Journal of Nature Studies 17(1): 24-40
ISSN: 1655-3179

A COMPARISON BETWEEN A NOVEL INDIRECT SOLAR DRYER AND CONVENTIONAL FUEL DRYERS BASED ON THE FINANCIAL ANALYSIS AND CO_2 EMISSIONS

Juanito D. Burguillos[1*], Marilyn M. Elauria[2], and Jessie C. Elauria[3]

[1]Department of Mechanical Engineering, School of Engineering and Architecture, Saint Louis University, Lower Bonifacio Street, Baguio City, Philippines
[2]College of Economics and Management, University of the Philippines Los Baños, College, Laguna 4031, Philippines
[3]Department of Engineering Science, University of the Philippines Los Baños, College, Laguna 4031, Philippines

*Corresponding author: jdburguillos@slu.edu.ph

ABSTRACT – A novel indirect solar dryer (NISD) was assessed on the financial analysis and carbon dioxide (CO_2) emissions in drying of mango halves and fermented cacao beans. Comparison was made between the NISD and conventional fuel dryers (CFDs) using electric, gas fired, and biomass heaters having the same shape and dimensions. Life Cycle Cost, Life Cycle Savings and Discounted Payback Period are the financial indicators and CO_2 emission as one of the many environmental indicators. The financial and CO_2 emissions analyses were based on the amount of heat energy required to dry 216 kgs of mango halves and 900 kgs of fermented cacao beans yearly using the various dryers. The results showed that the NISD has the least annual cost with the largest savings in drying both products and the initial investment can be recovered in less than a year when used to dry fermented cacao beans. CO_2 emissions from the NISD with values of 0.0099 and 0.0034 kgCO_2/kg of wet mango halves and fermented cacao beans, respectively, was found to be insignificant as compared with the CFDs.

Keywords: CO_2 emissions, conventional fuel dryer, financial analysis, solar dryer

INTRODUCTION

The Philippines is located between 5° to 21° north latitude which lies above the equator. Pangasinan is in the northern part of the Philippines where cacao (*Theobroma cacao* L.) and mango *(Mangifera indica* L.) are grown as cash crops. Pangasinan experiences an average sunshine duration of 10 hours with solar irradiation varies between 1800 to 2000 kWh/m^2 (MacDonald, 2015). Lowest recorded ambient temperature is 22^{O}C in the months of January and February with maximum of 42^{O}C during summer where relative humidity varies from 84% to 94%. Therefore, solar drying system for agricultural product may be viable with the climate of Pangasinan.

Pangasinan is a region in the Philippines where mango trees flourish and was hailed as the biggest producer nationwide (Micua, 2010). Cacao on the other hand, is mostly grown as backyard plantation and large plantation was started around 8 years ago in Mangaldan and Dasol, and in Umingan two years ago. Few years from now, cacao may follow mango as the next productive cash crop in Pangasinan.

To cite this paper: Burguillos, J.D., Elauria, M.M. & Elauria, J.C. 2018. A Comparison Between a Novel Indirect Solar Dryer and Conventional Fuel Dryers Based on the Financial Analysis and CO_2 Emissions. *Journal of Nature Studies*. 17(1): 24-40.

The problems facing the mango farmers are the volatility of market price and preservation of ripe mango to extend its shelf life. The market price of mango fluctuates; expensive starting December due to scarcity of harvest and declines slowly until it reach the lowest price in the months of May and June: the peak of the harvest season. Cold storage may be the solution to extend the shelf life of mango but, it is too expensive. Cacao beans on the other hand, failure to dry immediately after fermentation will cause mold formation that will eventually destroy the quality of the beans when dried. Hence, it is imperative that drying should be implemented as postharvest operation to convert perishable mango into more stabilized product than employing expensive storage system and to preserve the quality of fermented cacao beans.

Thermal drying is the common drying method used in industrial and agricultural processes. However, the use of conventional fuel such as fossil fuel has lead to environmental issues such as CO_2 emissions (Pirasteh, Saidur, Rahman, and Rahim, 2014). In most of the developing countries, the use of fossil fuels for drying of agricultural products has not been practically feasible due to unaffordable costs to majority of the farmers (Okoro and Madueme, 2004). Hence, an inexpensive alternative method in drying these agricultural products is essential to the mango and cacao growers that is affordable and environmental friendly.

Solar energy technologies such as solar dryer offer a clean, renewable, and domestic energy source, and are essential components of a sustainable energy future (Gunerhan, Hapbasli and Giresunlu, 2009). Solar drying system has been proven to preserve agricultural products such as mango and cacao beans by reducing the moisture content to a desirable level. Although there are various designs of solar dryers, only a few is widely accepted due to its technical, economical and socio-economical acceptability (Fudholi at al., 2011). The NISD has been tested for its technical performance in drying fermented cacao beans (Burguillos, Elauria, and De Vera, 2016). Results showed that 9 kgs of mango halves per batch can be dried from an initial moisture content of 84.5 to 10.5% wet basis (w.b.) and 55 to 7.5% (w.b.) for 50 kgs of fermented cacao beans. However, assessments of the financial and CO_2 emissions of the NISD simultaneously with the CFDs must be performed to determine its acceptability to the end users and to the policy maker.

