Enhancing Small and Medium Enterprises in Phayao, Thailand: Socio-Economic Impact of Greenhouse Solar Drying for Andrographis Paniculata

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Abstract. *This study has examined the influence of varied drying air temperatures and the application potential of greenhouse solar drying (GSD) technologies in the drying kinetics of Andrographis paniculata during summer, rainy, and winter seasons. The results indicated that the trends for the predicted and observed values are highly analogous. Specifically, an increase in the coefficient of determination (R^2) ranging from 0.9963 to 0.9992, a decrease in the root mean square error (RMSE) ranging from 0.0002 to 0.0022, and a reduction in chi-square values ranging from 0.0000 to 0.0005, demonstrated the feasibility and accuracy of all the models implemented. The moisture content analysis revealed a significant difference between GSD and natural convection drying methods. Using open sun drying, the final moisture content of Andrographis paniculata was reduced to approximately 12% after 7 days and further to a minimum of 9% after 14 days. In contrast, the GSD method decreased the final moisture content to less than 7% within just 2 days, highlighting its superior efficiency. From an economic perspective, the GSD system proved to be highly efficient and cost-effective. Despite the higher initial capital costs compared to natural convection systems, the life cycle costs of the GSD were lower than other previously studied solar drying systems. The economic feasibility was further supported by a swift payback period of 3.1 years, indicating a quick recovery of the initial investment relative to the system's lifespan. Additionally, the social impact assessment conducted using Social Return on Investment (SROI) analysis showed promising results. The SROI ratios for 2021, 2022, and 2023 were 2.09, 2.48, and 2.87 respectively, all well above the benchmark value of 1.00. This indicates a significant positive return, reflecting substantial social value and benefits to stakeholders and society. In conclusion, the GSD system not only offers superior drying performance and economic benefits but also generates substantial social value. Its implementation is both economically sustainable and socially beneficial, making it a highly advantageous technology for drying applications.*

Keywords:

Greenhouse solar drying, Andrographis paniculata, mathematical modeling, social return on investment analysis, small and medium enterprises

1. Introduction

Solar energy is a reliable, abundant source of clean energy and has been widely employed. Crops, herbs, and other products are often dried at low temperatures using solar drying [1]. Solar drying is typically seen as the most promising alternative to other conventional methods of drying. In contrast to conventional direct solar drying or open-air drying, the advantages of indirect solar drying are as follows: shortened drying time, best quality products, lesser raw material waste, larger scale of production. Previously, open-air drying was widely used in many countries of the world [2,3,4]. However, open-air drying can transfer pathogens to the product being dried. In recent years, solar dryers have been developed to dry agricultural products [5,6,7,8].

A solar dryer is a device that uses solar energy to dry crops, herbs, and other products. Solar dryers work by using solar energy to heat up the air inside the dryer, which then circulates around the product to remove moisture [9,10,11]. The dryer is designed to be efficient, with insulation and a heat-absorbing surface to maximize the amount of solar energy that is absorbed and used for drying [12,13]. Srisittipokakun et al. (2012) studied the potential and development of solar drying technologies for drying *Andrographis paniculata* as well as various types of agricultural products such as meat, fish, vegetables, and other products in small and medium enterprises; SMEs) [15].

Andrographis paniculata, also known as "King of Bitters", is a medicinal plant that has been traditionally used for centuries in Thai and Ayurvedic medicine to treat various illnesses [16,17]. In recent years, research has been conducted on its potential effectiveness against viruses, including the Coronavirus that causes COVID-19 [18]. In Thailand, *Andrographis paniculata* has been included in the national COVID-19 treatment guidelines. These guidelines recommend its use in combination with other medications for mild to moderate cases of COVID-19 [19,20]. The herb is believed to have anti-inflammatory and immune-boosting properties, which may help reduce the severity of symptoms and improve outcomes [21,22]. Some studies have also suggested that *Andrographis paniculata* may have anti-viral properties that could help inhibit the replication of the Coronavirus [23].

