally boiled the same day. Few small producers use a pre-filter, even though these are low-cost and can improve quality of the final product. Juice is moved to the pans by bucket or pipeline for evaporation. The cane fiber by-product, bagasse, accounts for about half the output by weight (Rodriguez et al., 2007).

Traditional evaporators are fueled with firewood, or, in the case of some larger producers, tires. Bagasse is generally considered inferior to firewood as a fuel and is often simply discarded. Producers who use bagasse as fuel dry the material in the sun, then bundle and load it into the evaporator. Larger producers have a roofed area (*bagassera)* to store bagasse, while most smaller producers dry the bagasse and use it the same day or the following day. For producers using the Ecological Evaporator, adopting bagasse as primary fuel is a core objective of the project.

Fuel is loaded into the firebox, and the juice is boiled down. In traditional systems still commonly in use among small *panela* producers, evaporators consist of a single pan with angled sides made of wood and a steel sheet bottom. Ovens for traditional producers frequently have no fire grates or chimneys.

Hot liquid syrup is drawn off by a scoop in traditional systems and emptied into a wooden box, where it is paddled to cool before transferring into molds. Many small producers in Honduras still use solid logs chiseled out to produce lines of cone-shaped holes for their molds. The sugar cools and hardens in these molds. Packaging for home and local consumption is often done with corn leaves and sold in pairs of blocks called *atados*. Larger volumes are sold in 200 lb (90.72 kg) units called cargas, wrapped in grain sacks and tied with string. Waste ash is rarely used and often dumped close to the *molienda* (Figure 1).

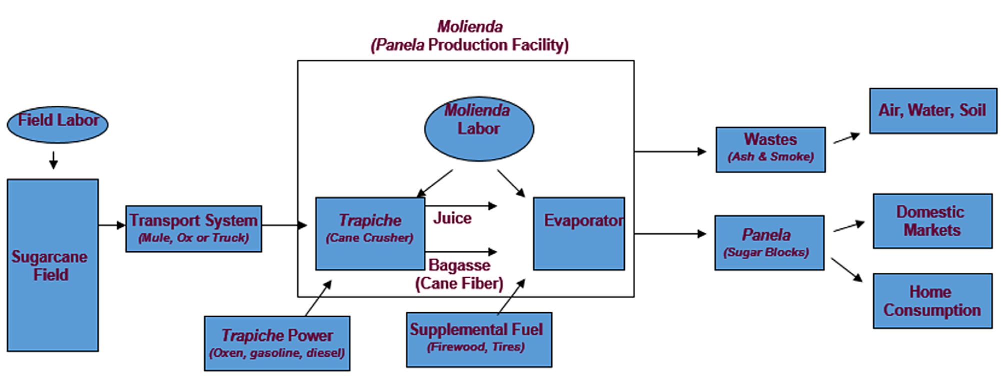
1.4. Description of the Ecological Evaporator

The Ecological Evaporator consists of a firebox with grates, a set of evaporator pans, and a chimney. The pair of pans consists of a front pan with 15.2 cm × 5.1 cm (6 in × 2 in) channels and a flat back pan. The channeled front pan, known as a flue pan, increases the surface area of the pan, increasing the heated surface area. These channels contain sugarcane juice, rather than being welded to the bottom of the pan as described in the improved jaggery evaporators described by Agalave (2015). The flue pan is directly over the fire, while the lower temperature under the flat back pan allows the denser syrup to be evaporated without burning. Juice enters the front flue pan by bucket or pipeline from the *trapiche*, and is moved to the back pan by scoops made of metal, plastic or gourds.

The oven consists of a firebox with grates and an ash pit. Steel grates are expensive and rarely used by producers in the Lempira region. The Ecological Evaporator uses locally made bricks or shaped stone for grates. Chimneys are built up out of adobe and brick.

Differences between the Ecological Evaporator and traditional evaporators include all-steel flue and finishing pans, the use of an elevated fire on grates, and a taller, vertical chimney.