In the present study, the NISD which has been tested and performed with acceptable performance in drying fermented cacao beans and mango halves, is to be assessed on its financial satisfactoriness for the farmers and CO_2 emissions for the environmentalists. Firstly, it aims to assess and compare the NISD in terms of financial viability and CO_2 emissions with CFDs. Secondly, to draw policy recommendations from the results of the study.

MATERIALS AND METHODS

Description of the NISD

The NISD features an indirect mode of solar heating but it adopts the structural arrangement of direct-type dryer. The solar collector and the drying chamber are integrated in one structural arrangement with a black cotton cloth in-between them. The black cotton cloth protects the drying product from problems associated with direct exposure to solar radiation such as discoloration and degradation of nutritional value which may deteriorate the product quality. The schematic diagram of the NISD system is shown in Figure 1.

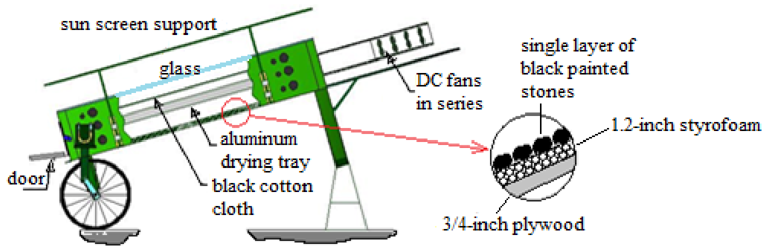

Figure 1. Schematic diagram of the solar drying system.

The NISD was constructed with 3/4-inches marine plywood for the enclosure to form a rectangular box. The major components of the dryer are the drying chamber with drying tray, solar collector, and converging nozzle with fans for moisture removal. The NISD is elevated by four wooden legs in such a way that the front supports with removable mounting are 580 mm above the ground and the rear supports with bicycle wheel for mobility are shorter to allow the solar box to form a tilt angle corresponding to the latitude of the drying site. The solar collector have wooden sidewalls enclosure of 100 mm depth and a collector area of 1.3896 m^2 (1.930 m long x 0.720 wide). The top covering is made of 6 mm commercial transparent glass with 85-90% solar radiation transmission and a black cloth beneath it serving as a heat absorber. An optimum air gap of 400 mm (Gatea, 2010) was provided between the glass covering and the heat absorber. The internal surfaces of the dryer were covered with 12.5 mm Styrofoam with flat black stones laid over it which serves as heat storage.

The heat absorber was made of thin white cotton cloth dyed with an organic black liquid solution. The black liquid solution is a mixture of liquid from boiled Talisay leaves which contains tannin acid and ferrous sulfate was added to form black color. The black cloth when installed has 50 mm x 609 mm vent at its end near the converging nozzle of the solar dryer. This vent serve as an exit passage of water vapor that diffused through the cloth from the drying product and was trapped inside the solar collector. This water vapor is immediately drawn out by the exhaust fans to prevent condensation on the surface of the glass that might reduce the transmissivity. Because the solar collector is integrated with the dryer design, a gap of 400 mm was provided between the heat absorber (black cotton cloth) and the drying product. It was assumed that this amount of air gap will give enough space for vaporized moisture and also cause uniform distribution of heat transmission from the heat absorber to the drying product. A sunscreen support made of 6 mm diameter steel bar is provided as shown in Figure 1 for black polyester cloth to cover the solar collector during high intensity solar radiation especially, between 10 AM to 3 PM to prevent the drying temperature goes beyond the recommended value.

The size of the drying chamber used for the NISD was based on the maximum surface that can be cut from a whole piece of 19 mm thick marine plywood to minimize material waste and reduce cost. Therefore, the drying chamber size resulted to 1930 mm long x 720 mm wide and a depth of 300 mm. It is provided with 38 mm x 38 mm angle bar along the longitudinal inner sides to slide the drying tray during loading and unloading. The dryer is provided with a wooden door at the rear end of the drying chamber for accessing the drying tray. The solar collector is above the drying chamber and the are integrated into one structural arrangment.

The drying tray that will fit into the drying chamber was constructed to have a size of 1900 mm long x 650 mm wide with an area of 1.235 m^2. It consists of steel square bar frame covered with 1 inch x 1 inch opening G.I. wire mesh with a top layer of aluminum mosquito screen. The tray was divided into 10 shallow compartments of equal sizes with a length of 380 mm x 325 mm wide and a depth of 64 mm made of corrosion resistant aluminum angle bar to accommodate the drying product in equal proportion with uniform thickness. Figure 2 shows the schematic diagram of the drying tray with dimensions. The drying tray has an approximate loading rate of 40.5 kg/m^2 of fermented cacao beans or approximately 50 kgs, according to Burguillos (2016). This is similar to the high loading rate used in the study of fermented cacao beans quality, conducted by Bonaparte et al. (1998). High loading rates have the potential to slow down the initial rate of drying in the bean mass and therefore allow a longer period for the loss of acids either enzymatically or physically (Jinap, Thien, and Yap, 1994). However, the loading rate of mango halves was limited to one layer and densely arranged side by side with an approximate weight of 9-10 kgs.

