Journal of Renewable Energies IREnDAYS'24 Algiers (2024) 235 – 243

DOI: https://doi.org/10.54966/jreen.v1i1.1265

Journal of Renewable Energies

Revue des Energies Renouvelables

journal home page: https://revue.cder.dz/index.php/rer

Conference paper

On the industrial solar drying of tomatoes in Biskra : A preliminary study

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ARTICLE INFO

Article history:
Received July 31, 2024
Accepted September 4, 2024

Keywords:
Solar energy,
Industrial Solar dryer,
RETScreen,
Energy analysis,
GHG emission.

ABSTRACT

The objective of this study is to carry out a pre-feasibility study of solar industrial drying as a preliminary step before investing in large-scale solar drying projects in Algeria. Our primary goal is to promote the use of industrial solar dryers and to incite public authorities and industrials to invest in this promising niche. This work aims to strengthen the contribution of renewable energies and particularly solar energy in the sustainable development of the agri-food sector. Indeed, using solar energy will reduce the energy consumption and decrease greenhouse gas emissions of drying process. The prefeasibility analysis is achieved using the RETScreen Suite. Our study aims to investigate energy consumption of an industrial solar dryer of tomatoes, located in the city of Biskra. Various parameters as solar collector type and drying air temperature were tested and discussed. The obtained results showed a reduction in energy consumption up to 35%. Likewise, the reduction of GHG emissions recorded very favorable rates. This study's findings provide a preliminary vision for investors in the agri-food sector to build their project so they may maximize their profit while supporting the environment by lowering carbon emissions.

1. INTRODUCTION

Drying Process is the oldest and the most common technique for food conservation. For large harvests, industrial dryers with large capacities are needed to reduce drying time and to avoid product deterioration and loss (Boulemtafes, 2016). However, drying process is a huge energy consumer. Indeed, drying is accounting for 12–15% of total global agricultural energy consumption (Ndukwu et al.,2023), consuming 6 to 30 times more energy than cooling and freezing (Machalaet et al., 2022). Using fossil energy for heat demand in drying process will result in significant car-bon emissions into the atmosphere, especially for large-scale dryers. Partial solar dryer (mixed) instead of 100 % conventional

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ISSN: 1112-2242 / EISSN: 2716-8247

dryer will lead to reduce conventional energy consumption and participate to environment protection by reducing GHG emissions. Before encouraging investment in this promising area, prefeasibility and feasibility studies are necessary. Prefeasibility is a preliminary phase in the evaluation of a project. It aims to analyze the different possibilities and constraints before starting an in-depth feasibility study and to identify the major issues, the necessary resources and the potential obstacles that could delay the execution of the project (*RETScreen*, 2004). The purpose of this paper is to conduct a prefeasibility study on partial solar industrial dryers as a first step before investing in large-scale solar drying projects in Algeria. We aim to encourage both government authorities and industrials to promote the use of industrial solar dryers and invest in this promising niche market. In addition, our goal is to enhance the contribution of renewable energy, especially solar energy, to the sustain-able development of the agri-food industry sector in Algeria.

2. METHODOLOGY

To perform this prefeasibility study, we have used RETScreen Suite 4, a free Clean Energy Project Analysis Tool, developed by Natural Resources Canada (NRCAN). RETScreen Suite 4 helps the user to determine whether a renewable energy and energy efficiency project is technically and financially viable. Hence, it is a very useful tool for decision makers and investors to validate or to reject a project proposal even at the project early stages (RETScreen, 2004). The steps followed to achieved this analysis are described in Figure 1.

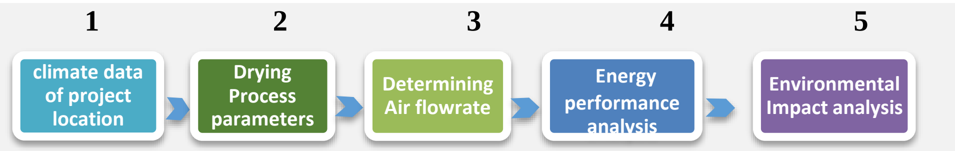

Fig.1 Prefeasibility analysis steps

The industrial solar dryer used is the RETScreen reference plant for drying process (RETScreen, 2004). It is a large-capacity building, where the product to be dried is stored on racks. The solar air heating system consists of two parts: a field of solar collectors (glazed or perforated) mounted vertically on the sunniest side of the building, or inclined on the roof. The second part is the air distribution system with a fan installed inside the building (Fig.2).