Figure 1. *Molienda* processing system.



1.5. Study region
Among the 174 Ecological Evaporators put into production, more than half (54%) were installed in the department of Lempira in western Honduras in the area surrounding Celaque, the tallest mountain in Honduras. Small-scale farmers have grown sugarcane in this region for almost 300 years, since at least 1725 (Tucker, 2008). Most farmers in this region rely on coffee, maize, and beans for their livelihood and *panela* is the second largest agroindustrial, income-generating crop in the region (Development Associates International, 2016).

The department of Lempira is the most rural region in Honduras, with 91% of its 321,179 population classified as "rural" in 2013. The majority of its economically active population (82%) is employed in agriculture. It is also one of the poorest regions in Honduras, second only to Gracias Adios in terms of the share of its population (74.3%) unable to meet basic needs. Similarly, it ranks second from the bottom in terms of the percentage of its population with access to computers or cell phones (Instituto Nacional de Estadística Honduras, 2013).

2. Methods
Data for this research is from several sources. Key informant interviews were used to build a database of the total number of Ecological Evaporators in use. Data on the national distribution of these evaporators and estimates of producers using the evaporators are drawn from databases from all projects the author has tracked since 2005. These include projects the author was directly involved with or learned about through collaborations with other consultants, fabricators, agencies and producers.

The survey was conducted in the department of Lempira in western Honduras, where more than half of evaporators are in use, and forms the core data-set for this study. Producers were identified from records maintained by the author of evaporators installed following introduction of the Ecological Evaporators in 2004/2005. Producers that were located and that were willing to be interviewed were surveyed. Sixty-four individual producers at 34 *moliendas* in the department of Lempira, Honduras, were surveyed between January 2010 and May 2014 at their *moliendas* or homes by one of four interviewers, including two Hondurans and two bilingual American research staff.

Producers were asked about their experiences with the new evaporator in either an initial survey or during a follow-up, depending on when the initial survey was administered relative to the time of adoption. Three responses fell well outside the range of other respondents (e.g. >3 SD). These outliers appeared to be in error and were removed from the analysis.

Survey instruments were reviewed and approved by the University of Vermont Institutional Review Board. The data was entered and analyzed using SPSS Version 22.

2.1. A note on terminology and measurement
Units of measurement common in Honduras combine imperial units of measurement and units of measurement that are uniquely Honduran. Measurements common to coffee production, such as the quintale, are also frequently used by producers. Metric units are infrequently employed. In reporting results, the unit in local use is reported, and converted to S.I. units as appropriate.

Production data in this paper was reported by producers using local units. While these units have defined, quantitative standards, in practice they are estimated by producers rather than measured precisely.

Units used in this paper and their conversion into the imperial or metric units with which they're most commonly associated is summarized in Table 1. However, in most cases, converting local units into S.I. implies a level of precision beyond what most respondents were able to measure.

Table 1. Local units of measurement and S.I. conversions

Local unit	Imperial and S.I. unit conversion
Carga panela	200 lbs (2 quintales) = 90.72 kg
Carga firewood	200 lbs, 40 thick/50 thin sticks = 90.72 kg
Tarea	1/16th manzana = 437.5 m^2/0.04375 ha
Manzana	7,000 m^2/0.7 ha

The carga is a commonly used measurement, and while it is defined as equal to 200 lbs (90.72 kg), producers typically measure cargas in sticks of wood. Block sugar is sold in *atados*, each of which is made up of two *panelas*. In western Honduras, most *panela* blocks are in the shape of cones, and most of the molds are chiseled out of single slabs of wood.

The proper noun "*trapiche*" refers to the *panela* processing facility in Colombia. However, in Honduras, *trapiches* are cane-crushing machines and "*moliendas*" refer to the production facility as a whole.