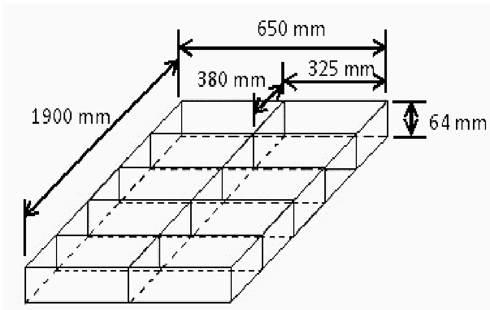

Figure 2. Schematic diagram of the drying tray.

Testing of the NISD

Fresh cacao pods were collected from different households in Mapandan, Pangasinan and other nearby municipalities. After gathering an equivalent weight of 53 kgs or more of fresh seeds, fermentation was done using the basket method for six days. After the fermentation process, the weight of the beans had decreased to approximately 50 kgs because of the pulp juice that was drained. The fermented cacao beans were then loaded and spread evenly into the drying tray. Drying was done until the weight of the beans became constant. This took approximately 5 days under good weather condition. The dried fermented cacao beans can be sold in the market or for “tablea” production. The other agricultural products are green mangoes which were bought from the source; contained in a bamboo basket lined and covered with newspaper and allowed to ripe for 3 days to attain fair ripenes. The ripe mangoes were peeled and cut into halves excluding the seeds. Mango halves were densely laid side by side to form one layer in the drying tray with an average amount of 9.5 kgs per batch. It took an average of 4.5 days to dry the mango halves in the NISD under good weather condition. Figure 3 shows the solar dryer in set-up position.

Figure 3. Solar dryer in set-up position.

Financial Assessment

The financial evaluation of the NISD was assessed and compared with the CFDs. To make a financial comparison between the NISD and CFDs, the amount of fuel necessary to dry a specific amount of product was determined. To realize this comparison, it was assumed that the CFDs have the same shape and dimensions with the NISD except that the sources of heat will come from electric, gas fired, and biomass heaters. For energy sources other than electricity, the amount of fuel consumption was determined by

$$fuel\ consumption = \frac{Q_{input\ gas\ or\ biomass}}{Gross\ calorific\ value\ of\ fuel} \quad \text{------(1)}$$

Where the gross calorific value of dry wood is 15400 kJ/kg fuel or 4.27 kWh/kg fuel and for the LPG is 49907 kJ/kg fuel or 13.86 kWh/kg fuel (Higher Calorific Value, 2005). The $Q_{input\ (electric\ or\ gas\ or\ biomass)}$, which is the amount of energy in kWh to produce the required heat energy Q taking into account the efficiency of the heating device, can be determined from the equation given by,

$$\eta_{heater} = \frac{Q_{output\ electric\ or\ gas\ or\ biomass}}{Q_{input\ electric\ or\ gas\ or\ biomass}} \quad \text{------(2)}$$

Where the values of the various efficiencies, η_{heater}, of the heaters using electrically heated air, gas fired hot-air (El-Mesery and Mwithiga, 2012) and biomass heater (Sudhakar, 2015) are 54, 70 and 35%, respectively. The $Q_{output\ (electric\ or\ gas\ or\ biomass)}$ which is equal to Q, the energy required to dry a specific amount of product, was determined using an equation according to Eke (2003) given as follows,

$$Q = \frac{[C_{PF}\ W_{FW}\ (T_h - T_a) + h_V M_W]\ x\ kWh}{3600\ kJ} \quad \text{------(3)}$$

here,
C_{PF} = is the specific heat capacity of the drying product in kJ/kg-^{O}C.
W_{FW} = is the weight of the drying product before drying in kg.
T = is the temperature of hot air in ^{O}C.
T_a = is the temperature of ambient air in ^{O}C.
h_v = is the latent heat of evaporation of moisture from the product in kJ/kg.
M_W = is the quantity of water removed from the product to reduce its initial moisture content to the desired final value in kg as shown in Equation 4.

The M_W in Equation 3 was determined by the equation,

$$M_W = \frac{(M_{db\,i} - M_{db\,f})}{100} \; x \; (W_{FW} - \frac{W_{FW}\, M_{wb\,i}}{100}) \text{ ---------- } (4)$$

Where,
M_{dbi} = is the initial moisture content in dry basis in %.
$M_{db\,f}$ = is the final moisture content in dry basis in %.
M_{wbi} = is the final moisture content in dry basis in %.

and the variables M_{dbi} and $M_{db\,f}$ were determined using Equations 5 and 6.

$$M_{db\,i} = \frac{M_{wb\,i}}{100 - M_{wb\,i}} \; x \; 100 \text{ ---------- } (5)$$

$$M_{db\,f} = \frac{M_{wb\,f}}{100 - M_{wb\,f}} \; x \; 100 \text{ ---------- } (6)$$

The values of the parameters mentioned in Equations 3-6 are summarized in Table 1. These values represent the properties of mango and cacao beans; unit cost of the various fuels; and the annual target output of the dryers of dried fermented cacao beans and mango halves. Also, these values were used in the computations of the financial and CO_2 emissions of the NISD and CFDs.

Table 1. Values of the parameters in the evaluation of the financial and CO_2 emissions of the dryers.

