INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

2024, Vol. 19(1), 37-51
e-ISSN: 2956-7971, License CC-BY 4.0

DOI: https://doi.org/10.14597/INFRAECO.2024.003

TECHNO-ECONOMIC ANALYSIS AND CARBON (IV) EMISSION REDUCTION

Benjamin Ternenge ABUR [1], Habou DANDAKOUTA [1], Adisa Ademola BELLO [1], Robinson Ichakpa EJILAH [1], Gideon Ayuba DUVUNA [2], Ede Egbudu GODWIN [3]

ABSTRACT

System profitability analysis and carbon (IV) oxide emission saved by an indirect passive solar cabinet dryer for tomatoes drying was evaluated under Bauchi (Nigeria) prevailing weather condition. Dryer minimum annual throughput of 27.89 kg occurred in the design month of August at 180 days of drying with thermal energy output of 262.55 kWh. Financial analysis indicated a minimum annual cash flow of ₦7,826.61 for electricity energy saved with a payback period of 14.22 years which is less than the economic useful life of the dryer in the design month, while preventing 105.02 kg of carbon (IV) oxide emission. This illustrates a conventional energy cost saving method for drying high moisture crop using a cleaner form of energy. The study recommends the development and adaptation of solar dryers with auxiliary heating units for proper harnessing of solar energy for environmental sustenance and economic growth.

Keywords: *profitability, solar dryer, thermal storage bed, carbon (IV) oxide, environmental friendliness*

INTRODUCTION

The search for adequate food preservation to enhance the nutritional status of children, increase global productivity and provide food security is immense. Improved technological innovations in the agricultural sector leading to increased crops annual yield hasn't overcome the challenge of food shortage due to inadequate storage facilities in some rural areas of the developing countries. The used of conventional energy as a power source in most food processing and storage units has further impacted negatively on the

[1] *Department of Mechanical/Production Engineering, Faculty of Engineering and Engineering Technology, Abubakar Tafawa Balewa University, Bauchi, Nigeria*
[2] *Department of Mechanical Engineering, Federal Polytechnic, Mubi, Nigeria*
[3] *Department of Mechanical Engineering, University of Jos, Nigeria*