3. Results

Between 2003 and 2015, 174 *moliendas* are known to have adopted the Ecological Evaporator in six departments with support from at least 16 NGO, national and international aid agencies, as well as private investment. Based on data collected from 100 producer surveys in six Honduras departments, there is an estimated minimum of 2,008 producers who have used the new evaporator. As of 2015, more than half (54%) were installed in the department of Lempira in western Honduras.

Results from Lempira are presented in two sections. The first describes the demographics and scale of production among this group of cane producers in western Honduras. The second half describes the new evaporator and its impacts on fuel use, sugar production and time.

3.1. Demographics

Panela production in Honduras primarily involves men and this was reflected in the survey, as there were 51 male producers found using the evaporators and only one female. Women and children are often around the *molienda* during production, and young boys frequently work carrying bagasse. Cane cutting, transport, crushing, and then boiling and making the blocks is almost universally done by men. The age of respondents ranged from 27 to 79, with a mean age of 48 years and a median of 49 years old (n = 45). Education levels were low, with 8% reporting that they had no schooling, and over half (52%) only partially completing primary school. An additional 32% completed primary school and only 8% had any secondary school (n = 50).

Household size ranged from two to 13 people, with a median household size of six (n = 46). Eighty-eight per cent of households had annual incomes of HNL40,000 or less (n = 44). During the survey period, the exchange rate was a mean of HNL19:US$1 (OANDA Corporation, 2016), so most households surveyed earned less than US$2,105 per year, or an average household income of less than US$351 per person/year (Table 2).

The majority of producers (80%, n = 51) market at least some of their *panela*, with 73% selling half or more. The majority of producers (76.1%, n = 42) also sell their *panela* directly, either locally or in a

Table 2. Age and household size demographics of adopters

Variable	Mean	Median	SD	*n*
Age	48.2	49	13.146	45
Household size	6.2	6.0	2.467	46

Note: SD is the standard deviation.

large town in the region. Only 9.5% market through their producers' group and only a small number (7.1%) sell to intermediaries. Prices range from HNL800 to a high of HNL2,400 per carga (US$0.46/kg to US$1.39/kg). The median price reported was HNL1,600/carga, equivalent to US$0.93/kg.

3.2. Scale of production

All respondents except one owned land planted to sugarcane. Producers using the new evaporator are smallholders with a median of 4.0 *tareas* (0.175 ha) from which they are able to obtain a median of 1.07 cargas/*tarea*, or 2,218.725 kg ha^{-1}, yielding a total of 388.277 kg of *panela*. The amount of land planted to cane ranged widely, from one producer who rented all his cane land, to three who reported owning 16 *tareas*, equal to a *manzana,* or about 0.7 hectares (Table 3).

3.3. Production facilities

In western Honduras, *moliendas* are simple constructions using wood poles, tin, adobe, brick and wood. They generally consist of a roofed area, the oven and pan, a wooden canoe for cooling, and molds. Relatively few producers own a cane-crushing machine, known locally as a *trapiche*. Only 18.9% (n = 54) own their own *trapiche* and more than half, 51.9%, rent it from another producer or share it with other producers (27.8%). All except two producers (n = 60) used ox-powered *trapiches* at the time of the initial survey.

More than half the producers interviewed (52.3%) either owned their own *molienda* or shared it with family. The remainder either shared a *molienda* as part of a producers group (18.2%) or rented from another producer (9.1%, n = 44). Most producers (92.3%, n = 52) reported belonging to a producers group with a median size of 12.8 active members (SD = 5.478, n = 47).

Panela production is labor intensive and each *molienda* employs a mean of 6.3 people when in production (SD = 2.293, n = 51).

3.4. Impact of Ecological Evaporator on fuel and production

The major improvements of the new evaporator are greater fuel efficiency, enabling replacement of firewood with bagasse, and reductions in production time. Increases in the quantity of *panela* were also reported. Fuelwood use declined following adoption from an average of 7.1 cargas per day to 1.29 cargas per day, a decrease of 82%. *Panela* production was reported to increase by 45%, from a mean of 1.37 cargas (124.286 kg) per day to 1.98 cargas (179.626 kg) per day.