Drying is a common method used to preserve medicinal plants, and solar drying is a sustainable and cost-effective method for the same. In the case of *Andrographis paniculata*, a solar dryer can be used to dry the leaves, stems, and other parts of the plant, for use in traditional medicine. Using a solar dryer for *Andrographis paniculata* can help preserve the medicinal properties of the plant and ensure that it is free from contaminants [14, 24]. It also helps to reduce the labor required for drying, as the dryer can be left unattended and does not require manual turning or monitoring [25]. However, previous studies did not consider the influence of various drying temperatures on the drying kinetics of *Andrographis paniculata*, though this is the most important factor to be considered for enhancing the drying quality of *Andrographis paniculata* [26]. This study aimed to outline the advancements and possibilities of the application of solar drying technologies to the drying kinetics of *Andrographis paniculata*. Therefore, the main objective of this study was to investigate the influence of different drying air temperatures on the drying characteristics and the drying kinetics of *Andrographis paniculata*.

2. Materials and Methods

2.1 Materials

The raw material used in this study consisted of fresh samples of *Andrographis paniculata*, obtained from SMEs of Boa 12 in a local area in the Phayao Province of Thailand. *Andrographis paniculata* was chosen to investigate the performance of solar dryers and then compare the same with natural sun drying (Fig 1). *Andrographis paniculata* samples were cleaned, peeled, and cut to a length of 10.0 mm to 20.0 mm. An electronic weighing scale was selected to determine the weight of the prepared samples. In order to minimize overlapping, the samples were carefully put into the dryer tray. The products were removed and weighed at an appropriate time. The drying experiment was conducted between 8:00 am and 4:00 pm each day, until the experimental runs were completed. The weather was generally sunny, and it did not rain.

Fig 1. Andrographis paniculata

2.2 Description of the GSD

GSD was selected for this research study, as shown in Fig 2 and Table 1. The concepts of convective force are used to operate the dryer. A concrete floor, parabola dome, insulator, centrifugal ventilator, dryer shelf, and thermoregulatory system are among the parts of the apparatus. It is 8 m wide, 12 m long, 3 m high, and covered with a polycarbonate sheet of 6 mm thickness. Steel was selected for construction of the drying frame. Five shelves with equal spacing were arranged inside the drying zone. Theoretical air velocity of 1.5 m/s A was ensured with centrifugal ventilator axial fan of 220 V and 1.2 A. Wind velocity was measured using a digital anemometer. A temperature sensor measured the temperature within the range of 0-100°C with an accuracy of 0.1°C.

Fig. 2 Construction of the GSD

Table 1. Specifications of solar dryer

Components	Specifications
Solar Construction	
High	3 m
Wide	3 m
Long	4 m
Material cover	polycarbonate sheet of 6 mm thickness
Blower connected with temperature sensor	
Velocity	1.5 m/s
Voltage	220 V
Drying Chamber	
Tray size	1 ×3×1.5 m
Tray area	0.56×0.56 m

2.3 Drying Process

The initial moisture content of the *Andrographis paniculata* employed in this method was 54.23% w.b. It was determined using the Association of Official Agricultural Chemists (AOAC) method. A total of four samples amounting to 300 g of *Andrographis paniculata* were spread out, one sample per aluminum tray. These samples were dried outside in a GSD under natural sunlight, from 8:00 am to 4:00 pm, until the moisture content fell to less than 12% w. b. The weight of the sample was recorded every 60 mins. The temperature inside the solar dryer was in range 38-60°C, 35-50°C, 34-56°C, respectively, using an automatic fan.

2.4 Analysis

The initial moisture content in the *Andrographis paniculata* samples was evaluated on both wet and dry bases. The moisture content has been stated in percent format, for every 60 minutes, according to the following equations by (27,28).

$$\boldsymbol{M_C(wet\ base) = \frac{M_i - M_d}{M_i} \times 100} \tag{1}$$

$$\boldsymbol{M_C(dry\ base) = \frac{M_i - M_d}{M_i} \times 100} \tag{2}$$

In addition to estimating the amount of moisture, the drying rate (R_d, in g/hr) at any given time (t, hr) was measured using equation 3 given [29]:

$$\boldsymbol{R_d = \frac{M_i - M_d}{t}} \tag{3}$$

Here, M_i is initial mass (g); M_d is mass after drying (g); R_d is drying speed; and t is drying time (hour) calculated the specific energy consumption (SEC) of GSD system as follows [30]:

$$\boldsymbol{SEC = \frac{w}{q}} \tag{4}$$

Here, q is the total energy input to dryer (kWh/g) and SEC refers to specific energy consumption (kWh). The efficiency of the solar collector was estimated according to the following equation by [30,31].

