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LIFE CYCLE ASSESSMENT AND ECONOMIC VALUATION OF A NATURAL CONVECTION SOLAR GREENHOUSE DRYER IN WESTERN MAHARASHTRA, INDIA

Aditya Arvind YADAV[1*], Pravin A. PRABHU[2], Jaydeep S. BAGI[2]

[1]M. Tech (Energy Technology), Department of Technology, Shivaji University, Kolhapur, Maharashtra State, India, e-mail: adiyadav821@gmail.com
[2]Co-ordinator M. Tech (Energy Technology), Department of Technology, Shivaji University, Kolhapur, Maharashtra State, India
[3]Director, Department of Technology, Shivaji University, Kolhapur, Maharashtra State, India

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Abstract: The current study focuses on the life cycle assessment and an economic valuation of a natural convection solar greenhouse dryer in Western Maharashtra, India. The Solar Greenhouse Dryer is an active device that gains solar radiation incident on to the surface of the dryer and along with wind energy, it removes moisture from agricultural yield. The combination of solar energy and wind energy removes moisture from agricultural yield. The Solar Greenhouse Dryer is primarily used in rural settings; hence, it is very important to analyse the environmental and economic aspects associated with the dryer to obtain the maximum benefit from the dryer with less investment possible. The experiment involving a natural convection solar dryer was conducted at Bahe, Borgaon, Tal-Walwa, Dist- Sangli, Maharashtra, India located at 17.115° N and 74.33° E. The environmental parameters taken into considerations during the analysis covered energy, energy payback time and CO_2 emissions, mitigation and carbon credits earned by the dryer. The economic analysis of the solar dryer consists of the annual cost of the dryer, the salvage value, the annual saving obtained and the payback period respectively. The embodied energy of the solar greenhouse dryer considering all the components of the dryer is 238.317 kWh, the energy payback time is 0.588 years and CO_2 emissions are 24.327 kg per year, the carbon dioxide mitigation is 2.042 kg per kWh and the carbon credits earned by the dryer are nearly 28, 600. The annual cost of the dryer is Rs. 21, 600, the salvage value of the dryer is Rs. 7, 160, the annual savings obtained from the dryer are Rs. 1,62, 574 and the payback period is around 2 years respectively. The Solar Greenhouse Dryer is a cost-effective and environmentally friendly solution that can effectively be used in rural settings by farmers to prevent various post-harvest losses associated with the agricultural yield and to gain extra additional income from the dried products.

Keywords: solar greenhouse dryer, drying, moisture removal, life cycle assessment, economic valuation

1. INTRODUCTION

The solar drying technique is one of the oldest and traditional techniques used for the post-harvesting of crops, vegetables, and fruits. The main aim of the drying process is to decrease or release the moisture of the crop so that no excess growth of microbes should cause any further losses. Open drying was implemented in many countries as the drying process is easily accessible for crops, but the open sun drying affects the flavor of the dried product, its texture and the color because the temperature exceeds some limit [1]. Therefore, controlled drying is one of the advanced techniques that is used for drying crops under adequate temperature conditions to avoid flavor, texture, and color losses during the drying process. The loss during the open sun drying is sometimes unrecoverable. The texture of the dried products affects the taste of the product. The atmospheric conditions also affect the open sun drying phenomenon. The uneven change in the climate, uneven rainfall, uneven winds affect the dried products to a greater extent. The quality and quantity of the final drier products are affected due to such uneven climatic conditions. The actual working of open sun drying is that the dried product is laid under solar radiation for drying [2]. The solar energy incident onto the dried product heats the product and finally releases the moisture content into the dry adjacent air thereby reducing the moisture of the dried product. The drying process is very useful in the agricultural context as it lowers post-harvest crop losses. It is been estimated that nearly 10% to 40% of the crops harvested every year face the problem of post-harvest losses. [3]