Table 3. Cane land and yields

Variable	Mean	Median	SD	*n*
Cane land				
(tareas)	6.26	4.00	4.214	45
(ha)	0.274	0.175	0.184	
Yield from cane land				
(cargas/tarea)	1.39	1.07	0.933	36
(kg ha^{-1})	2,882.304	2,218.725	1,934.669	
Traditional evaporator: total annual production				
(cargas)	17.60	14.00	12.540	34
(kg)	1,596.672	1,270.080	1,137.629	
Ecological Evaporator: total annual production				
(cargas)	23.90	15.80	19.340	34
(kg)	2,168.208	1,433.376	1,754.525	

Note: SD is the standard deviation.

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Using these statistics to calculate fuel use per carga of *panela* standardizes the change in fuel use across production levels. Using this measure, the quantity of firewood required to produce a carga of *panela* decreased by 85% (n = 33). The results of paired sample t-tests are presented in Tables 4 and 5. Not all producers answered all pre-post questions. Forty-five producers responded pre-post to firewood use and 42 responded pre-post for total production, while only 33 answered pre-post to both questions such that the ratio of firewood use to production could be calculated. The analysis found that firewood use per day, production per day, and firewood per carga of *panela* were all significantly different following adoption.

Table 4. Mean and standard deviation (SD) of production and fuel use of traditional evaporators compared to Ecological Evaporators (paired samples *t*-test, pre-post)

Variable	Mean	SD	*n*	Sig. (2-tailed)[a]
Firewood/day				0.000
Traditional evaporator (Pre)				
(cargas)	7.10	2.123	45	
(kg)	644.112	192.599		
Ecological Evaporator (Post)				
(cargas)	1.29	1.103	45	
(kg)	117.029	100.064		
Total panela production/day				0.000
Traditional evaporator (Pre)				
(cargas)	1.37	0.458	42	
(kg)	124.286	41.550		
Ecological Evaporator (Post)				
(cargas)	1.98	0.882	42	
(kg)	179.626	80.015		
Cargas firewood/cargas panela[b]				0.000
Traditional evaporator (Pre)	5.77	2.953	33	
Ecological Evaporator (Post)	0.84	0.665	33	

[a]$p < 0.01$.

[b]Ratio of firewood/panela in cargas is identical to ratio when converted to kg.

Table 5. Mean and standard deviation (SD) of production time of traditional evaporators compared to Ecological Evaporators (paired samples *t*-test, pre-post)

Variable	Mean	SD	*n*	Sig. (2-tailed)[a]
Total production hours/day				0.000
Traditional evaporator (Pre)	15.76	2.739	42	
Ecological Evaporator (Post)	11.53	2.638	42	
Panela production hours/carga				0.000
Traditional evaporator (Pre)				
(hours/carga)	12.65	5.642	40	
(hours/kg)	0.139	0.062		
Ecological Evaporator (Post)				
(hours/carga)	6.71	2.950	40	
(hours/kg)	0.074	0.033		

[a]$p < 0.01$.

Firewood was replaced by the bagasse waste product following adoption. The quantity of bagasse available did not appear to be a limiting factor following adoption, with 54.9% of producers using all the bagasse they had to boil their cane juice and 37.3% reporting that they had surplus bagasse ($n = 48$).

3.5. Production time and employment impacts

In concert with the shift from wood fuel to bagasse was an average 27% decrease in the amount of time spent to complete a day's production. Prior to adoption, an average day's production required 15.76 h, decreasing to 11.53 h following adoption of the new evaporator. Standardizing for production and calculating hours/carga of *panela* showed an average reduction of 47% ($n = 40$) following adoption.