2.5 Mathematical Modeling

The thin layer drying equations in Table 2 [32,33,34,35] were put to the test in order to determine which drying model best described the drying properties of *Andrographis paniculata* when it was dried using the GSD. The chosen models were assessed using non-linear regression analysis. The criteria to choose the best model describing the drying curve equation was based on the coefficient of determination (R^2), reduced chi-square (χ^2), and root mean square error (RMSE). Higher values of (R^2) and lower values of (χ^2) and RMSE indicate the appropriate model. These parameters were calculated based on the following equations [36]

$$\boldsymbol{R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{pr,i} - MR_{ex,i}\right)^2}{\sum_{i=1}^{N}\left(\overline{MR}_{pr} - MR_{ex,i}\right)^2}} \tag{5}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{ex,i} - MR_{pr,i}\right)^2}{N-n} \tag{6}$$

$$\boldsymbol{RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pr,i} - MR_{ex,i}\right)^2\right]^{1/2}} \tag{7}$$

The independent parameters measured in these experiments were solar radiation intensity, temperatures, product mass loss, relative humidity, and velocity. The uncertainties in the independent variables are summarized in Table 2.

Table 2 Mathematical models for thin layer drying

Model	Model formula	References
Newton	MR = exp(-kt)	Ertekin and Firat 2017
Page	MR = exp(-kt^n)	Yaldýz and Ertekýn 2001
Modified Page	MR = exp[-(kt)^n]	Yaldýz and Ertekýn 2001
Henderson and Pabis	MR = a exp(-kt^n)	Mewa et al., 2019
Logarithmic	MR = a exp(-kt) + c	Mewa et al., 2019
Midilli model	MR = a exp(-kt) + bt	Mewa et al., 2019
Modified Midilli model	MR = a exp(-kt) + b	Karathanos,, 1999

The initial moisture content of *Andrographis paniculata* left can be evaluated on a damp and dry basis, which is expressed in percent for every 60 minutes using the following equations (Eq. 8)

$$Mc\ (wet\ base) = \frac{Mi - Md}{Mi} \times 100 \tag{8}$$

Where M_i is initial mass (g); M_d is mass after drying (g); Mc is moisture content (g)

As part of this investigation, 7 thin-layer drying models were used to determine which model best described the drying behavior of the *Andrographis paniculata* leaf while using a GSD. These models have been developed by reducing the complexity of the general series solution of Fick's second law and were implemented with the assistance of the MATLAB computer program. Table 3 shows the drying models used. Such thin-layer drying models are often used for agricultural products [37]. The Moisture Ratio (MR) was defined using equation 9 below [37]:

$$\mathrm{MR} = \frac{\mathrm{M-ME}}{\mathrm{MO-ME}} \tag{9}$$

Table 3 The parameter values derived from the thin-layer drying models.

Model	Conditions	Mathematical model constant					The statistical correlation		
		k	n	a	b	c	R2	RMSE	χ^2
Newton	A	0.1329	-	-	-	-	0.9969	0.0022	0.0003
	B	0.1022	-	-	-	-	0.9990	0.0006	0.0001
	C	0.1208	-	-	-	-	0.9972	0.0020	0.0002
Page	A	0.1403	0.9740	-	-	-	0.9971	0.0003	0.0002
	B	0.0951	1.0326	-	-	-	0.9994	0.0004	0.0001
	C	0.1053	1.0641	-	-	-	0.9981	0.0012	0.0002
Modified Page	A	0.1331	0.9740	-	-	-	0.9967	0.0021	0.0003
	B	0.1025	1.0326	-	-	-	0.9994	0.0004	0.0001
	C	0.1206	1.0641	-	-	-	0.9984	0.0012	0.0002
Henderson and Pabis	A	0.1383	0.9788	0.9964	-	-	0.9971	0.0003	0.0003
	B	0.0937	1.0378	0.9970	-	-	0.9992	0.0004	0.0001