In India, the climatic zones are divided into five types, namely hot and dry, warm and humid, composite, temperate and cold respectively. According to climatic zones, crops are grown in those particular areas, there is a need for proper post-harvest technology that needs to be implemented considering the climatic zones. The farmers in India rely most on open sun drying for agricultural yields, but in some parts of the nation like cold zones, probably the northern states of India have a very little amount of solar radiation. Therefore, there is a need for implementing a proper post-harvest technology that can suit the various climatic zones of India. The Solar Greenhouse Dryer (SGHD) is an active device that utilizes the incident solar radiation onto the surface of the dryer to allow heat gained by solar insolation to be trapped into the dryer and it utilizes that heat energy to dry agricultural yield by using natural convection. The rural areas of India lack electricity; due to excess load shedding, this leads to a major loss of agricultural yield in rural areas. The system designed for drying agricultural yield should be independent of grid electricity, thus natural convection is to be considered for drying. The objectives of the present study are to determine the parameters of the Solar Greenhouse dryer that matches the local conditions i.e., the local environmental conditions of Western Maharashtra, and to evaluate the performance parameters such as the temperature, moisture content of the dried product.

The term greenhouse dryer is used for a building that is highly glazed with thermal conditioning for the desired range and it is used for cultivating crops, plants, vegetables, etc. The actual working of a greenhouse is that short-wave radiation falling on the greenhouse is absorbed by the outer glazing material thereby heating the interior area of the greenhouse and providing ambient heat for plants and vegetable growth respectively. The heated space is retained within the enclosure of the greenhouse. This phenomenon is called the greenhouse effect. The important role played during the greenhouse effect phenomenon includes the atmosphere, insulating roofs, walls, etc. [4].

When solar radiation strikes the surface of the earth, some of it is absorbed by the earth's surface, while the rest is reflected as infrared radiation. This infrared radiation emitted by the surface of the earth is then absorbed by various gases like CO_2, methane, NO_x, and water vapor. This absorption of infrared radiation by the atmosphere and various gases like CO_2, methane, NO_x, and vaporized water is called the greenhouse effect. The greenhouse effect helps in maintaining the temperature of the earth at ambient temperature; without the greenhouse effect, the earth's temperature would be -18°C [4].

The various parameters considered during the designing of the solar greenhouse dryer are as follows.

1. Glazing Materials. The proper glazing materials allow maximum solar radiation to enter the greenhouse dryer. The heat loss from the glazing material should be as minimum as possible. The glazing material should have maximum absorptivity and minimum reflexivity. The thin plastic foil absorbs direct and diffuse solar radiation.
2. Ventilation methods can be divided into free and forced ventilation. Free ventilation can be effectively used for solar drying as there is a lack of electricity in rural areas.
3. Solar Orientation. The Solar Greenhouse Dryer should be south-oriented to gain maximum solar radiation. The roof inclination should have a 23° to 25° roof angle to gain 90% of solar radiation. The north wall of the Solar Greenhouse Dryer is well insulated to avoid heat loss.[4]

2. OBJECTIVES OF THE STUDY

An environmental and economic analysis of the Solar Greenhouse dryer is important to find out the cost required for drying agricultural yields. The study was conducted using standard environmental and economic tools with the following objectives.

1. To estimate the Energy Payback Time (EPT) using the embodied energy.
2. To evaluate the economic feasibility of the natural convection of the Solar Greenhouse Dryer in Western Maharashtra, India in terms of the annual cost of the dryer, savings obtained from drying and the payback period.
3. To evaluate the methods of profitability such as the payback period, the rate of return etc.

3. METHODS

The parameters analyzed during the environmental analysis include the embodied energy, the energy payback time and the Co_2 emissions, the mitigations and carbon credits earned. The economic analysis consists of such parameters as the annual cost of the dryer, the salvage value, the annual savings earned from the dryer and the payback period respectively.

4. EXPERIMENTAL SETUP

The proposed Solar Greenhouse Dryer has a triangular roof with a vent on the roof side to allow air passage for ventilation. The Solar Greenhouse Dryer is manufactured initially with a Mild Steel square pipe and is covered with a thin plastic foil of 2 mm thickness, to allow maximum solar gain during sunshine hours. The bottom surface of the Solar Greenhouse dryer was covered with a sandbar or course sediment for the heat gained from the sun to be trapped into the Solar Greenhouse Dryer [9]. The roof of the Solar Greenhouse Dryer was provided with an inclination of 17° i.e., the latitude of Bahe Borgaon, Tal-Walwa, Dist-Sangli, Maharashtra, India, where the experiment was conducted [10]. The overall dimensions of the Solar Greenhouse Dryer are as given in Table 1.