Item	Value
Cost of electricity per kWh (Php)	12
Cost of LPG per kilogram (Php)	45
Cost of firewood per kilogram (Php)	5
Annual weight of wet mango halves per dryer, $W_{FW\ mango}$ (kg)	216
Annual weight of dried mango halves per dryer, $W_{FD\ mango}$ (kg)	65
Annual weight of wet fermented cacao beans, $W_{FW\ cacao}$ (kg)	900
Annual weight of dried fermented cacao beans, $W_{FD\ cacao}$ (kg)	360
Total annual cost of fresh mangoes per dryer (Php)	17280
Total annual cost of fresh cacao beans per dryer (Php)	45000
Specific heat mango halves, $C_{PF\ mango}$(kJ/kg-^{O}C)	3.8016
Specific heat cacao beans, $C_{PF\ cacao}$(kJ/kg-^{O}C)	2.262
Initial moisture content of mango halves, $M_{wbi\ mango}$ (%)	84.5
Initial moisture content of fermented cacao beans, $M_{wbi\ cacao}$ (%)	43.8
Final moisture content of mango halves, $M_{wbf\ mango}$ (%)	10.5
Final moisture content of fermented cacao beans, M_{wbf} (%)	7.5
Average ambient air temperature, T_a (^{O}C)	35
Average drying temperature of mango halves, $T_{h\ mango}$ (^{O}C)	60
Averaged drying temperature of fermented cacao beans, $T_{h\ cacao}$ (^{O}C)	65
Latent heat of vaporization of water at 60^{O}C, h_v (kJ/kg)	2358.5

Three economic indicators: Life Cycle Cost analysis (LCC), Life Cycle Savings (LCS), and Discounted Payback Period (DPP) were used to compare the financial analysis of the dryers without considering depreciation cost, taxes, and insurance. According to Thumann and Mehta (2001), the best way to evaluate the actual cost for an asset is through the LCC because it can incorporate the fuel cost increase into the economic model and the cost over the life of the system rather than just the initial cost (as cited in Ohijeagbon, Waheed, &Jekayinfa, 2011). To perform the LCC, the present value of the initial investment (IC) and the annual overhead and maintenance costs (O&M) were determined using the following equation,

$$LCC = \frac{IC\ x\ (1+r)}{(1+d)^n} + \sum_{n=2}^{n=t} \frac{O\&M\ x\ (1+r)^n}{(1+d)^{n+1}}$$

$$= \frac{IC\ x\ (1+0.02)^0}{(1+0.05)^1} + \frac{O\&M\ x\ (1+0.02)^1}{(1+0.05)^2} + \frac{O\&M\ x\ (1+0.02)^2}{(1+0.05)^3} + \frac{O\&M\ x\ (1+0.02)^3}{(1+0.05)^4}$$

$$+ \frac{O\&M\ x\ (1+0.02)^4}{(1+0.05)^5} + \frac{O\&M\ x\ (1+0.02)^5}{(1+0.05)^6} \quad \text{------(7)}$$

Equation 7 was based from the assumption that the profitable life of the dryers is 5 years. With the rapid advancement of research, better and more economical solar dryer designs may emerge within this span of time, hence, the disposal or salvage value was considered zero. The costs for electricity, liquified petroleum gas (LPG), and firewood were assumed to inflate at a constant rate (*r)* of 2% and the time value of money (*d*) of 5% according to the Philippines forecast ranging from 3%-5% made by Trading Economics for the next five years starting 2016 (www.tradingeconomics.com).

LCC does not entirely represent the economic performance of the NISD because the cost of drying varies little over its entire life. In the case of conventional dryers, the increasing cost of conventional energy increases the cost of drying. Therefore, for assessing the economic benefits of the NISD, it is also essential to determine the savings over the life of the dryer which can be done using LCS. The LCS was determined by

$$LCS = LCC_{(electric\ or\ gas\ or\ biomass)} - LCC_{solar\ dryer} \quad \text{------(8)}$$

Aside from the LCC and LCS, the DPP was used to determine the liquidity or how fast the investment can be recovered. The DPP was determined by

$$DPP\ of\ solar\ dryer = \frac{Initial\ cost}{computed\ annual\ saving\ from\ LCS\ analysis} \quad \text{------(9)}$$

Assessment of the CO_2 emissions

The magnitude of CO_2 emission of the NISD was compared with the same dryer that uses conventional fuel such as electricity, LPG, and biomass as the source of energy in heating the selected agricultural products. The electrical power consumed by the NISD and the CFDs using electrically heated hot-air was monitored using OMNI power meter. The power meter has a feature of accumulating the power consumed per drying test. In order to calculate the equivalent CO_2 emissions attributed to electricity consumption, it is necessary to determine the specific carbon dioxide emissions of the various fuel (Table 2) used in the production of electricity and the percentage of electricity generation by fuel (Figure 4).

Table 2. Specific fuel emission of the different energy sources (Source: http://www/Volker-quaschning.de/datser/CO2-spez/index_e.php).