Model	Conditions	Mathematical model constant					The statistical correlation		
		k	n	a	b	c	R2	RMSE	χ^2
	C	0.1036	1.0698	0.9965	-	-	0.9979	0.0011	0.0002
Logarithmic	A	0.1257	-	1.0089	-	-0.0209	0.9963	0.0020	0.0003
	B	0.0920	-	1.0573	-	-0.0600	0.9995	0.0002	0.0004
	C	0.1024	-	1.0883	-	-0.0910	0.9992	0.0006	0.0001
Midilli model	A	0.1269	-	0.9873	-0.0011	-	0.9964	0.0019	0.0003
	B	0.0959	-	0.9975	-0.0021	-	0.9997	0.0002	0.0005
	C	0.1091	-	0.9977	-0.0034	-	0.9993	0.0005	0.0001
Modified Midilli model	A	0.1256	-	1.0089	-0.0209	-	0.9972	0.0003	0.0003
	B	0.0920	-	1.0572	-0.0600	-	0.9996	0.0002	0.0000
	C	0.1024	-	1.0882	-0.0910	-	0.9992	0.0005	0.0001

Here, MR is the moisture content at any given time, whereas M_o is the initial moisture content, and M_e is the equilibrium moisture content. However, in this experiment, the values of relative humidity changed continually during the drying process, and the values of M_e were comparatively low in comparison to M or M_o [37]. Therefore, equation 9 may be rewritten as equation 10:

$$MR= M/MO \tag{10}$$

2.6 Economic Evaluation

The general assumption is that GSD system is economically feasible, if the lifetime costs are lower than the costs of a conventional solar dryer system, and if it includes natural convection in terms of increasing efficiency, cost effectiveness, and economic feasibility. In this study, we examined the cost/economic parameter, capital cost, maintenance cost, annual electricity cost for fans, and the dryer capacity. The payback period for a conventional solar dryer and a hybrid solar system was calculated as follows (equation 11) [38].

$$N = \frac{In[1-\frac{Ccc}{S1}(d-i)]}{In(\frac{1+i}{1+d})} \tag{11}$$

2.7 Social Return of Investment (SROI) Evaluation

The SROI is determined as the ratio between the income and social performance (the net amount for a given period) and the resources of the organization (primarily the remaining net assets) according to the following equation 12 [39].

$$SROI = \frac{Total\ Present\ value\ (PV) of\ Impact}{Total\ Present\ Value\ (PV) investment} \tag{12}$$

3. Results and Discussion

3.1 Mathematical Modeling

Thailand has a relatively high potential of solar energy drawn from nature and the intensity of the distribution of solar radiation in Thailand varies each month, thereby directly impacting the product. Table 4 shows various parameters related to atmospheric conditions in Thailand. The data is divided into 3 seasons: summer, rainy and winter seasons, consisting of parameters such as solar radiation, relative humidity, drying temperature, and drying time. ln general, most of the country receives maximum solar radiation between April and June, followed by the rainy months and winter, with values of 18-22, 12-18 and 14-17 (MJ/m^2-day) respectively. In the months between July and October, the sky is cloudy, resulting in low solar radiation (12-18 MJ/m^2). This information concurs with previous reports related to relative humidity, drying temperature, and drying time for the 3 seasons [40,41,42].

Table 4 Comparative study of different parameters parameter in Thailand.

Parameter	Summer (RH A; %)	Rainy (RH B; %)	Winter (RH C; %)	Ref.
Month	Apr.-Jun	Jul-Oct	Nov-Feb	
Solar radiation (MJ/m^2)	18-22	12-18	14-17	[41]
Relative humidity (%)	65-80	80-95	60-88	[42]
Drying temperature (°C)	38 - 60	35-50	34- 56	[43]
Drying time (hr.)	14	18	16	-