environment creating more health challenges in addition to their cost implication. Alternative solar energy source has been explored for water and space heating applications. The used of well-designed solar air heaters attached to a housing arrangement where crops are kept for drying has demonstrated effectiveness for crop drying which serves as a post-harvest losses reduction method. The life cycle cost analysis of solar dryer is a function of numerous factors such as initial cost of investment for development, auxiliary heating cost (if any), system operational cost, total annual maintenance cost, annual cost of crops to be dried, useful expected life of solar dryer and its salvage value etc. Various empirical works existed on financial gains of solar drying and are review. Ahmad *et al.,* (2009) evaluated a solar dryer system suitable for agricultural and marine products under the Malaysia climate conditions. The double-pass solar collector with finned absorber, blower, the auxiliary heater and the drying chamber was evaluated for drying seaweed. From assuming potential market prices, the results of economic analyzes indicated that using the double-pass solar collector are best suited to be developed or marketed in marine products, as it is a payback period as low as 2.33 year to the drying of seaweed. Barnwal and Tiwari (2008) carried out a life cycle cost analysis of a self-sustained hybrid photovoltaic/thermal (PV/T) greenhouse dryer. The hybrid PV/T integrated greenhouse (roof type even span) dryer designed and constructed at Solar Energy Park, Indian Institute of Technology, New Delhi, India using dry Thompson seedless grapes under forced mode of operation. The annualized cost method was used to determine the payback period of the hybrid PV/T greenhouse dryer. The payback period was about 1.24 to 4.63 years which is lower than the 30 years expected life of the dryer. Kamble *et al.,* (2013) conducted performance test for drying green chilli using a solar cabinet dryer coupled with gravel bed heat storage system. The loading capacity of the dryer was about 15 kg of fresh produce per batch. An exhaust fan was provided in the drying chamber to suck the hot air from gravel bed heat storage during off sun shine hours for better heat retrieval. Drying time for drying green chilli from initial moisture content of 88.5% (wb) to 7.3% (wb) was estimated to be 56 hours in solar dryer whereas 104 hours was observed in the open sun drying. Drying efficiency of the solar cabinet dryer was found to be 34 %, while the ascorbic acid content in chilli, dried in solar dryer coupled with gravel bed heat storage system and in open sun drying was found to be 55.3 mg/100g (d.b) and 50.22 mg/100g (d.b), respectively. The benefit cost ratio and payback period for drying chilli in solar dryer coupled with gravel bed heat storage system was found to be 1.11 and 7 month and 11 days respectively. Samatcha *et al.,* (2019) investigated a developed parabolic greenhouse solar dryer to overcome product quality and post-harvest loss problems. Due to their high investment costs, economic feasibility and the potential of carbon dioxide (CO_2) mitigation were investigated. Owners and managers of 17 enterprises, producing several varieties of herb products, investing in different sizes of solar dryers and using various traditional drying methods before investing in solar dryers, were interviewed in depth to create a data set. The net present value (NPV), internal rate of return (IRR), payback period and CO_2 mitigation were evaluated. The enterprises with annual production capacities higher than 1,200 kg or the annual revenues higher than solar dryer investment costs tended to have positive NPV indicating that the investments were attractive. Most enterprises showing CO_2 mitigation higher than 130t CO_2 over 15 years had positive NPV. The annual production capacity, annual revenue and the amount of CO_2 mitigation could be used to assess investing in greenhouse solar dryers. Sengar *et al.,* (2009) selected Prawns (Kolambi) as drying material in low cost solar dryer (LCSD). Time required for reducing the moisture content from 75 to 16% were observed in open sun drying and solar drying for its comparison. Salted prawns were found most liked for its colour and texture than unsalted solar dried sample in sensory evaluation. Unsalted prawns sample dried in solar dryer was overall accepted, while traditionally open sun dried sample was least liked for its colour and texture. The value of F is calculated as 1.98 during the sensory evaluation. The economic cost of solar dryer was compared with mechanical drying for beneficial to local fishermen. The cost of LCSD was found to be affordable to poor fisherman comparing to other costly mechanical dryer. Local fisherman could recover solar dryer cost within the period of 0.19 years by adopting solar drying technology. Manjarekar and Mohod (2010) carried out a study for a solar tunnel dryer for drying peeled prawns. Economic evaluation of solar tunnel dryer was done in comparison with open sun drying method. The cost economics of dried peeled prawns was proved to be better for solar tunnel dryer than open sun dried method. Thus, solar tunnel dryer can be proposed as a suitable alternative to the local method of drying fish.

It is worth noting that, the use of solar energy has proven to have positive, indirect effect on the environment when solar energy systems replaces or reduces the use of conventional energy sources that have larger negative effects on the environment. However, it is inappropriate declaring that solar energy systems have zero emissions. For instance, photovoltaic modules and solar thermal systems production or manufacturing processes of their various components are made of materials that are mined and processed in addition to the environmental impact when such equipments are delivered to project sites for installation (Parliamentary Office of Science and Technology, 2006; Solar Bay, 2020). Nonetheless, the lifetime emissions from solar power and solar thermal systems are much less than those produced by fossil fuels. Accordingly, a United States based National Renewable Energy Laboratory, NREL estimated that solar power produces lifetime emissions of 40 g carbon (iv) oxide, CO_2 equivalent per kilowatt-hour, kWh. Comparatively, many coal power plants produce over 1,000 g of carbon (IV) oxide, CO_2 equivalent/kilowatts hour, with the cleanest coal power generally above 700 g CO_2 equivalent/kilowatts hour. Natural gas generation is less polluting, with emissions above 400 g of carbon (IV) oxide, CO_2 equivalent/kilowatts hour (Parliamentary Office of Science and Technology, 2006; WNA, 2011; NREL, 2020).

This study focuses on the profitability of a solar dryer having sensible heat storage for drying high moisture crop, electricity energy and carbon (IV) oxide savings.

MATERIALS AND METHODS

Materials

System description

The investigated solar dryer is of indirect natural convention type incorporated with a sensible heat storage material (gravels) under the collector. The absorber plate material is made from an aluminium sheet of 0.5 mm thickness, a 4 mm plain glass served as the glazing for providing the system greenhouse effect, while the drying chamber houses two trays made from stainless wire mesh which could hold tomatoes slices of 3 kg per tray. The supporting frames for the collector and drying chamber housing were both made from mild steel angle iron of 25 mm by 25 mm by 2.5 mm and covered with 1.5 mm mild steel sheet. The units were well insulated using saw dust to a thickness of 50 mm to minimise heat losses. Two doors are provided for product loading and unloading. The experimentation was for a span of six months (March, 2020 to August, 2020) with each drying batch of 6 kg.