Fuel source	**Specific CO_2 (kg CO_2/kWh)**
Hard Coal	0.34
Natural Gas	0.2
Geothermal	0
Hydro	0
Solar and Wind	0
Liquified Petroleum Gas (LPG)	0.23
Wood (air dry)	0.39

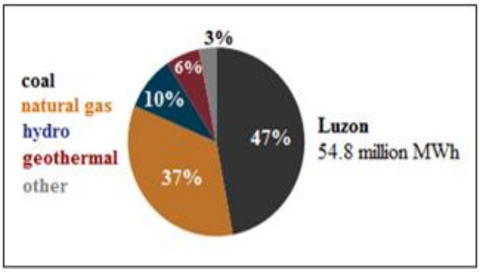

Figure 4. Pie chart of power generation by fuel source in the Luzon Grid, Philippines (Source: U.S. Energy Information Administration based on the Department of Energy).

Figure 4 represents a pie chart of electricity generated by fuel in the Luzon grid during the year 2014 and the drying location is part of the Luzon grid. According to Figure 4, the combined electricity generated by the various power plants in Luzon, come from coal (47%), natural gas (37%), hydro (10%), geothermal (6%), and others (3%) such as solar, and wind. Therefore, the equivalent CO_2 emissions of 1 kWh consumption is a partial composition of emissions from coal and natural gas because the CO_2 emissions from geothermal, hydro, solar, and wind were considered as zero value. The electrical power consumption of the NISD were mainly due to the running of the fans in series to remove vaporized moisture therefore, the equivalent CO_2 emissions was calculated by

$$\text{Equivalent } CO_2 \text{ emissions, } CO_2e \text{ (kg)} = \text{total electric consumption} \times \frac{\sum_1^n(\text{Specific fuel emission}_{1,2,\ldots n} \times \text{\%contribution generated by fuel}}{n} \text{ --------(10)}$$

Where,

$$\frac{\Sigma_{1}^{n}(Specific\ fuel\ emission_{1,2,\ldots n}\ x\ \%contribution\ generated\ by\ fuel}{n} = \frac{Specific\ Coal\ CO_2e\ x\ 0.47 + Specific\ Natural\ gas\ CO_2e\ x\ 0.37}{number\ of\ fuel}$$

The values of the specific carbon emissions in $kgCO_{2e}$ / kWh and the percentage of power contribution generated by fuel were taken from Table 2 and Figure 4, respectively.

If the NISD uses a back-up heater coming from commonly used fuel mentioned from related literatures such as: LPG or biomass then, the emission is computed based on the CO_2 emission coefficient of that fuel in kg per kWh used (Lal, 2004). The amount of emission was computed by

$$CO_2\ emission = Specific\ CO_2\ emission\ of\ fuel\ in\ kg_{CO2e}\ x\ \frac{Q_{output\ (electric\ or\ gas\ or\ biomass)}}{\eta_{heater}} \text{ ---------------- } (11)$$

Where the value of specific CO_2 emission of fuel in $kgCO_2$ is taken from Table 2 and the procedures in determining the values of η_{heater} and $Q_{output\ (electric\ or\ gas\ or\ biomass)}$ are already mentioned earlier.

RESULTS AND DISCUSSION

Salient features of the NISD

The NISD is affordable to construct, simple to operate, easy to load and unload the drying product, and it is mobile. When in operation, the dryer has a relative humidity higher than the ambient condition due to rapid evaporation. This high humidity causes the surface of the beans not to dry rapidly promoting the effective evaporation of the acetic acid from the beans. High acetic acid retained in the beans may affect the flavor of the products produced from the dried beans (Jinap, Thien, & Yap, 1994). This condition is also favorable to mango halves drying to avoid wrinkling of the external surface when dried.

Financial Assessment

The financial aspects of the dryers were focused on the comparison of cost (LCC) and the savings made in the future years (LCS) between the NISD and CFDs using biomass and conventional fuel. Its acceptability was measured based on the number of years (DPP) to recover the initial investment.

The initial investment in producing the NISD is PhP 17,467. It comprises the construction material cost of PhP 9867 and labor cost of PhP 7,600. The average cost of fresh mangoes and cacao beans are sold at 40 and 50 pesos per kilogram, respectively, during the peak season of January to June. For a drying period of six months, an ordinary man in the rural areas of Pangasinan can be hired for a total cost of 12,000 pesos in the preparation of the drying product and for operating the NISD. Because the NISD was made to resist the wear and tear under extreme weather conditions for the duration of its profitable life of five years, maintenance cost may be incurred only in the replacement of the four pieces of fans worth 1,000 pesos assuming it will cease to function properly at the end of each year due to a non-stop operation. During drying operation, the fans would require an energy of 0.0812 kWh and 0.02764 kWh per kilogram of wet mango halves and fermented cacao beans according to Burguillos (2016). Conservatively, an amount of 400 and 500 pesos would be spend to drive the fans for yearly drying demands of 216 and 900 kgs of mango halves and fermented cacao beans for an electricity cost of 12 pesos per kWh in the rural area. In addition, these estimates have already accounted for the fluctuations of electricity consumptions during the drying operations. Hence, annual operating costs include maintenance, electricity, labor, and drying products.

For the NISD and CFDs having the same shape and dimensions, the cost of maintenance, electricity cost to drive the fans in series, labor cost, and the cost of drying products are similar except for the fuel cost in heating the drying product. Table 3 gives the parameters taken from Table 1 and the computed annual moisture, M_W, to be removed using Equations 4-6.

Table 3. Annual moisture removed in drying mango halves and fermented cacao beans.