An interesting aspect of the reduction in production time is the distribution of these benefits. *Molienda* workers in western Honduras are paid per day, and interviews with producers confirmed that workers were paid the same even if they worked fewer hours per day. While producers benefited from the shorter day in terms of lowered opportunity cost, the major portion of the benefit resulting from a shortened workday accrues to the workers who receive the same total pay for fewer hours. The mean days of use per producer was 11.8 days of production/season. For workers, the 27% reduction in hours worked per day translates to a time savings equivalent to 3.2 days of work for each producer using the *molienda*. A day's labor for work in a *molienda* varies depending on the job, but averages HNL100/day (US$5.26/day, $n = 40$).

The majority of producers (64.6%) reported no change in employment. However, more than a third (35.4%, $n = 48$) of producers reported that the number of workers employed did change slightly after adoption; this may be related to the use of personal and family labor for cutting and collecting firewood, which was the most common reason for reduced labor needs. Bagasse burns more quickly than firewood and the evaporator requires more frequent loading, which may lead to shifting demand for labor from firewood cutting to management of bagasse. A few producers noted that they increased employment because of added work managing bagasse.

3.6. Income and financial viability

A 0.9 m × 2.7 m (3 ft × 9 ft) evaporator pan like those used by producers in this study cost an average of HNL12,500 (US$658 at HNL19:US$1) to build in 2014 based on the average costs from two fabricators in the market town of Gracias, Lempira. The oven, constructed of local adobe and brick with donated unskilled labor and one hired foreman, cost HNL4,278 (US$225) in 2014. To evaluate the financial viability of the evaporator, this analysis assumes that the pans were financed at 16% simple interest paid annually over three years. These are the same terms as the actual agreement now in effect in Lempira. The oven was assumed to be built with local labor and materials and did not require a loan. The total cost of the evaporator pans, oven, and interest is HNL20,778 (US$1,094).

The financial viability of the Ecological Evaporator is detailed in Table 6. It is based on survey results that found a mean of 11.8 days of use/year/producer and a reduction of about 5.81 cargas (527.083 kg) of wood per day after adoption. Based on a firewood cost of HNL40/carga (US$2/carga, $n = 50$) daily, fuel savings averaged approximately HNL232/day (US$12/day). Given these savings, repayment of the total evaporator loans and oven construction costs within three years requires that the evaporator be used for 30 days per year. At the scale of production in the region of 11.8 production days per producer per year, 2.54 producers would need to use the evaporator each year to achieve sufficient days of use. After the third year and until the evaporator wears out, each individual producer gains an additional HNL2,738 (US$144) annually from fuel savings alone.

In the Lempira region, cane can be harvested roughly once every 18 months. Among the producers surveyed, the median producer group size was 12 members ($n = 47$). Given these factors, evaporators could be used by more than three producers/year and the cost recovered more quickly than shown in the analysis above. In addition, the analysis above assumes no cash savings from the

Table 6. Financial viability of Ecological Evaporator

Variable	Lempiras (HNL)	US Dollars (US$)
Cost of pans	12,500	657.89
Interest on pans (three years)	4,000	210.53
Cost of oven	4,278	225.16
Total cost of evaporator	20,778	1,093.58
Fuel savings/day[a]	232	12.21
Additional annual income from fuel savings/producer[b]	2,738	144.11

Note: Exchange rate during the survey period was HNL19 to US$1.

[a]Fuel savings/day are rounded to the nearest Lempira, based on HNL40/carga and mean reduction pre-post of firewood/day of 5.81 cargas (Table 4).

[b]Based on 11.8 (n = 39) mean days of use/producer and HNL232 in fuel savings/day.

reductions in time nor the increases in production reported by producers. Including either or both of these into the analysis would significantly increase the returns to the new evaporator.

This analysis demonstrates that purchasing the evaporator is within reach of small producers at the scale in the Lempira region. These results were presented to producers currently involved in an expansion of the Ecological Evaporator project in the Lempira region in February 2016. This group of *panela* producers, known by the acronym APECACEL, currently participates in a USAID-financed *panela* project. The meeting took place at the *molienda* of one of the most experienced producers who initially rented the Ecological Evaporator and subsequently took out a loan to purchase his own evaporator. At that meeting, producers confirmed that this analysis tracked their own experience.