Methods

Theoretical consideration of techno-economic analysis

Profitability of a solar thermal system is a function of varying factors including region, maintenance, and design etc. (Sreekumar, 2013). The system is studied for its net present value, annualized uniform cost, annualized salvage value, annual cash flow and payback period.

Annual Cash Flow

The annual cash flow of this renewable energy based thermal device is computed on the basis of its energy savings accruing from it as provided by the cost of electricity tariff by Jos Electricity Distribution Company, JED (Tshewang, 2005; Adeaga *et al.,* 2015). The expression for the batch thermal energy output of the system is given in Equation 1 (Sujata *et al.,* 2012):

$$(Qu)_{batch} = moisture\ evporeted\ (kg) x\ latent\ heat\ of\ evaporation\ (\frac{J}{Kg})$$

$$\frac{(M_w \times 2.26 \times 10^6)}{3.6 \times 10^6} Kwh \qquad (1)$$

Therefore, annual thermal output of the dryer, E_{cout}

E_cout=Batch thermal output of system, kWh× number of drying batch
(2)

$E_{cout} = B_T \times D_{ba}$ for the month of August

$E_{cout} = B_T \times D_{bm}$ for the month of March

where:

$D_{bm} = \frac{N_c}{1.67}$ for the month of March (3)

$D_{ba} = \frac{N_c}{2.42}$ for the month of August (4)

N_c is the number of clear days in a year

Hence, the annual cash flow,

$CF = E_{cout} \times unit\ cost\ of\ electircty$
(5)

Net Present Value, P_{NPV}

The net present value, NPV for each year of the net cash flow less capital costs. It is given in Equation 6 as reported by Fudholi (2006).

$$P_{NPV} = \left[P_i + R_m \times \left(\frac{(1+i)^n - 1}{i(1+i)^n}\right) + R_p\left\{\left(\frac{1}{(1+i)^5}\right) + \left(\frac{1}{(1+i)^{10}}\right) + \cdots\right\} - S \times \left(\frac{1}{(1+i)^n}\right)\right] \quad (6)$$

For a solar thermal system of 15 years, Equation 6 becomes
where:
i, annual rate of interest in fraction, %; P_i, is the initial investment of the system, ₦ ; S, salvage value of the system at the end of its useful life, ₦; n, expected life of the system, years ; R_m, operational and maintenance expenses, ₦; $R_{p,}$ cost of any replaceable part, ₦.

Annualized Uniform Cost, Unacost (R)

The annualized uniform cost, Unacost (R) of net present value for the system and its capital recovery factor (CRF) according to Tiwari (2002) can be written as in Equation 7

$$Unacost(R) = P_{NPV} \times capital\ recovery\ factor\ (CRF) \quad (7)$$

$$Unacost\ (R) = P_{NPV} \times F_{PR,i,n} = P_{NPV} \times \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \quad (8)$$

Where the capital recovery factor (CRF) is expressed as:

$$CRF = F_{PR,i,n} = \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \quad (9)$$

Payback Period, n_p

are uniform annual net cash flow (CF) the net present value (N_NPV) can be expressed as in Equation 10 as given by Tiwari and Tiwari (2007):

$$P_{NPV} = CF \times F_{RP,i,np} = CF\left[\frac{(1+i)^{n_p} - 1}{(1+i)^{n_p}}\right] \quad (10)$$

or

$$(1+i)^{n_p} = \left[\frac{CF}{CF - iP_{NPV}}\right] \quad (11)$$

or

$$n_p = \frac{ln\left[\frac{CF}{CF - iP_{NPV}}\right]}{ln(1+i)} \quad (12)$$

Annualized Salvage Value R′ of the System

The system annualized salvage value as given by Tiwari and Tiwari (2007) is stated in Equations 13 and 14.

$$R' = S\frac{i}{(1+i)^n - 1} \quad (13)$$

$$R' = SF_{SR,i,n} \quad (14)$$

CoCost of Drying, C_g

If D_P is the dried product output per year in kg, then cost of drying C_g, is evaluated by Equation 15:

$$C_g = \frac{Unacost,R}{D_P} \quad (15)$$

Where;

D_P is the quantity of dried product output per annual, kg.