Product	M_{wbi} **(%)**	M_{wbf} **(%)**	M_{dbi} **(%)**	$M_{db\,f}$ **(%)**	W_{FW} **(kg)/year**	M_W **(kg)/ year**
Mango	84.5	10.5	545.161	11.7318	216	178.592
Cacao beans	43.8	7.5	77.9359	8.10811	900	353.189

To evaluate the economic indicators (LCC, LCS, and DPP), the computed annual Q to remove M_W (Table 3), amount of equivalent fuel consumptions and total cost of the fuel used by each CFDs per drying product are shown in Table 4 for mango halves and fermented cacao beans, respectively. The amount of annual Q and equivalent fuel consumptions were computed using Equations 1-3. The Q_{input} for NISD was considered zero because it does not use conventional fuel.

Table 4. Annual fuel cost of the different drying methods in drying mango halves and femented cacao beans.

MANGO HALVES				
Parameter	**NISD**	**Electric heater**	**Gas fired heater**	**Biomass heater**
Efficiency (%)	-	54	70	35
Q=Q_{output} (kW/year)	122.823	122.823	122.823	122.823
Q_{input} (kW/year)	0	227.45	175.461	350.92
Annual fuel consumption	0	227.45 kWh	12.66 kg LPG	82.18 kg firewood
Annual cost of fuel consumption (PhP)	0	2729.4	569.67	410.92

Table 4 (Continued). Annual fuel cost of the different drying methods in drying mango halves and femented cacao beans.

FERMENTED CACAO BEANS				
Parameter	**NISD**	**Electric heater**	**Gas fired heater**	**Biomass heater**
Efficiency (%)	-	54	70	35
$Q=Q_{output}$ (kW/year)	248.35	248.35	248.35	248.35
Q_{input} (kW/year)	0	459.91	354.79	709.58
Annual fuel consumption	0	459.91 kWh	25.59 kg LPG	166.18 kg firewood
Annual cost of fuel consumption (PhP)	0	5518.95	1151.9	830.9

For the CFDs, the heat energy to produce the required Q to dry 900 kgs of fermented cacao beans and 216 kgs of mango halves was the basis in determining the equivalent annual fuel consumptions for each CFDs taking into account their efficiencies. The variations of the annual fuel consumptions observed in Table 4 can be accounted to the different efficiencies of the conventional heaters in utilizing the calorific value of the fuel in heating the drying air. Table 4 also shows the cost of the equivalent fuel consumed by each CFDs based on the prevailing prices during the study as given in Table 1.

The yearly cost of the NISD and the CFDs in terms of the IC and O&M in drying mango halves and fermented cacao beans for a 5-year period are summarized in Table 5 where the IC was assumed to be the cost of the dryer without considering the cost of back-up heater such as electric coil, LPG burner and furnace for biomass. The term fuel in both tables refers to the cost of conventional fuels such as electricity, LPG and biomass required in producing the required Q to dry mango halves and fermented cacao beans.

Table 5. The IC and O&M of the NISD and CFDs in drying the two agricultural products.

MANGO HALVES						
	Cost Element	**NISD**	**Electric**	**Gas fired**	**Biomass**	**Time**
IC (PhP)		17467.5	17467.5	17467.5	17467.5	0-1 year
O&M (PhP)	Maintenance	1000	1000	1000	1000	2-6 year
	Electricity (fan)	400	400	400	400	2-6 year
	Labor	12000	12000	12000	12000	2-6 year
	Fuel	0	2729.4	569.67	410.92	2-6 year
	Mangoes	17280	17280	17280	17280	2-6 year
	Total O&M	30680	33409.4	31249.25	31090.9	

Table 5 (Continued). The IC and O&M of the NISD and CFDs in drying the two agricultural products.

FERMENTED CACAO BEANS						
	Cost Element	**NISD**	**Electric**	**Gas fired**	**Biomass**	**Time**
IC (PhP)		17467.5	17467.5	17467.5	17467.5	0-1 year
O&M (PhP)	Maintenance	1000	1000	1000	1000	2-6 year
	Electricity (fan)	500	500	500	500	2-6 year
	Labor	12000	12000	12000	12000	2-6 year
	Fuel	0	5518.95	1151.9	830.9	2-6 year
	Mangoes	45000	45000	45000	45000	2-6 year
	Total O&M	58500	64018.9	59651.9	59330.9	

The results of the LCC, LCS, and DPP analyses using Equations 7, 8 and 9, respectively, are summarized in Tables 6, 7, and 8. In Table 6, the LCC represents the present value of the IC and O&M using Equation 7 in drying mango halves and fermented cacao beans. It shows that the NISD experienced the lowest LCC in both drying of mango halves and fermented cacao beans followed by the conventional dryer using biomass. However, the dryer using electric heater has the highest LCC; this confirm the finding of El-Mesery and Mwithiga (2012) that gas fired hot-air dryer was cheaper to operate than electrically heated hot-air dryer producing dried product from both dryers with the same quality. Aside from this, Singh and Gundimeda (2014) reported that the used of biomass is cheaper than using LPG as a source of heat energy.

Table 6. LCC of the NISD and the CFDs in drying mango halves.