Tab. 1. Dimensions of Solar greenhouse dryer

Sr. no.	Specifications	Details, mm
1.	Length	1000
2.	Height	400
3.	Width	600

The drying tray provided for SGHD was inclined to the base surface to maximize the inclined solar radiation onto the dryer. The two-air inlet was provided along with the upper duct section for a free passage of air into the Solar Greenhouse Dryer. The drying tray is provided with a fine wire mesh for drying the agricultural yield. The North wall of the Solar Greenhouse Dryer was insulated to avoid heat loss during the drying process [11]. The drying process was performed using free convection, as in many rural areas there is load-shedding due to which electricity cannot be effectively used for the drying phenomenon [12]. The actual experimental setup with the north wall insulation is as shown in the Figure 1.

Fig. 1. Experimental Setup of Solar greenhouse dryer

5. RESULTS

5.1. ENVIRONMENTAL ANALYSIS

The Environmental Analysis covers the actual calculations of the embodied energy, the energy payback time and CO_2 Emission, the mitigation, and carbon credits. The details of the environmental analysis are as described.

Embodied Energy

The embodied energy can be defined as the total energy required to manufacture the experimental setup of a solar greenhouse dryer and it is called embodied energy (Eb) [5-6]. Various materials are used during the the manufacturing of solar greenhouse dryer such as aluminium mesh (tray), steel frames, pebbles and sand coarse mixture for thermal energy storage, and thin plastic foil. The details of the embodied energy for the proposed solar greenhouse dryer is as described in Table 2.

Tab. 2. Details of embodied energy

Sr. no	Details of materials used	Embodied energy, kWh/kg	Q-ty used, kgs	Total embodied energy, kWh
1.	Aluminium mesh (Tray)	55.28	1	55.28
2.	Steel (Frame)	8.89	20	177.8
3.	Pebbles and sand (TES)	0.0278	5	0.139
4.	Thin Plastic Foil	10.1974	0.500	5.0987
Total				238.317 kWh

Energy Payback Time

The Energy Payback Time is defined as the time taken by the solar greenhouse dryer to recover the energy invested through embodied energy [6].

Mathematically. it can be expressed as:

$$\text{Energy Payback Time} = \frac{\text{Embodied Energy (kWh)}}{\text{Annual Energy Output }(\frac{\text{kWh}}{\text{Yr}})}. \quad (1)$$

Now the daily thermal output can be calculated using the formula:

$$\text{Daily Thermal Output} = \frac{\text{Mositure Evaporated per day (kg)} \times \text{Latent Heat(J/kg)}}{3.6\times10^{\wedge}6}, \quad (2)$$

$$\text{Daily Thermal Output} = \frac{4\times2430000}{3.6\times10^{\wedge}6}. \quad (3)$$

Therefore, Daily Thermal Output = 2.7 kWh.

The Annual Energy Output can be calculated using Formula 4.

$$\text{Annual Energy Output} = \\ = \text{Daily Thermal Output} \times \text{No. of sunshine days}, \quad (4)$$

therefore:

$$\text{Annual Energy Output} = 2.7 \times 150, \quad (5)$$

$$\text{Annual Energy Output} = 405 \text{ kWh / Year}. \quad (6)$$

Now, if the Energy Payback Time is equal to:

$$\frac{\text{Embodied Energy (kWh)}}{\text{Annual Energy Output } (\frac{\text{kWh}}{\text{Yr}})}, \quad (7)$$

then:

$$\text{Energy Payback Time} = \frac{238.317}{405} \quad (8)$$

$$\text{Energy Payback Time} = 0.588 \text{ Years} \quad (9)$$

CO_2 emissions per year

The electricity generated from the grid is usually generated in a coal-powered thermal power plant, thus CO_2 emission is taken as 0.98 kg/kWh [7]. The annual CO_2 emission is given by the following formula:

$$CO_2 \text{ Emission per year} = \\ = \frac{\text{Embodied energy} \times 0.98}{\text{Life of Dryer}} \times \frac{1}{1-Lda} \times \frac{1}{1-Ldt}, \quad (10)$$

where *Lda* – domestic appliances losses (20%), *Ldt* – transmission and distribution losses (40%).
Therefore

$$CO_2 \text{ Emission per year} = \\ = \frac{238.317 \times 0.98}{20} \times 2.0834 = 24.327 \text{ kg}. \quad (11)$$