In general, the intensity of solar radiation varies during the day from 6:00 am to 6:00 pm in Phayao, Thailand, in the summer, rainy, and winter seasons. The results showed that, a cloudless day in the summer season showed the maximum solar radiation intensity of 850 W/m^2. In the rainy season, on a mostly cloudy day, the maximum solar radiation was 701 W/m^2, followed by the winter season with a maximum solar radiation of 653 W/m^2 (Fig 3). These factors were considered during the examination of the altered moisture content in *Andrographis paniculata*. The samples were tested for initial and final moisture content using the standard method. The initial moisture content of the product was ~85%, which reduced to 15% under a drying time of 9-10 days post natural convection drying during the winter and rainy seasons. The analysis of the moisture content curve is illustrated in Fig 4. It shows a comparison among the humidity changes in the solar dryer during summer season (RH A; %), rainy season (RH B; %), and winter season (RH C; %) vis-à-vis the *Andrographis paniculata* samples. The experiment showed that the moisture content of the product decreased rapidly when the temperature of the GSD ranged from 40-60 °C at a low relative humidity of 65.5%. The reason was the intensity of the radiation at that point of time, which had an average value of 1059.49 W/m^2; there were no significant changes between the temperatures of RH A and RH C. The higher the solar radiation, the higher would be the air temperature. Due to high temperature, the atmosphere picks up moisture more quickly from agriculture products; so, the drying process is quickened. This results in the lowest moisture content in summer (~7%), followed by winter (~9%) and the rainy season (~15%). Therefore, during the GSD tests, it was found that drying for only 1 day could reduce the moisture in the product as much as drying in the open air for 9-10 days. Likewise, previous studies by Srisittipokakun et al. 2012, reported that the heat from the sunlight and the collectors leads to a reduction in moisture content of about 7% w.b. after solar drying.

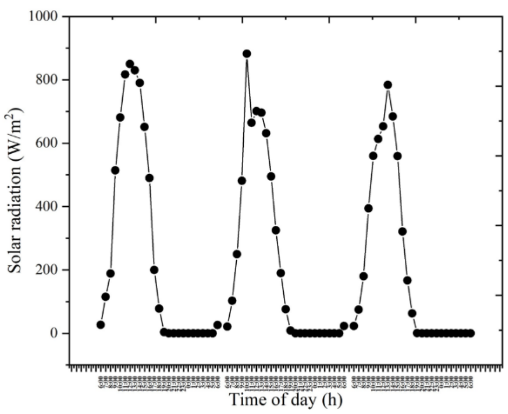

Fig.3 Intensity of solar radiation during the day from 6:00 a.m. - 6:00 a.m. in Phayao, Thailand in the summer, rainy and winter seasons.

The MR data received from the experiment have been projected into 7 different thin-layer drying models, in order to identify which model provides the most accurate description of the drying behavior of the *Andrographis paniculata* leaf while utilizing a solar dryer. The results of the modeling are shown in Table 3, which includes the values of R^2, χ^2, and RMSE in addition to all of the parameters of the models.

The drying data obtained from experiments were fitted to 7 thin-layer models as mentioned in the theoretical background section. The models were evaluated and compared in terms of the statistical parameters R^2 and RMSE. The results of the statistical study are summarized in Table 2. R^2 is considered to be one of the best correlations used to select the best equation for variation in the solar drying curves. The calculated R^2 value is intended to provide a stronger correlation between the MR and drying time. It represents the proportion of the total variation that is attributable to the independent variable possessed by the dependent variable. All cases gave consistently high values of R^2 in the range of 0.9963 to 0.9992. This suggests that all models were capable of accurately describing the drying rates achieved by solar energy. The RMSE values ranged between 0.0002 to 0.0022, whereas the χ^2 values varied between 0.0000 to 0.0005 respectively. Further, the predicted and observed results of RH A, RH B, and RH C in different thin-layer drying models consisted of the following: Newton, Page, Modified Page, Henderson and Pabis, logarithmic, Midilli model and modified Midilli model models, as shown in Fig 5. The results showed that the trend for the predicted and observed values was analogous, in the sense that the increase in R^2 and the decrease in RMSE and χ^2 values showed that all models were feasible in terms of their implementation. Therefore, the 7 different thin-layer drying models were considered the best models to represent the GTD in RH A, RH B, and RH C for drying of *Andrographis paniculata* using a GSD.

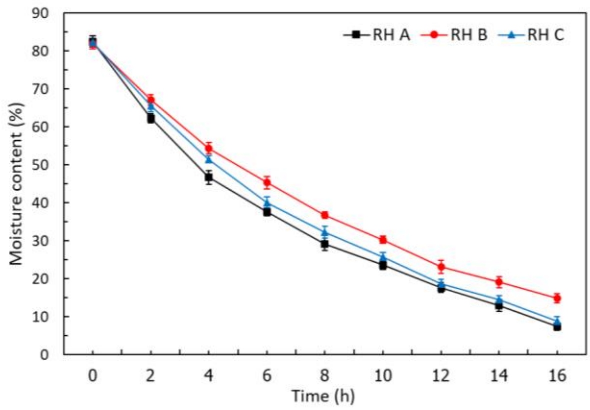

Fig. 4 Comparison of the humidity changes in the solar dryer under summer (RH A; %), rainy (RH B; %) and winter (RH C; %) of *Andrographis paniculata*.