4. Limitations

There are a number of limitations of this study. The survey data reported here is based on producers' own estimates. There are a number of considerations that could influence the accuracy of these estimates, including producers' low levels of education and limited record keeping by producers in the region.

Producers were enthusiastic about the project. While this could affect their reported outcomes, it was also an indication that they perceived benefits. Producers were observed recruiting neighbors to the project, supporting their quantitative estimates of benefit. The research team was also able to directly observe the reductions in fuel wood and production time, qualitatively supporting producers' estimates.

The evaporator pans and ovens varied in age and quality during the survey period. Survey questions asked about pre- and post- experience, but the influence of the age of the evaporator at the time of the survey was not captured. Age and quality may have influenced fuel efficiency and production time.

Self-reported data and variability of the evaporators likely contributed to the relatively large standard deviations in the data and should be controlled in future projects through more accurate tracking of evaporators and direct measurement of fuel use.

The financial viability of the evaporator is dependent on days of use. Most producers in the project region have too little cane land to support individually owning an evaporator. Most producers using the Ecological Evaporator are part of a group. However, few groups maintained records of all producers who used the evaporator. Estimations of potential days of use and repayment periods would be improved with better record keeping of the total annual days of use by all group members.

Complicating quantitative analysis is that many of the metrics used in the region have defined values that are less specific in use. For example, the carga is recognized as equal to 200 lbs., while in practice, rural producers rarely weigh their cargas and instead estimate what amounts to a carga. During the research a few samples of *panela* blocks were weighed and were about evenly split between over- and under-weight cargas.

An important consideration of interest to project developers in other regions is the baseline condition from which this project began. Though sugarcane *panela* has been produced in this region for hundreds of years, technological advances have been slow to reach the region. Thus, traditional evaporator systems are very inefficient, lacking even basic improvements such as chimneys and fire grates. Including these changes as part of the technology package augmented the newer innovations of the flue pan and amplified the benefits that accrued from adoption of the flue pan evaporator system.

5. Challenges and opportunities

At the farm-scale, success of the Ecological Evaporator depends on its ability to provide clear benefits to producers that outweigh its costs. To achieve larger-scale impacts, including reductions in deforestation and regional economic development, this LEIT technology has to transfer and disseminate beyond project boundaries.

The 2005 study by Tripp assessed the performance of LEIT technologies in three countries and found that diffusion beyond those immediately affected by the project was more limited than expected, highlighting the challenges facing LEIT projects. Incorporating social-learning strategies, such as the farmer experimentation developed by Bunch (1997), appeared to facilitate LEIT.

In the case of the Ecological Evaporator in Honduras, the similarity of the Ecological Evaporators scale and management to traditional technology encourage experimentation and innovation. In addition, increased income and labor saving are apparent in the short-term, facilitating diffusion. However, three additional issues appear critical for dissemination: the quality of the pans, ability to purchase and maintain the pans locally, and the availability of credit.

An initial challenge is fabrication. The materials and skills to build the ovens and evaporators are commonly available and generally not limiting. The single tool required for fabrication that might not be available in rural areas is a large sheet metal bending brake that facilitates constructing the flues. These are typically available in larger towns and cities. Once the metal is bent, it can be welded using wire feed welders common in many smaller shops. Arc welding is not recommended.

One of the challenges is ensuring that pans are built correctly and to uniform quality. While in most cases differences in quality were minor, involving experimentation by the fabricator, researchers encountered a few evaporators where the fabricator had eliminated important features to save on expenses. In the most egregious case, an evaporator was found that lacked a channel to "draw off" hot liquid sugar. Producers reported this resulted in burned arms and more difficulties drawing off the sugar. Furthermore, this particular pan deteriorated rapidly, which could have been a function of design, insufficient training in maintenance, or a combination of both. Allowing production of low-quality pans can damage the reputation of the technology and limit adoption by new producers.