Annualized Cost of Drying Product

The annual cost of drying the product is given in Equation 16:

$$R^* = (R - R') \tag{16}$$

System cost evaluation

The cost implication for the development of the various components that made up the indirect solar passive cabinet dryer with thermal storage bed is stated Table 1.

Table 1. Evaluation cost for the construction of the solar cabinet dryer as at January, 2020

S/No	Unit	Total Cost (₦)
1	Solar collector	19,625.00
2	Solar collector support	8,550.00
3	Drying chamber housing	12,500.00
4	Dryer drying chamber housing	8,750.00
5	Drying trays	5,750.00
6	Cost of labour	17,500.00
7	Grand Total	72,675.00

Data for Techno-Economic Analysis

The following are the data used for the techno-economic analysis:

1. Economic life, n of system = 15 years (Sreekumar, 2013; Sajith and Muraleedharan, 2014; SRCC, 2017)
2. P_i is the initial investment = ₦72,675.00
3. R_m is operational and maintenance expenses = ₦0:00
4. R_p is cost of any replaceable part every five years (wood and nails) = ₦925.00
5. Salvage, $S_l$value of system = 1816.87 (2.5% of the initial investment)
6. i is annual rate of interest taken as 2, 4 and 6% respectively
7. Price of electricity = ₦29.81 kWh (Jos Electricity Distribution, JED, March-August 2020)

Data for estimating the equivalencies of carbon (iv) oxide, CO_2 emission saved

1. Carbon (IV) oxide, CO_2 emission from natural gas power plants = 0.4 kg/kWh (WNA, 2011; Agrawal *et al.*, 2014; NREL, 2020)
2. Carbon (IV) oxide, CO_2 emission from coal power plants = 0.7 kg/kWh (WNA, 2011; Agrawal *et al.*, 2014; NREL, 2020)

RESULTS AND DISCUSSION

Techno-Economic Analysis

The initial estimated cost for the solar cabinet dryer investment is put at, P_i is ₦72,675 with a expected lifespan of 15 years considering system materials composition and its location (Sreekumar, 2013; Sajith and Muraleedharan, 2014; SRCC, 2017). Equations 6, 9 and 14 were used to work out the net present values P_{NPV}, Unacost, R and the annualized salvage value, R' of the system respectively with interest rates of 2, 4 and 6% and results presented in Table 2. The interest rates of 2, 4 and 6% are appropriate for some government agencies that promote agricultural and renewable energy activities, loans from some cooperatives, and borrowings from friends, families and relations. However, this excludes commercial banks which interest rates are usually exorbitant for small and medium scale enterprises which mainly do not enjoy economies of large scale production. Other relevant equations were employed to compute the dryer annual product output, cost of drying, system annual thermal output, annual cash flow and payback period respectively for variation in annual total number of clear days in a year (Figures 1, 5 and 5). The results shows the annual cash flow as a function of the system annual thermal output, and is proportional to the number of clear days in a year, while the system annual cost of drying indicated an increasing trend as the interest rate increases with reduction in the total annual number of clear days for drying leading to decreased in dryer output (Figure 4). The economic analysis clearly show that the highest cost of solar dried tomatoes slices occurred in the design month (#271.38/kg) at an interest rate of 6%, which corresponds to minimum total annual number of clear days of drying (180 days) with a payback period of 14.22 years (less than the system expected useful life of 15 years). It can also be seen that the payback period increases with a decrease in the annual cash flow (i.e. total annual income) due to reduction in number of clear days (decrease dryer output). Additionally, it is further noted that the effect of interest rate is significant on payback period in the design month most especially at low annual cash flow (i.e. low dryer output) but show no significant effect on higher annual cash flow as shown (Figures 5 and 6). Thus, the system will be more profitable if government and other financial institutions could lend out credit facilities at interest rates not exceeding 6% to encourage small scale farmers borrowing for such investment to boost their socio-economic life.