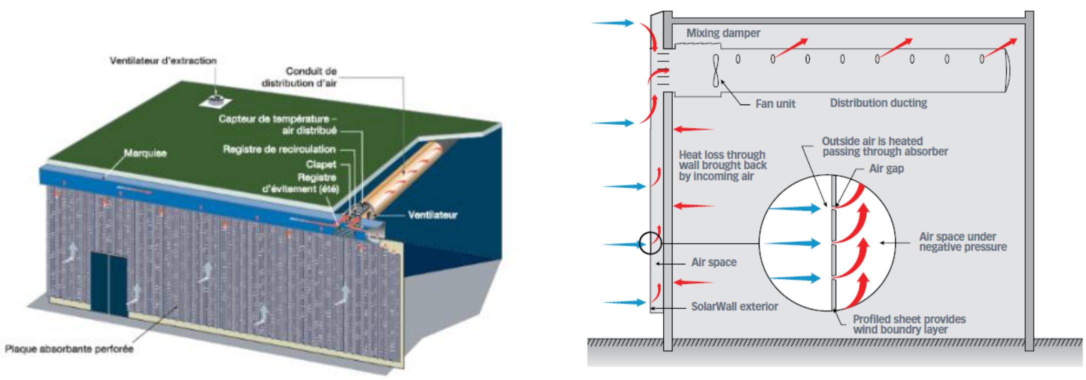

Fig.2 Industrial solar dryer used as reference in this study (RETSreen, 2004)

2.1 Geographic and Climate data of project's location

The wilaya of Biskra is located in the eastern south of the country, on the southern flank of the Aurès Mountains, at 470 km from the capital Algiers. More precisely in the transition zone between the Atlas Saharien and the Sahara. Biskra covers an area of around 21,671 km^2 (ANIREF, 2021). Biskra has been chosen as the reference location of our prefeasibility assessment project, for its high solar potential and also because Biskra is actually on the top of tomatoes producers cities in Algeria, with an annual production of **3 664 280 qx** and **1462, 8 qx/ha** production rate (Statistiques Agricoles, 2019).

Geographic (38, 4 N° and 5.7 E°) and climate data of Biskra city have been uploaded from NASA satellite and ground measurement database. Generally, the NASA station nearest to the project location is selected as the climate data location in order to calculate a "normal year" based on 20 years historical data. Global horizontal irradiation, ambient temperature, air relative humidity and wind speed are available as monthly averaged values (Fig.3).

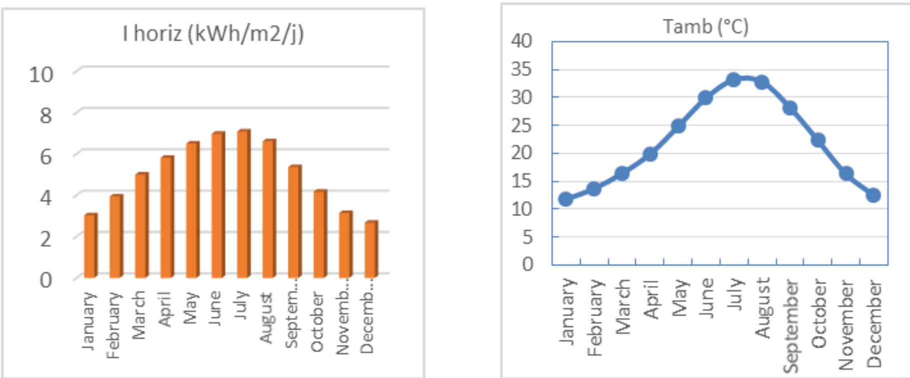

Fig. 3. Monthly solar radiation and ambient temperature of Biskra city (NASA database)

2.2 Drying Process parameters inputs

Before using Energy analysis tool of RETScreen, we have to perform some calculations to determine the following parameters, that are necessary for the analysis:

- **Mass flow rate of drying air:** it is calculated based on a mass and humidity balance, that depends on climatic conditions (temperature and humidity of the ambient air) and the product characteristics to be dried (initial moisture, drying temperature, etc.) (Table 1)
- **Maximum drying air temperature:** depending on the product to be dried. In this study we are interested in the drying of an agricultural product widely consumed in Algeria: tomatoes.
- **Drying mode** (continuous or discontinuous)
- **Type of solar collector** (glazed, unglazed, perforated)
- **Solar collector surface**: a sizing calculation is necessary to determine the optimal collector surface needed to provide the necessary flowrate of drying air
- Conventional energy used for the partially solar dryer (gas, electricity, fuel oil, or other).