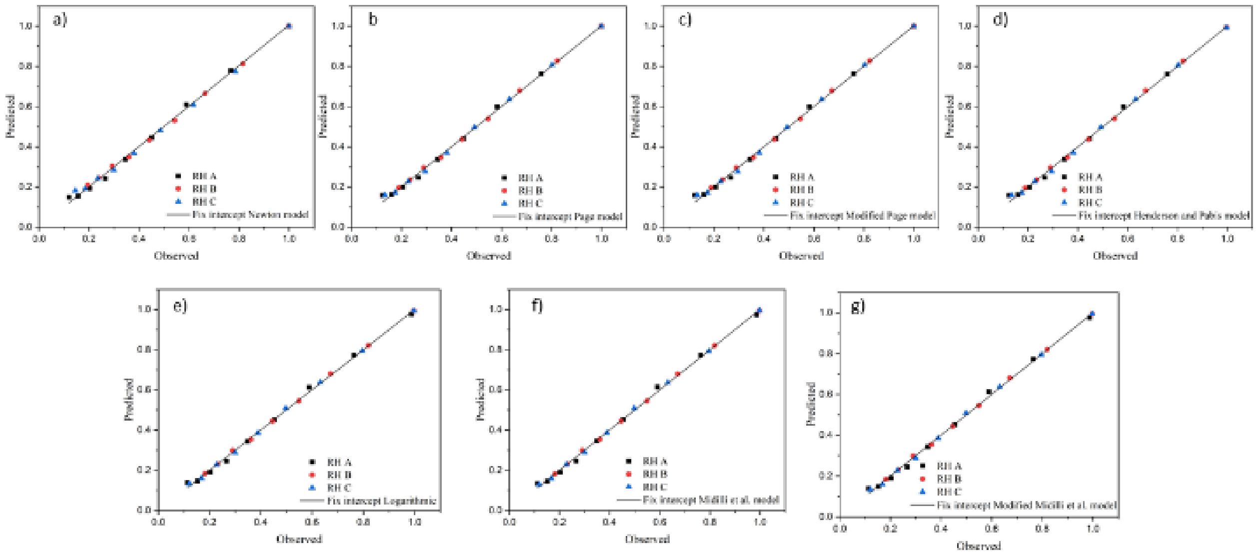

Fig.5 Comparison of predicted and observed data from RH A, RH B, and RH C with different models a) Newton b) Page c) Modified Page d) Henderson and Pabis e) logarithmic f) Midilli model g) modified Midilli model

3.2 Economic evaluation

In our study, the economic evaluation of the GSD system consisted of a comparison between costs and results, including an assessment of the sustainability and feasibility of investing in GSD systems, depending upon which one showed the highest efficiency in drying and minimization of production cost.

Table 5 lists the data related to the economic assessment, consisting of various parameters. The results have shown that the capital or life cycle costs of the solar dryer system are much higher in all cases, when compared with natural convection. The capital cost of GSD systems includes maintenance costs, annual electricity cost for fans and capacity of dryer. The final moisture content of *Andrographis paniculata* that stood at ~12 wt.% after 7 days, decreased to a minimum of 9% on day 14. In case of the GSD, the final moisture content decreased to less than 7% w.b, after 2 days. Also, the life cycle costs of the GSD systems were found to be lower than those of the other solar systems previously studied [10]. These results indicate that the GSD system is economically sustainable and feasible. The economic assessment was conducted by applying the payback period criterion, resulting in a swift recovery of investment within 3.1 years, relative to the lifespan of the GSD system.

3.3 Social Return on Investment Analysis (SROI)

This study focused on calculating the social return value following the use of GSD systems using the SROI evaluation. SROI analysis is a tool to measure and compare the social success of solar dryers, based on direct and indirect investments. Further, the SROI is an indicator of the success obtained from organizations engaged in social activities [43].