Table 2. Net present value and unacost of the solar cabinet dryer (n=15 years)

P_i (₦)	S (₦)	R_p, (₦)	i, (%)	P_{NPV} (₦)	R, (₦)	R′ (₦)	R* (₦)
72675	1816.87	925	2.0	73608.94	5728.65	105.06	5623.59
			4.0	73564.95	6616.54	90.74	6525.80
			6.0	73510.52	7568.84	78.05	7490.79

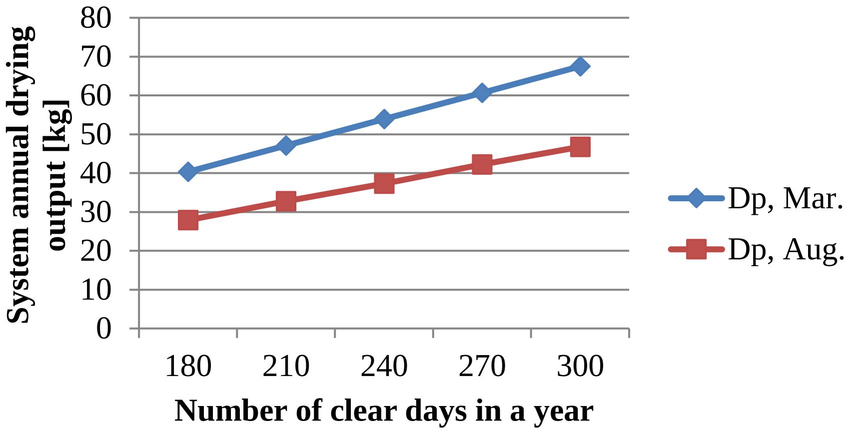

Figure 1. Solar dryer annual drying output for the months of march and august.

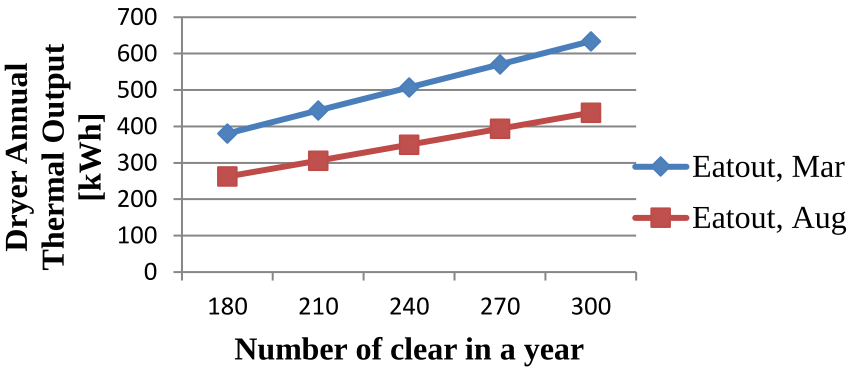

Figure 2. System annual thermal output against number of clear days for the months of March and August

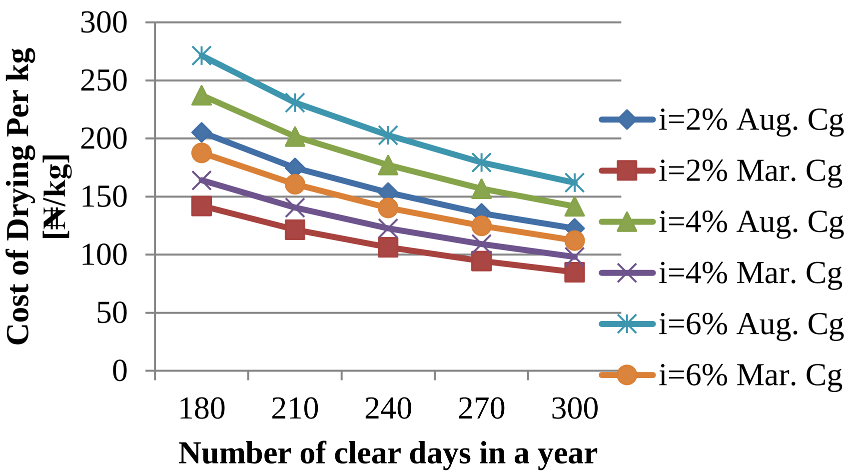

Figure 3. System cost of drying against number of clear days in a year at varying interest rates for the months of March and August