Carbon Mitigation through Greenhouse

The carbon mitigation by the solar greenhouse dryer can be given by the formula below:

$$CO_2 \text{ mitigation (kWh/Yr)} = \frac{1}{1-Lda} \times \frac{1}{1-Ldt} \times 0.98, \quad (12)$$

$$CO_2 \text{ mitigation (kWh/Yr)} = 2.042, \quad (13)$$

$$CO_2 \text{ mitigation (lifetime)} = \\ = \text{Embodied energy} \times 2.042, \quad (14)$$

$$CO_2 \text{ mitigation (Lifetime)} = 486.64 \text{ kg}. \quad (15)$$

Now, the net carbon mitigation over the lifetime of 20 years of the solar greenhouse dryer is given by net carbon mitigation that is equal to total CO_2 mitigation minus total CO_2 emission. Therefore, net carbon mitigation equals the annual energy output times the life of the dryer minus the embodied energy times 2.042:

$$\text{Net Carbon Mitigation} = \\ = 405 \times 20 - 238.317 \times 2.042 = 7613.36 \text{ kg}. \quad (16)$$

Now, the carbon credits earned by the solar greenhouse dryer can be calculated using the formula:

$$\text{Carbon Credit Earned} = \\ \text{Net } CO_2 \text{ Mitigation} \times \text{Price per ton of } CO_2 \text{ Mitigation} \quad (17)$$

$$\text{Carbon Credit Earned} = 7.613 \times 3750 \quad (18)$$

$$\text{Carbon Credit Earned} = 28,548.75 \sim 28,600. \quad (19)$$

5.2. ECONOMIC ANALYSIS

The economic analysis is defined as the cost invested in the solar greenhouse dryer during its construction, operation and maintenance. The amount invested in the solar dryer can be either recovered by dried byproducts and is termed as the payback period [8]. The assumptions made in the economic analysis are given below.

Assumptions

The following assumptions were made to assess the economic feasibility of the solar dryer for grapes drying.

1. The useful life of the solar greenhouse dryer is taken as 10.
2. The processing capacity of the Solar Greenhouse Dryer is 5 kg/batch/day.
3. The discount rate considered is 8%.
4. The dryer can be operated 200 days a year.
5. The annual maintenance cost of the solar dryer is taken as 1 % of the annual cost of the solar greenhouse dryer.

The details of the energy cost in solar greenhouse dryer are as given below. The energy requirement of the solar greenhouse dryer can be calculated. The capacity of the dryer is equal to 5 kg/batch.
Now,

$$\text{Energy requirement of SGHD per day per batch} = \\ = m \times Cp \times \Delta T, \quad (20)$$

$$\text{Energy requirement of SGHD per day per batch} = \\ = 5 \times 3.81 \times (58 - 25) = 628.65 \text{ kJ} \quad (21)$$

For the economic analysis, the energy requirement needs to be converted into kWh, as the grid electricity and charges are as per kWh rating. We know that 1 kJ is equal to 0.000277 kWh.

The energy Requirement of SGHD (kWh) is equal to 628.65× 0.000277. Therefore, the energy requirement of SGHD/day/ batch(kWh) is 0.1746 kWh.
Now,

$$\text{Energy requirement per kg (kWh)} = \frac{0.1746}{5}, \quad (22)$$

$$\text{Energy requirement per kg (kWh)} = 0.0349. \quad (23)$$

Now, the Total Annual Consumption (kWh) is equal to 0.1746 × 200, so:

$$\text{Total Annual Consumption (kWh)} = 34.92. \quad (24)$$

The annual energy cost can be calculated considering 1 unit at 6 Rs:

$$\text{Annual Energy Cost} = 34.92 \times 6 = 209.52 \text{ Rs.} \quad (25)$$

The specific cost per kg can be calculated using the following formula:

$$\text{The specific cost of drying per kg} = \frac{210}{5} = 42 \text{ Rs.} \quad (26)$$

Tab. 3. Economic analysis of Solar Greenhouse Dryer.