Drying Method	**MANGO HALVES**		
	IC (PhP)	**O&M (PhP)**	**LCC (PhP)**
NISD	17467.5	30680	150675.4
Electric heater	17467.5	33409.4	162600.1
Gas fired heater	17467.5	31249.25	153162.5
Biomass heater	17467.5	31090.9	152471
Drying Method	**FERMENTED CACAO BEANS**		
	IC (PhP)	**O&M (PhP)**	**LCC (PhP)**
NISD	17467.5	58500	272219.9
Electric heater	17467.5	64018.9	296331.8
Gas fired heater	17467.5	59651.9	277252.6
Biomass heater	17467.5	59330.9	275850

The results of LCC from Table 6 showed that the NISD is better. Therefore, there would be a positive annual savings in using the NISD. This conclusion can be confirmed from the results of the LCS in Table 7. In Table 7, the amount of annual savings from the used of the NISD is the difference between the LCC of the NISD and the CFDs.

Table 7. LCS of the NISD versus the CFDs.

Drying Method		MANGO HALVES			FERMENTED CACAO BEANS		
		LCC (PhP)	**Δ**	**LCS (PhP) NISD vs CFD**	**LCC (PhP)**	**Δ**	**LCS (PhP) NISD vs CFD**
NISD	A	150675.4			272219.9		
Electric heater	B	162600.1	B-A	11924.7	296331.8	B-A	24111.9
Gas fired heater	C	153162.5	C-A	2487.1	277252.6	C-A	5032.7
Biomass heater	D	152471	D-A	1795.6	275850	D-A	3630.1

According to Table 7, the savings in using the NISD versus the CFDs are greater than zero and the largest savings occured when the NISD was used in drying fermented cacao beans. This can be accounted to the heavy loading rate of the fermented cacao beans, however, the loading rate of mango halves was limited to one layer therefore, the capacity is small.

The recovery of the IC at the shortest possible time will dictate the economic attractiveness of a particular dryer. The results of the LCS from Table 7 was applied to determine the DPP and the findings are shown in Table 8. The shortest possible time to recover the IC of the NISD was attained when drying fermented cacao beans. It can be recovered in less than a year about 8-9 months (0.72 year) when the payback period was based on the largest amount of LCS. However, it will take 5 years when the least LCS was used.

Table 8. Payback period of the NISD based on the largest and least LCS in drying mango halves and fermented cacao beans.

	MANGO HALVES	
Item	**Largest LCS**	**Least LCS**
IC (PhP)	17467.50	17467.50
LCS (PhP)	11913.3	1793.6
DPP (year)	1.47	9.7
	FERMENTED CACAO BEANS	
IC (PhP)	17467.50	17467.50
LCS (PhP)	24111.9	3543.3
DPP (year)	0.72	5

Assessment of the CO_2 emissions

The CO_2 emissions of the NISD comes only from the use of electricity to drive the four DC fans in series. If the mango halves and fermented cacao beans were dried using conventional fuels, the amount of CO_2 emissions is equivalent to the amount of heat energy to bring the beans to its desired final moisture content plus the energy to run the DC fans. The required energy to run the DC fans depends on the drying products and the value is similar to all dryers. The computations of the equivalent CO_2 emissions for each dryers were done using Equation 10 when the energy source comes from electricity and Equation 11 when conventional fuels such as LPG and biomass were used. To make an accurate assessment of the CO_2 emissions between dryers, CO_2 emissions per kgs of wet products was considered as the basis of comparison. The energy requirements of the various drying methods and the results of the CO_2 emissions are shown in Table 9 in drying mango halves and fermented cacao beans.

Table 9. CO_2 emissions of the NISD and CFDs in drying mango halves and fermented cacao beans.

Drying Method	**MANGO HALVES (wet)**			
	***Q_{fan}* (kWh/kg)**	***Q_{input}* (kWh/kg)**	**Q_{total} (kWh/kg)**	**Emission (kg CO_2/kg)**
NISD	0.0812	0	0.0812	0.0099
Electric heater	0.0812	1.053	1.1342	0.1388
Gas fired heater	0.0812	0.8123	0.8935	0.2055
Biomass heater	0.0812	1.6246	1.7058	0.6653
Drying Method	**FERMENTED CACAO BEANS (wet)**			
	***Q_{fan}* (kWh/kg)**	***Q_{input}* (kWh/kg)**	**Q_{total} (kWh/kg)**	**Emission (kg CO_2/kg)**
NISD	0.02764	0	0.02764	0.0034
Electric heater	0.02764	0.5110	0.5386	0.0659
Gas fired heater	0.02764	0.3942	0.4218	0.0970
Biomass heater	0.02764	0.7884	0.8161	0.3183

Results showed that the NISD has the least equivalent CO_2 emissions among the CFDs when drying mango halves and fermented cacao beans as shown in Table 9. Therefore, the use of the NISD will help in mitigating the problem of CO_2 emissions to the atmosphere.

SUMMARY AND CONCLUSION

A NISD was assessed on its financial and CO_2 emissions in comparison to CFDs with the same shape and dimensions using electricity, LPG and biomass. Wet mango halves and fermented cacao beans weighing 216 and 900 kgs per year, respectively, were dried using the NISD and CFDs. The economic indicators considered to evaluate the financial attractiveness of the various drying methods were the LCC, LCS, and DPP. The equivalent CO_2 emissions was also evaluated to compare the magnitude of emissions contributed by the various dryers.