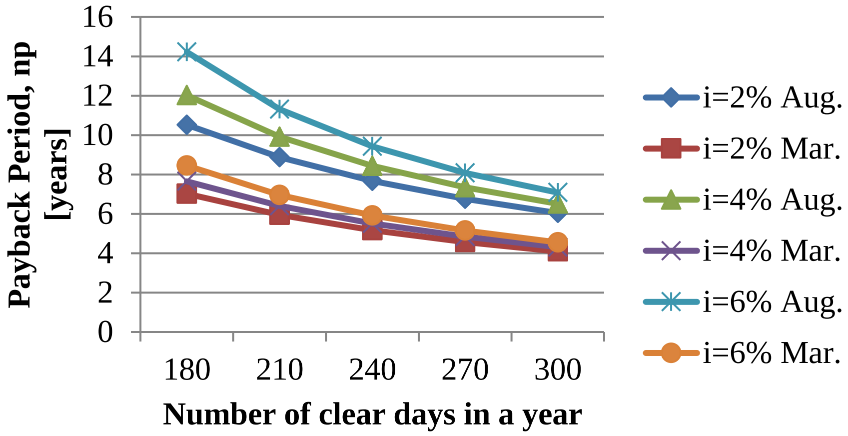

Figure 4. System payback period against number of clear days in a year for the months of march and august

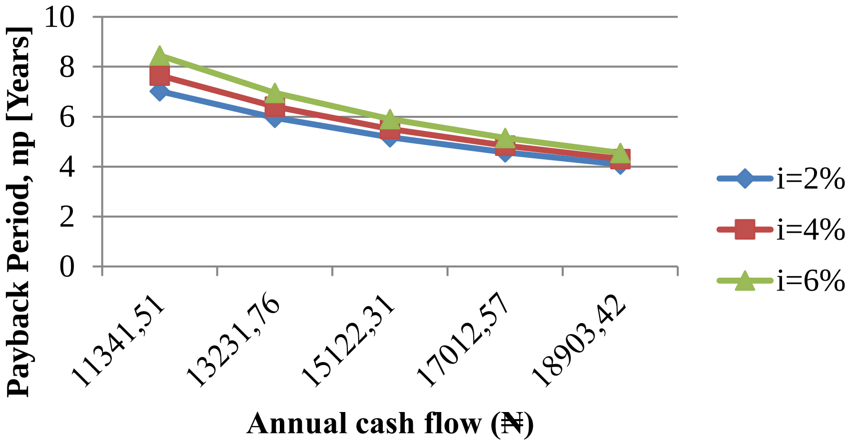

Figure 5. Effect of annual interest rate on payback period for the solar cabinet dryer for the optimum month (March)

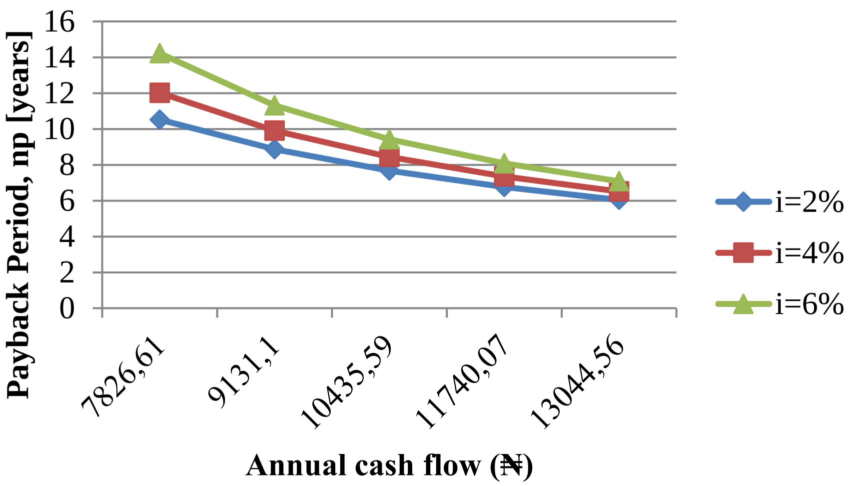

Figure 6. Effect of annual interest rate on payback period for the solar cabinet dryer for the design month (August)

Carbon (IV) Oxide Emission Saved

The total equivalencies of the saved carbon (IV) oxide emission for utilizing the solar thermal system for its economic useful of 15 years is estimated based on the minimum established carbon (IV) oxide, CO_2 emissions from natural gas and coal power plants for one kilowatts hour of electricity generation using such power plants respectively. Natural gas and coal power plants have estimated annual minimum and maximum carbon (IV) oxide, CO_2 emissions of 105.02 kg and 183.79 kg, and 253.65 kg and 443.89 kg respectively for the solar thermal system (Figure 6). These figures are relatively high and the reduction in the emission of carbon (IV) oxide, one of the greenhouse gases will impact positively on individuals, businesses, communities and countries in a number of ways. Improvement in public health, slow climate change, cost savings by businesses and countries will make available resources for other meaningful developments and investments. Countries will tend to improve in their external relations with other nations creating healthy allies, while ensuring proactive regulatory compliance is prevalent in the minds of organizational leadership, public spheres and stakeholders. The implementation of an effective greenhouse gas emission reduction strategy is imperative for continue operations and fines reductions for multinational companies.