Sr. no	Details	Q-ty
1.	Dryer Capacity (kg)	5 kg
2.	Energy requirement of SGHD/day/ batch	628.65 kJ
		0.1746 kWh
3.	Energy Requirement per kg (kWh)	0.0349 kWh
4.	Total Annual Consumption (kWh)	34. 92 kWh
5.	Annual Energy Cost	209.52 Rs
6.	Specific cost of drying per kg	42 Rs

The detailed economic analysis considering Salvage value, the depreciation rate is as follows. The Annual Cost of Dryer can be given by the formula:

$$\text{Annual Cost of Dryer} = \\ = Cap + Cmt - Sv + Cacf, \quad (27)$$

where: *Cap* – annual capital cost, *Cmt* – annual maintenance cost, *Sv* – salvage value, *Caf* – annual operational cost of fan.

The annual capital cost (*Cap*) can be calculated using the following formula:

$$Cap = Cc \times Fcp, \quad (28)$$

where: *Cc* – capital cost, *Fcp* – rate of interest on the capital cost. Therefore:

$$Cap = 20{,}000 \times \frac{d(1+d)^n}{(1+d)^n - 1}, \quad (29)$$

$$Cap = 20{,}000 \times \frac{0.08(1+0.08)^1}{(1+0.08)^1 - 1}, \quad (30)$$

$$Cap = \text{Rs.} 21{,}600 \text{ Rs.} \quad (31)$$

Now, the salvage value (*Sv*) can be calculated using the formula:

$$Sv = V \times Fsf, \quad (32)$$

$$Sv = P(1 - i)^n, \quad (33)$$

where, *P* – original capital cost, *i* – depreciation rate (5%), *n* – age in years. The salvage value is calculated:

$$Sv = 20{,}000 \times (1 - 0.05)^{20} = 7{,}160 \text{ Rs.} \quad (34)$$

The annual cost of the dryer is calculated:

$$Annual\ Cost\ of\ Dryer = \\ = Cap + Cmt - Sv + Cacf, \quad (35)$$

$$Annual\ Cost\ of\ Dryer = \\ = 21{,}600 + 1200 - 7{,}160 + 0 = 15{,}640 \text{ Rs.} \quad (36)$$

Now, the total quantity of the product dried (*Mpa*) can be calculated using the formula given below.

$$Mpa = \frac{Mpd \times D}{Db}, \quad (37)$$

where: *Mpd* – mass of the product dried per batch, *D* – No. of days the dryer is used in the year, *Db* – No. of days taken for drying per batch,

$$Mpa = \frac{5 \times 200}{4} = 250 \text{ kg.} \quad (38)$$

Now, the drying cost of one kg of material (*Cu*) can be given by the formula:

$$Cu = \frac{Can}{Mpa}, \quad (39)$$

$$Cu = \frac{15{,}640}{250} = 62.56\ Rs. \quad (40)$$

Now, the cost of the fresh product per one kg of the dried product (*Cfd*) can be given by the formula:

$$Cfd = Cfp \times \frac{Mf}{Mpd}, \quad (41)$$

where: *Cfp* – cost of one kg of the fresh product, *Mf* – mass of the fresh product per batch, *Mpd* – mass of the product dried per batch.

$$Cfd = 50 \times \frac{5}{5} = 50 \text{ Rs.} \quad (42)$$

Now, the cost of one kg of the dried product inside the dryer (*Cud*) can be given by the formula:

$$Cud = Cfd + Cu, \quad (43)$$

$$Cud = 50 + 62.56 = 112.56 \text{ Rs.} \quad (44)$$

Now, the saving obtained from one kg of the dried product (*Skg*) can be given by the formula:

$$Skg = SPdp - Cud, \quad (45)$$

where: SP_{dp} – selling price of the dried product.

$$Skg = 370 - 112.56 = 257.44 \text{ Rs.} \quad (46)$$

Now, the saving obtained from one batch of the dried product (*Sb*) can be given by the formula:

$$Sb = Skg \times Mpd, \quad (47)$$

$$Sb = 257.44 \times 5 = 1287.2 \text{ Rs.} \quad (48)$$

Now, the savings from drying of the `material per day (*Sd*) can be given by the formula:

$$Sd = \frac{Sb}{Db} = \frac{1287.2}{4} = 321.8 \text{ Rs.} \quad (49)$$

Now, the annual savings (*Sk*) in a k[th] year can be calculated using the formula:

$$Sk = Sd \times D\,(1 + Rif)^{k-1}, \quad (50)$$

$$Sk = 321.8 \times 200 \times (1 + 0.05)20 - 1, \quad (51)$$

$$Sk = 1,62,573.3 \text{ Rs.} \quad (52)$$

Now, the payback period (Pb) can be calculated using the formula:

$$Pb = \frac{ln\{1 - \frac{Ccc}{S1} \times (d - Rif)\}}{ln\{\frac{1+Rif}{1+d}\}}, \quad (53)$$

$$Pb = \frac{ln\{1 - \frac{15,640}{7,160} \times (0.08 - 0.05)\}}{ln\{\frac{1+0.05}{1+0.08}\}}, \quad (54)$$

$$Pb = \frac{ln(0.9344)}{ln(0.9722)} = 2.4\ Years \sim Approx. 2\ Years. \quad (55)$$

6. CONCLUSIONS

The environmental analysis of the solar greenhouse dryer consists of the embodied energy, the Energy Payback time, CO_2 emissions per year and the Carbon Credits earned by the dryer. The details of the environmental analysis are as given below in Table 4.

Tab. 4. Carbon dioxide emission, mitigation and carbon credits

Sr. no	Details	Amount
1.	Embodied energy	238.317 kWh
2.	Energy payback time	0.588 Years
3.	CO_2 emission per year (kg)	24.327
4.	CO_2 mitigation per Year (kg/kWh)	2.042
5.	Net CO_2 mitigation lifetime (kg)	486.64
6.	Net carbon mitigation (kg)	7613.36
7.	Carbon credits earned	28,600

The major parameter in the environmental analysis is CO_2 emission, the CO_2 emission by the solar dryer per year is nearly 25 kg, which is much less as compared to conventional grid electricity drying. The net carbon mitigation by the solar dryer is 7,613 kg and the carbon credits earned by the dryer is 28,600 respectively. Thus, the solar greenhouse dryer has a significantly smaller environmental impact.

The economic analysis of the solar greenhouse dryer consists of the annual cost of the dryer, the salvage value, the annual savings from dried products and the payback period. The details of the economic analysis are as given below in Table 5.

The Solar Greenhouse Dryer is to be used in rural settings where agricultural yields are available on a large scale. Therefore, the Solar Dryer should be more economical and have a shorter payback period. The grid electricity used by the dryer should be as low as possible to avoid expenses in the drying process. The annual cost of the solar dryer estimated is Rs. 21,600 and the salvage value is around Rs. 7,160. The annual savings obtained from the solar dryer is around Rs. 1,62,574, which is high as compared to the cost of the dryer. The payback period of the solar dryer is around 2 years respectively.

Tab. 5. Details of economic analysis

Sr. no	Details	Amount
1.	Annual cost of dryer	Rs. 21,600
2.	Salvage value	Rs. 7,160
3.	Annual savings	Rs. 1,62,574
4.	Payback period	2 Years

The Solar Greenhouse Dryer is an effective way to prevent the agricultural yield from deterioration due to an excess growth of micro-organisms. The Solar Greenhouse Dryer provides the optimum temperature that is required for drying agricultural yields with high moisture content. The life cycle assessment and economical valuation are some of the important parameters that need to be considered as the solar dryer is to be used in rural settings. The embodied energy estimated for the solar dryer is 238.31 kWh and the energy payback time are 0.588 years. The CO_2 emissions from the solar dryer annual are in the range of 24.3 kg, which is much less as compared to conventional grid electricity drying. The carbon credits earned by the dryer are nearly 28,600. The annual cost of the solar dryer is Rs. 21,600 with a salvage value of Rs. 7,160. The annual savings obtained from the solar dryer is nearly Rs. 1,62,574 and the payback period is around 2 years. The savings earned by the solar greenhouse dryer are comparatively higher as compared to that of investment. Another major factor associated with the economic analysis is that the solar dryer does not use grid electricity; thereby reducing the energy costs. Thus, the Solar Greenhouse Dryer is a cost-effective and environmentally friendly solution that can effectively be used in rural settings by farmers to prevent various post-harvest losses associated with the agricultural yield and to gain extra additional income from dried products.