Financial analysis showed that the NISD have the least annual cost and the largest savings amongst the CFDs. The initial investment on the NISD can be recovered in less than a year about 8-9 months (0.72 year) when used to dry fermented cacao beans. The CO_2 emissions from the NISD of 0.0099 and 0.0034 kg CO_2/kg of mango halves and fermented cacao beans, respectively, were insignificant compared to the emissions of the CFDs ranging from 0.1 to 0.6 of kg CO_2/kg of wet product. Therefore, the results showed that the NISD is economically and environmentally better than the CFDs.

RECOMMENDATIONS

The NISD must be promoted by presenting the results to different government agencies such as the Department of Agriculture and the Local Government Units. In cooperation of these agencies, the researcher may reach the farmers or any concern group by conducting a talk. An actual demo of the device may be conducted if necessary to communicate a firsthand information regarding the many features of the novel solar dryer especially, on its financial attractiveness and insignificant CO_2 contribution to the environment.

STATEMENT OF AUTHORSHIP

The first author conducted the literature research, prepared the conceptual framework, performed the experiments and undertook the preparation of the manuscript. The second and third authors made substantial revisions on the manuscript.

REFERENCES

Burguillos, J. D., Elauria, J. C. and De Vera, I. 2016. Design, development and performance testing of a novel indirect solar dryer. Journal of Nature Studies. 15 (1): 1-18.

Bonaparte, A., Alikhani, Z., Madramootoo, C. A., Raghavan, V. 1998. Some quality characteristics of solar-dried cocoa beans in St. Lucia. Journal of the Science of Food and Agriculture, 76, 553-558.

Dhanushkodi, A., Wilson, V.H., and Sudhakar, K. 2015. Life cycle cost of solar biomass hybrid dryer systems for cashew drying of nuts in India. Environmental and Climate Technologies. 15(1), 15pp.

Eke, A.B. 2003. Investigation of low cost solar collector for drying vegetables in rural areas. Agricultural EngineeringInternational: CIGR Journal, 16(1), 118-125.

El-Mesery, H.S. and Mwithiga, G. 2012. Comparison of a gas fired hot-air dryer with an electrically heated hot-air dryer in terms of drying process, energy consumption and quality of dried onion slices. African Journal of Agricultural Research, 7(31), 4440-4452.

Fudholi, A., Othman, M.Y., Ruslan, M.H., Yahya, M., Zaharim, A., and Sopian, K. 2011. Design and testing of solar dryer for drying kinetics of seaweed in Malaysia. Proceedings of the 5th International Conference on Energy and Development-Environment-Biomedicine (EDEB '11), 119-124.

Gatea, A. A. 2010. Design and construction of a solar drying system, a cylindrical section and analysis of the performance of the thermal drying system. African Journal of Agricultural Research, 6(2), 342-351. DOI: 10.5897/AJAR10.347

Gunerhan, H., Hepbasli, A. and Giresunlu, U. 2009. Environmental Impacts from the Solar Energy Systems. Energy Sources Part A - Recovery Utilization and Environmental Effects. 31, 131-138. DOI: 10.1080/15567030701512733.

Higher Heating Value. 2005. Retrieved from: http://www.mrsphoto.net/4-IMTE%20AG/2-2005-06.pdf

Jinap, S., Thien, J. & Yap, T.N. 1994. Effect of drying on acidity and volatile fatty acids content of cocoa beans. Journal of the Science of Food and Agriculture, 65, 67-75. DOI: 10.1002/jsfa.2740650111

MacDonald, M. 2015. Philippine solar resource characterization, challenges and implications for the sector. Retrieved from: https://d2oc0ihd6a5bt.cloudfront.net/wp-content/uploads/sites/837/2015/06/Iban-Vendrell_Mott-MacDonald-ASEF-Solar-Energy-Forum-Session-2_03062015.pdf

Micua, V.L. 2010. Pangasinan hailed as the biggest mango producer nationwide. Balita. Retrieved from: http://balita.ph/2010/02/25/pangasinan-hailed-as-biggest-mango-producer-nationwide/

Ohijeagbon, I.O., Waheed, M.A., &Jekayinfa, S.O. 2011. Annual and compound life cycle cost analysis of a steam boiler. LAUTECH Journal of Engineering and Technology, 6(2), 91-96.

Okoro, O.I. and Madueme, T.C. 2004. Solar energy: A necessary investment in a developing economy. Nigerian Journal of Technology, 23(1), 58-64.

Pirasteh,G., Saidur, R., Rahman, S. M. A. and Rahim, N. A. 2014. A review on development of solar drying applications. Renewable and Sustainable Energy Reviews, 31, 133-148.

Singh, P. and Gundimeda, H. 2014. Life Cycle Energy Analysis (LCEA) of cooking fuel sources used in India households. Energy and Environmental Engineering, 2(1), 20-30.

Thumann, A. and Mehta, D. P. 2001. Hand Book of Energy Engineering, the Fairmont Press Inc., 700 Indian Trail, 5th Ed. Trading Economics. 2016. Retrieved from: http://www.tradingeconomics.com/philippines/inflation-cpi

JOURNAL OF NATURE STUDIES
(formerly Nature's Bulletin)
ISSN: 1655-3179