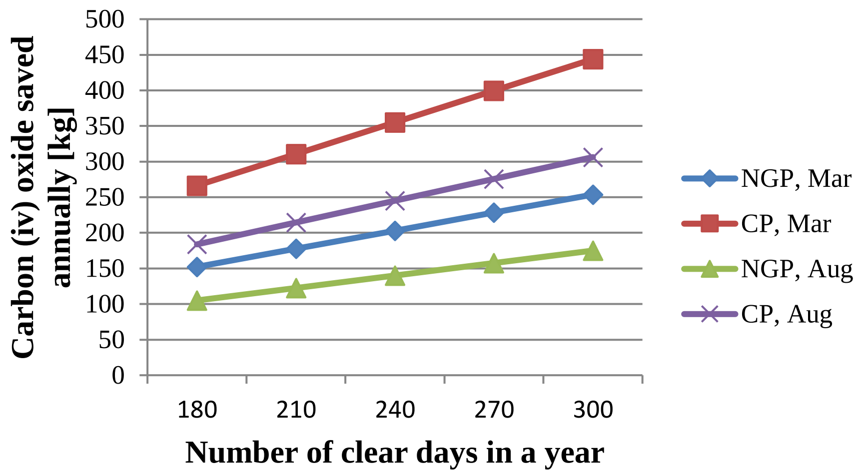

Figure 7. Annual equivalencies of carbon (IV) oxide, CO_2 emission saved for the month of March and August

CONCLUSION

A two tray passive solar cabinet dryer with thermal storage bed designed and constructed for drying high moisture content crop was presented. The results of this research study led to the following conclusions. The system indicate a capacity of producing between 27.89 kg to 67.48 kg solar dried tomatoes slices per annual under hygienic condition with annual energy savings cost (electricity) of ₦7,826.61 to ₦13,044.56 in the design month and ₦11,341.51 to ₦18,903.42 in the optimum month. The maximum payback period for the optimum and design month at 6% interest rate considering annual minimum drying duration of 180 days is 8.45 and 14.22 years respectively which is less than system economic useful life of 15 years. This implies a significant cost savings for solar drying using the system to cost of drying with electricity.

Besides, there is enormous savings of carbon (IV) oxide, a greenhouse gas emission which contribute evasively toward greenhouse effect. This is due to cost by accumulation and energy expenditure. This makes solar drying more cost efficient when the total energy cost over the system's life is taken into account. Government, corporate organizations and individuals should invest more funds in the area of research and development for renewable energy technology (solar air heating application). This will aid in the massive production and utilization of better improved renewable systems that will curtail the use of conventional energy devices. Renewable energy devices could also be subsidy to end users to reduce the initial cost implication of acquiring such systems most especially for rural dwellers in developing countries.

REFERENCES

1. Adeaga, O.A., Dare, A.A., Odunfa, K.M. and Ohunakin, O.S. (2015). *Modeling of solar drying economics using life cycle savings (L.C.S) method*. Journal of Power and Energy Engineering, 3: 55-70.
2. Agrawal, K.K., Jain, S., Jain, A.K. and Dahiya, S. (2014). *Assessment of greenhouse gas emissions from coal and natural gas thermal power plants using life cycle approach.* International Journal of Environmental, Science and Technology, 11: 1157-1164.
3. Ahmad, F.M., Yusof Otman, Mohd Hafidz Ruslan, Muhammad Yahya, Azami Zaharim and Kamaruzzaman Sopian (2009). *Techno-economic analysis of solar drying system for seaweed in Malaysia*. Recent Researches in Energy, Environment and Landscape Architecture: 89-95.
4. Barnwal, P. and Tiwari, G.N., (2008). *Life cycle cost analysis of a hybrid photovoltaic/thermal greenhouse dryer*. Open Environmental Sciences, 2: 39-46
5. Fudholi, A. (2006). Analisis teknoekonomi sistem hibrid angin fotovolta (SHAF) dalam memperoleh tenaga elektrik untuk rumah kediaman di Malaysia. Tesis Master, Universiti Kebangsaan Malaysia.
6. Kamble, A.K., Pardeshi, I.L., Singh, P.L. and Ade, G.S. (2013). *Drying of chilli using solar cabinet dryer coupled with gravel bed heat storage system.* Journal of Food Research and Technology, 1(2): 87-94
7. Manjarekar, R.G. and Mohod, A. G. (2010). *Economic evaluation of solar tunnel dryer for drying peeled prawns.* International Journal of Agricultural Engineering, 3(1): 68-72.
8. National Renewable Energy Laboratory, NREL (2020).
9. Parliamentary Office of Science and Technology (2006). *Carbon footprint of electricity generation*. Post-Note, No. 268.
10. Sajith, K.G. and Muraleedharan, C. (2014). *Economic analysis of a hybrid photovoltaic/thermal solar dryer for drying amla*. International Journal of Engineering Research and Technology, 3(8): 907-910.
11. Samatcha, K., Kanokwan Kingphadung, Suphaphat Kwonpongsagoon and Mahayothee (2019). *Costs and benefits of using parabolic*