Nomenclature

Symbols

Caf – Annual operational cost of fan
Can – Annual cost of dryer
Cap – Annual capital cost
Cc – Capital cost
Cfd – Cost of fresh product per one kg of dried product
Cmt – Annual maintenance cost
Cu – Drying cost of 1 kg of material

Cud – Cost of one kg of dried product inside dryer
Eb – Embodied energy
Fcp – Rate of interest on capital cost
i – Depreciation rate
Lda – Domestic appliances losses
Ldt – Transmission and distribution losses
Mpa – Total quantity of product dried
n – Age in years
P – Original capital cost
Pb – Payback period
Sb – Saving obtained from one batch of the dried product
Sk – Annual savings
Sk – Annual savings
Skg – Saving obtained from one kg of dried product
Sv – Salvage value
Sv – Salvage value

References

1. Vijayan S, Arjunan T. V., Anil Kumar. Fundamentals of Drying. Solar Drying Technology- Concept, Design, Testing and Modeling, Economics and Environment 2017; 3-38.
2. Labuza TP, McNally L, Gallagher D, Hawkes J, Hurtado F. Stability of intermediate moisture foods. 1. Lipid oxidation. *Journal of Food Science* 1972; 37(1):154–159.
3. Prakash O, Kumar A. Annual performance of modified greenhouse dryer under passive mode in no-load conditions. *International Journal of Green Energy* 2015; 12:1091–1099.[4] Yadav Aditya Arvind, Yadav [4] Akshay Vijay, Bagi Jaydeep, Prabhu Pravin. Design of a Solar Modified Greenhouse Prototype. *Journal of Science and Technology*; 2021; 06(01); 118-125.
4. Pushpendra Singh, M. K. Gaur. Environmental and economic analysis of solar greenhouse dryer: A Review. *International Journal of Energy Technology* 2020; 2(1): 55-69.
5. Mohamed A. Eltawila, Mostafa M. Azama, Abdulrahman O. Alghannamb. Energy analysis of hybrid solar tunnel dryer with PV system and solar collector for drying mint. *Journal of Cleaner Production* 2018; 1-32.
6. Saravanan Dhanushkodi, Vincent Wilson, Kumarasamy Sudhakar. Life Cycle Cost of Solar Biomass Hybrid Dryer Systems for Cashew Drying of Nuts in India. *Environmental and Climate Technologies* 2015; 22-33.
7. Aymen ELkhadraoui, Sami Kooli, Ilhem Hamdi, Abdelhamid Farhat. Experimental investigation and economic evaluation of a new mixed mode solar greenhouse dryer for drying of red pepper and grape. *Renewable Energy* 2015; 1-8.
8. Ketki Deshmane S, Yadav AA, Ingawale SM. Winddata Estimation of Kolhapur district using Improved Hybrid Optimization by Genetic Algorithms (iHOGA) and NASA Prediction of Worldwide Energy Resources (NASA Power). *International Research Journal of Engineering and Technology* 2020;2530–2538.
9. Yadav AA, Prabhu PA, Bagi JS. Numerical simulation and experimental validation of solar greenhouse dryer using finite element analysis for different roof shapes. *Journal of Mechanical and Energy Engineering* 2021; 5(1): 69-80.
10. Yadav AA, Prabhu PA, Bagi JS. Response Surface Modelling and performance evaluation of solar dryer for drying of grapes. *Journal of Mechanical and Energy Engineering* 2021; 5(2): 157-168.
11. Yadav AA, Prabhu PA, Bagi JS. Experimental Performance and Response Surface Modelling of Solar dryer for drying of bitter gourd in western Maharashtra, India. *Journal of Post-Harvest Technology*. 2021; 9(3): 1-16.

Biographical notes

Aditya Arvind Yadav is M. Tech Research Scholar in Energy Technology at the Department of Technology, Shivaji University, Kolhapur, Maharashtra, India. He has published 19 research articles. His research metrics include google scholar citations 13 and h-index 2. His area of research includes solar thermal energy, solar drying and Thermal Energy Storage.

Pravin A. Prabhu is Assistant Professor and Co-Ordinator of M. Tech Energy Technology at the Department of Technology, Shivaji University, Kolhapur, Maharashtra, India. He has published 08 research articles. His research metrics include google scholar citations 39, h-index 3 and i-10 index 1. His area of research includes solar thermal energy, solar drying and Thermal Energy Storage.

Jaydeep S. Bagi is Professor and Director at the Department of Technology, Shivaji University, Kolhapur, Maharashtra, India. He has published more than 50 research articles in National and International Journals. His research metrics include google scholar citations 160, h-index 7 and i-10 index 5.