Table 5 Summary of the costs and economic parameters of solar dryer system and natural convection

Parameter	Solar dryer	Natural convection
Capital cost of solar dryer system	$12,893	-
Maintenance costs	$20	-
Annual electricity cost for fans	$10	-
Capacity of dryer	1400 kg fresh of Andrographis aniculata	1400 kg fresh of Andrographis aniculata
Cost of fresh *Andrographis paniculata* (77% (wb) moisture content)	$0.58/kg	$0.58/kg
Cost of dried *Andrographis paniculata* (~5% (wb) remaining moister)	$23.35/kg	$23.35/kg
Life of the dryer	25years	-
Drying period	2days	8days
Interest rate	7%	-
Inflation rate	4%	-
Total system cost	$12,923	$0.58

Fig 6 shows a framework of GSD based on which the SROI was calculated. A GSD in Phayao province, Thailand was selected for SROI analysis by collecting data from related stakeholders: community enterprise, local agency, and local community in Phayao province. The SROI analysis also included various forms of data collection: surveys, online forms, and stakeholder interviews.

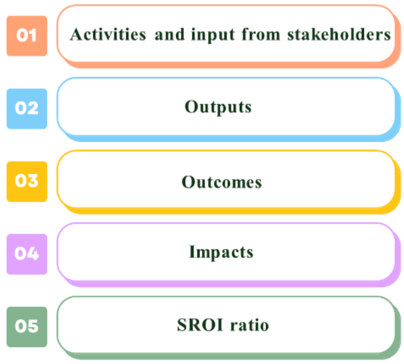

Fig.6 Framework of calculating the social impact.

Table 6 shows the results obtained following the data collection. It shows the financial information used to calculate SROI impact, based on the use of solar dryers between 2022-2024. The data used to calculate SROI are as follows: deadweight data, attribution data, displacement data, and drop-off data that lead to a reduction in the calculation. In addition, a social impact assessment was conducted using SROI analysis. It was found that the SROI ratios for the years 2022-2024 were 1.67 (2022), 1.91 (2023), and 2.18 (2024) respectively, which when compared with the SROI criteria were > 1.00 (greater than 1.00). Thus, the study demonstrated that the use of GSD led to a profitable turnover and added social value, thereby benefitting both stakeholders and society at large.

Table 6 Social return on investment analysis (SROI) of solar dryer

No.	Data	2022	2023	2024
Inputs	Total initial Investment	$12,500		
	Discount	4%	4%	4%
	PV average rate	1.050	1.025	1.158
	Total PV investment	$12,500	$11,904.8	$11,446.9
Impacts	Proxy		$989.2[a], $17.8[b], $191.0[c]	
	Deadweight	40%[a], 50%[b], 60%[c]	40%[a], 50%[b], 60%[c]	40%[a], 50%[b], 60%[c]
	Attribution	70%[a], 30%[b], 60%[c]	70%[a], 30%[b], 60%[c]	70%[a], 30%[b], 60%[c]
	Displacement	0%	0%	0%
	Drop-off	9%[a], 0%[b], 10%[c]	8%[a], 0%[b], 10%[c]	9%[a], 0%[b], 10%[c]
	Total PV values of impact	$20,821.9	$22,683.8	$24,714.1
SROI ratio		1.67	1.91	2.18

Group of stakeholders: [a]Community enterprise; [b]Local agency; [c]Local community

4. Conclusions

The performance of the GSD in drying *Andrographis paniculata* was investigated during the summer, rainy, and winter seasons, through mathematical modelling, in order to determine the optimization and economic potentials of the GSD. The results showed that the initial moisture content of *Andrographis paniculata* was 75% w.b.; post drying using a GSD, the final moisture content decreased to less than 7% w.b. after just 2 days of drying. Overall, the GSD system is not only effective in terms of drying performance but also proves to be economically viable and sustainable, offering substantial long-term cost savings and a quick return on the initial investment. These factors make the GSD system a favorable choice for drying applications. The results clearly demonstrate that the adoption of solar dryers not only leads to profitable turnover but also generates substantial social value. The higher SROI values imply that stakeholders and society at large have significantly benefitted from this initiative. Therefore, it can be concluded that the implementation of solar dryers is a highly effective strategy for generating economic and social benefits, reinforcing the value of continued investment in and expansion of this technology.

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