Table 1. Tomatoes drying characteristics

Product	Wi	Wf	Tdmax
Tomatoes	98%	13%	65°C

3. MATHEMATICAL MODEL

3.1 For Glazed solar collector (solar air heater)

RETScreen software is actually using the following equations to determine useful energy and thermal efficiency of glazed solar collector (Duffie and Beckman, 1991):

$$Q_u = F_R A_c [I_t(\tau\alpha) - U_L(T_i - T_a)] \quad (1)$$

$$\eta_c = \frac{mc(T_{out} - T_{in})}{A_c I} \quad (2)$$

F_R and U_L are given by solar collector constructors.

3.2 For Perforated solar collector

Thermal efficiency of SolarWAll (perforated solar collectors) is calculated using the following equation (Carpenter et Meloche, 2002):

$$\eta = \frac{\alpha}{\left(1 + \frac{\left(\frac{20 \; v'_{vent}}{\dot{Q}_{capt}}\right) + 7}{\dot{Q}_{capt} \; \rho \; C_p \; (1 - 0{,}005 \, \dot{Q}_{capt})}\right)} \quad (3)$$

For GHG emission saving, it is calculated by RETScreen software based on the following expression: (RETScreen 2004; Carpenter et Meloche 2002):

GHG saving = (Reference GHG emission factor (TCO2)-Project GHG Emission factor)*Annual useful energy (4)

3.3 Mass flow rate of drying air

Drying is a thermodynamic process that follows the diagram on Fig.4. The following steps enable us to calculate the necessary air flow rate to dry 1000 kg of tomatoes/day. Humid air volume rate necessary to the drying of a mass product m is given by (Charreau et Cavaille, 1995) :

$$V_{ah} = \frac{m_{ah}}{\rho_{ah}} \quad (5)$$

Where: m_{ah} is the mass of drying air ρ_{ah} is the density of drying air

According to the mass balance of the dryer, the minimum mass of drying air to use is:

$$m_{as} = \frac{\Delta m}{X2 - X1} \quad (6)$$

From the humid air diagram, we determine the enthalpies values X1 and X2

The evaporated water mass: Δm is calculated by:

$$\Delta m = mi - mf \quad (7)$$

we have : $$m_f = ms + m_{ef} \quad (8)$$

with:

$$m_{ef} = m_s \, . \, W_f \quad (9)$$

And:

$$m_s = \frac{m_i}{1+Wi} \quad (10)$$

3.4 Calculation of air flow rate (m3/h)

It is calculated using the following expression:

$$Q = \frac{Vah}{ts} \quad (11)$$

where V_{ah} is the volume of moist air and t_s is the drying time (h)