To facilitate tracking and ensure quality, recent projects in Lempira, Honduras, have begun to include a metal plate on each evaporator that documents the fabricator's name and location, a serial number, date of manufacture and the agencies involved with the project. In 2015, project partners initiated a guarantee that ensures producers that if manufacturing defects are found within the first year of manufacture, producers can have them repaired at no cost.

Working with technical high schools that have programs in metal work can create a regional information resource and increase the number of metal fabricators with the skills and knowledge to build and repair pans. In the central market town of Gracias, Lempira, a technical high school partnered with a local welding shop to build evaporators. Integrating local businesses, young entrepreneurs and technical training builds local capacity to repair and replace evaporators as they wear out. It also ensures a local supply of the evaporators and deepens knowledge of their construction. In a number of cases producers modified the design, in particular changes to handles and valves, later adopted by local fabricators. These factors speak to the adaptability of the design and increase self-reliance after projects end.

A key element to the sustainability of the project depends on development agencies showing restraint in their rollout of these evaporators. The Ecological Evaporator supports viable businesses that can repay the capital investment. The data supports fuel savings sufficient to enable producers to borrow funds, repay principal and interest, and earn additional income. The sustainability of this technology and its ability to diffuse is greatly improved if development agencies resist the urge to give away the evaporators, and instead design projects that ensure that credit is available for repair, replacement and purchases by future adopters. Funders can support the development of sustainable financing models by collaborating with local credit institutions to loan money to *panela* producers that is repaid into a dedicated fund for producers wanting to adopt the technology or expand operations following adoption. Establishing a credit system and connecting producers to local fabricators who can repair and replace the evaporators over the years are essential steps to support the sustainability of the project.

On the other hand, seeking rapid dissemination over a short period of time without building a network between producers, local credit institutions and fabricators diminishes the likelihood this technology will diffuse. In Honduras, some development agencies have sought a quick fix and given the evaporators away. This has deleterious effects in the short and long terms. Producers who don't have to invest in their evaporator have little incentive to care for it. In one of the most striking failures encountered in this research, a brand new, well-constructed evaporator sat unused after five years because it had been purchased and installed at no cost to producers, and without technical support to ensure that producers understood how to use it effectively. The project had cost the producers little and they had no incentive to invest in learning how to use a system they didn't understand.

A more common problem with donations of evaporators is that this approach fails to consider replacement of worn-out evaporators at the end of the useful lifetime of 5–7 years. "Give-away" programs undercut the sustainability of the evaporators by dis-incentivizing involvement of lending institutions that are essential to sustaining the technology beyond the project's boundaries. An important component of promoting these evaporators as sustainable businesses includes training modules that explain the concept of credit, depreciation, maintenance, and replacement in partnership with local credit institutions during small farmer recruitment and training.

The number of days of use is critical to the viability of the evaporator. Increasing the days of use reduces the repayment period. In Lempira, individual producers used the evaporator less than 12 days per year during a three-month production season. Renting to other small producers, forming a group, or intensifying cane production to increase yields can all increase days of use. An evaporator that is used for a full harvest season could repay its loan in one year. Days of use should be a central part of training on the new evaporator.

In western Honduras, where existing levels of technology are low and the corresponding change in efficiency from adopting the new evaporator is great, farmers are able to repay the cost of the system and increase their incomes from fuel savings alone, while selling to the same markets at the same price. Expanding markets through improved product quality, packaging and value-added products, such as granulated brown sugar, can further increase the profitability of ecological, small-scale sugarcane production. Recent studies have found both increased demand for *panela* in Latin America (International Sugar Organization, 2013) and for granulated sugar (Rodríguez-Entrena, Salazar-Ordóñez, Cordón-Pedregosa, & Cardenas, 2016). Several producers using the Ecological Evaporator were able to produce excellent quality granulated brown sugar by drawing off the sugar at higher temperatures without any further modification to the design.