greenhouse solar dryers for dried herb products In Thailand. International Journal of GEOMATE, 18(67): 96-101.

12. Sengar, S. H., Khandetod, Y.P. and Mohod, A.G. (2009). *Low cost solar dryer for fish*. African Journal of Environmental Science and Technology, 3(9): 265- 271.
13. Solar Bay (2020). *How much emissions does a solar power system Prevent?* Solar Bay Publication Limited, New South road, Double Bay, Australia.
14. Solar Rating and Certification Corporation (SRCC) (2017). Information on http://www.solar-rating.org
15. Sreekumar, A. (2013). *Evaluation of a roof-integrated solar air heating system for drying foodstuffs*. International Journal of Emerging Technology and Advanced Engineering, 3(3): 209-213.
16. Sujata, N., Zeba, N., Pushpendra, Y. and Ruchi, C. (2012). *Economic analysis of hybrid photovoltaic-thermal (PVT) integrated solar dryer*. International Journal of Engineering Inventions, 1(11): 21-27.
17. Tiwari, G.N and Tiwari, A.K. (2007). *Solar distillation practice for water desalination systems*. Anamaya Publishers. New Delhi, India.
18. Tiwari, G.N. (2002). Solar energy, fundamentals, design, modelling and applications. First Edition; Narosa Publishing House, New Delhi: India.
19. Tshewang, L. (2005). *Technical and financial feasibility of a solar dryer in Bhutan*. Published M.Sc Thesis, International Technologies Centre (IDTC), University of Melbourne.
20. World Nuclear Association, WNA (2011). *Comparison of lifecycle greenhouse gas emissions of various electricity generation sources*. World Nuclear Association Report. Carlton House London, United Kingdom.

Corresponding Author: Benjamin Ternenge Abur
ORCID:0009-0005-3072-4004
e-mail:tbabur@atbu.edu.ng
Phone:+2348065951129

Department of Mechanical/Production Engineering
Faculty of Engineering and Engineering Technology
Abubakar Tafawa Balewa University
Bauchi, Nigeria

Habou Dandakouta
e-mail:dhabou@atbu.edu.ng
Phone:+2348038530933

Department of Mechanical/Production Engineering
Faculty of Engineering and Engineering Technology
Abubakar Tafawa Balewa University
Bauchi, Nigeria

Corresponding Author: Adisa Ademola Bello
Phone:+2348035733944

Department of Mechanical/Production Engineering
Faculty of Engineering and Engineering Technology
Abubakar Tafawa Balewa University
Bauchi, Nigeria

Robinson Ichakpa Ejilah
ORCID: 000-0002-6941-3570
e-mail:irejilah@atbu.edu.ng
Phone:+2348057243194

Department of Mechanical/Production Engineering
Faculty of Engineering and Engineering Technology
Abubakar Tafawa Balewa University
Bauchi, Nigeria

Gideon Ayuba Duvuna
e-mail:ayubagideon2@gmail.com
phone:+2347032692982

Department of Mechanical Engineering
School of Engineering
Federal Polytechnic
Mubi, Nigeria

Godwin Egbudu Ede
ORCID:0000-0003-1514-2880
e-mail:tbabur@atbu.edu.ng
phone:+2348065951129

Department of Mechanical Engineering
Faculty of Engineering
University of Jos
Jos, Nigeria

Received: June 04, 2024
Revised: September 7, 2024
Accepted: September 11, 2024