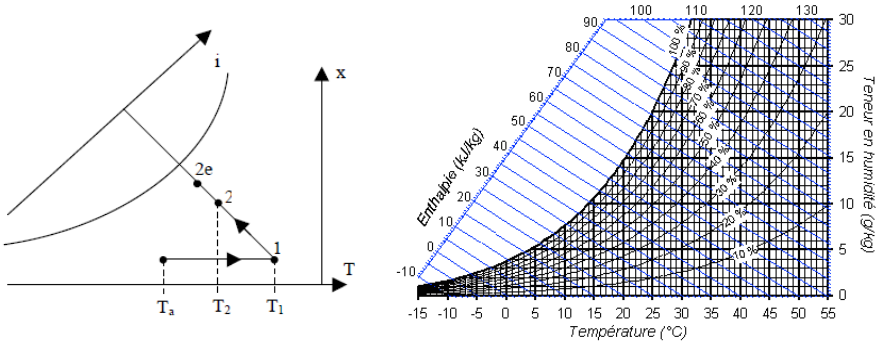

Fig. 4. Thermodynamic Drying process and Humid air Diagram

4. RESULTS AND DISCUSSION

In this prefeasibility study, we have used the following parameters to calculate the energy saving and GHG emission avoided using industrial partially solar dryer compared to a 100% conventional dryer. Considering the sizing part, for perforated collector (Solarwall) the collector surface area is suggested by RETScreen tool, based on the technical characteristics of perforated solar collector (Carpenter et Meloche, 2002) . To deliver the airflow rate necessary to dry 1000 kg of tomatoes per day, the estimated collector surface is 166 m^2 for perforated collector and 100 m^2 for glazed one. For the glazed collector, we have estimated the collector surface based on the relationship between collector efficiency and the air flowrate (Duffie and Beckman, 1991). The collector's thermal parameters (U, Fr) were used from constructor technical characteristics.

Table 1. Input parameters used in this study

Output parameters	values
Maximum air temperatures	60,65 °C
air flow rate	23880 m^3/h
Operating hours per day	10 h (discontinuous)
Operating days per week	5 days
Operating months per year	7 months
Solar collector area	100-166 m^2
Type of solar air heater	Perforated, glazed
Solar tracking mode	Fixed
Slope	Vertical/Location latitude
conventional energy	Electricity, natural gaz,

4.1 Annual energy consumption and GHG emission

Figure 5 depicts the annual energy used and the GHG emission for the drying of tomatoes during 7 month (March to November). We have considered three cases:

- Case1 is the reference case of tomatoes drying using 100% conventional energy
- Case 2: partial solar drying using vertical perforated solar collectors

The main results are summarized in Table 3. We can observe that the use of perforated solar collectors decrease the energy consumption whatever the conventional energy used.(from 629.4 to 472.08 MWh for electricity).

We have compared those results to a third case where we have considered perforated solar collectors inclined at a slope equal to Biskra city latitude (38, 4°). The results are plotted in Figure 5. As we can see, energy saving and GHG emission avoided is more important for inclined perforated collectors.

Table 3 Energy consumption for reference case and partially solar dryer

Ref Energy	ref case	Partial solar
Electricity (MWh)	629,44496	472,08
Natural gaz (m3)	92992,1756	69744,1317
Mazout (l)	86050,4396	64537,8297

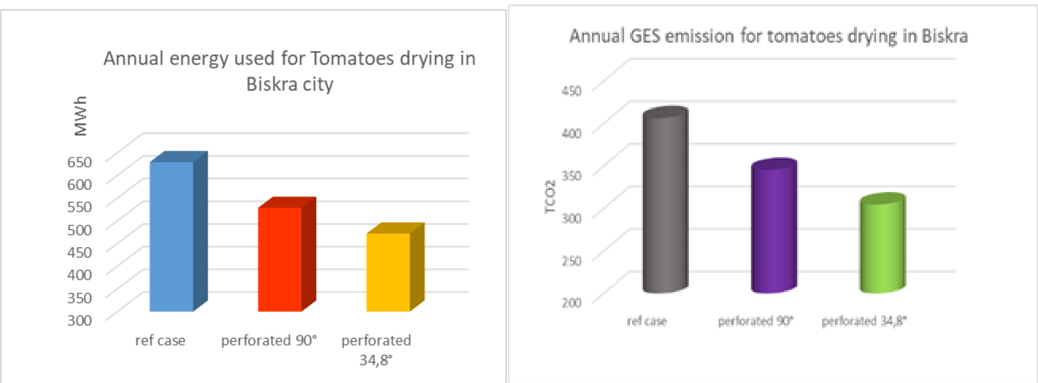

Fig. 5.Annual energy used and GHG emission for solar drying of tomatoes in Biskra city

4.2 Effect of the type of solar collector

We have compared the energy saving and GHG emission avoided for tomatoes drying using two type of collectors: glazed and perforated as shown in Figure 6. As expected, glazed solar collectors give the best energy saving. This is concordant with laboratory tests found in literature that shown the efficiency of glazed collector to be higher of 17% in windy sites (IEA solar heating and cooling Report, 1999). This is the case in Biskra city with an annual wind velocity of 4.5m/s. However, we cannot neglect the fact that solar perforated collectors are cheaper and simplest to be incorporated in an existing building.