Selling carbon credits has great potential to help finance this technology. Black et al. (2000), estimated that burning wood to produce *panela* produced 2.7 kg of carbon per kg of *panela*. A challenge is finding mechanisms that can aggregate many small producers so that they can achieve scales that will allow them to benefit from these markets. Large-scale energy projects have demonstrated the viability of selling carbon credits through co-generation with bagasse (Junqueira, 2005). However, the ability of the small-scale *panela* sector to enter the carbon market has been investigated but is still largely theoretical (United Nations Development Progamme, 2011).

Finally, integrating entrepreneurship education in all programs that promote this technology is critical, if not new. The basic skills of record keeping, depreciation, certification standards, and marketing all enable producers to more fully engage in projects involving this evaporator technology and increase the resiliency of the project in the face of economic, institutional and market changes.

A number of these recommendations are currently being explored through a USAID-funded project in western Honduras. Currently, there is on-going interest in the department of Lempira, including investment of international development agencies from Germany (GIZ) and the US (USAID), both of which have funded evaporator projects based on the research and design reported in this paper. The USAID funded project is implementing a number of recommendations outlined above.

6. Conclusion

Panela has been produced in rural areas of Honduras for hundreds of years. However, as in many other countries in Latin America, inefficient traditional methods and systems prevail. Relatively simple improvements can have a dramatic effect on fuel use and time. The substantial positive impacts of the new evaporator technology reported in this study should be viewed in this context. While the initial emphasis was on disseminating the flue pan, the project's evolution into improved ovens combined to yield these positive results. Improving traditional ovens by adding grates and chimneys, even for producers who do not have access to the pan technology, is likely to yield net benefits and deserves additional study.

The goals of sustainable agroecological systems outlined by Astier, Speelman, López-Ridaura, Masera, and Gonzalez-Esquivel (2011), include seven broad attributes, including high productivity, stability, reliability, resilience, adaptability, equity and self-reliance. In this study, the quantitative evaluation found positive production impacts, particularly the synergy between output, fuelwood use, and time. Increased efficiency enables use of a waste product as primary fuel. The technology's scale matches those of small rural producers in Central America. It can be built and maintained locally at low cost, has a rapid repayment from fuel savings alone, and a lower cost of production yields higher incomes from selling to existing markets. Little change in management from traditional systems is required, and after initial technical training, farmer-to-farmer transfer of knowledge is relatively simple. Substantial changes in scale of production or the location of production facilities are not required. These combine to make adoption relatively low-risk and build capacity for local control and long-term adoption and adaptation.

In this study, time savings were documented but not valued. This reflects the regional practice of either using non-paid family labor or paying workers by the day rather than by the hour or quantity produced. For the purposes of this study, this was appropriate as it is reflects the way that participants viewed the shorter production days, i.e. as a substantial, yet non-monetized, benefit. However, this ignores the reduction in opportunity costs afforded by this new evaporator. Time freed from *panela* production is put into other economic activities, such as tending *milpa*, working in coffee production, or attending to family needs. Perhaps most importantly, while the savings resulting from reduced fuel costs are earned by the producer, time savings are distributed equally to workers and provide a significant, added benefit. Were monetized values assigned to time savings, the repayment rate for the evaporator would be substantially lower.

Data on the number of farmers producing *panela* and the scale of their technology is extremely limited for most countries in Latin America and particularly in Honduras. This makes it difficult to know the extent to which similar results could be accomplished in other regions. However, journals, websites and blogs suggest that similar production systems using inefficient pans and ovens are widespread in Latin America (Balcáceres, 2005; Castillo & Elías, 2013; Cummings, 2013; Forero, Bernal, & Guerrero, 2015; Ramírez et al., 2012; Ullrich, 1984). Although often underappreciated, *panela* production is widespread, and helping low-income producers adopt more efficient systems can promote rural development with less environmental impact in sugar-cane producing regions around the world.

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