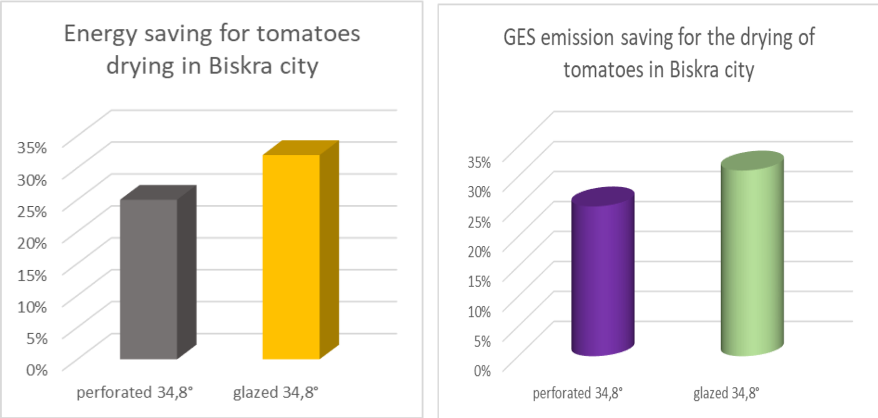

Fig. 6. Energy and GHG emission savings for perforated and glazed solar collector

4.3 Effect of project's location

The climatic and geographic location of the project are very important for solar devices because the solar collector's efficiency is dependent on solar irradiation and ambient temperature and humidity. To confirm this fact we have compared the energy saving for tomatoes drying of Biskra to a northern Algerian city, Blida (36.5N°; 2.8E°), in Fig.7. As we can observe, the energy saving decrease from 32 % to 14 % for glazed solar collectors and from 25% to 9 % for perforated collectors.

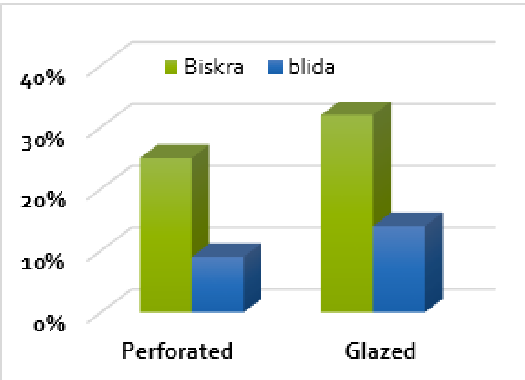

Fig. 7. Comparative Energy saving for tomatoes drying for glazed and perforated collectors in Biskra and Blida

4.4 Effect of air drying temperature

To highlight the effect of air drying initial temperature and humidity we have compared the results of two drying process at 60°C and 65°C respectively (Fig.8). On can observe that a decrease of 5°C in air drying temperature can lead to an enhancement of 3 % of energy saving and GHG emission as well, which is not negligible.

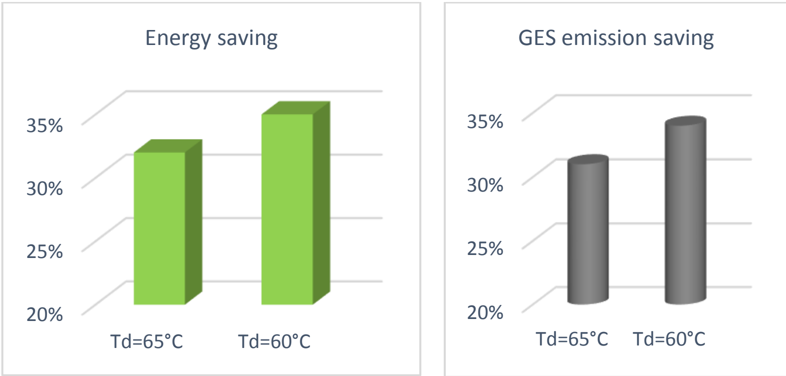

Fig. 8. Effect of drying air temperature

5. CONCLUSION AND PERSPECTIVES

From this prefeasibility analysis of tomatoes drying in an industrial dryer, we have noticed the following:

- Biskra city with its high solar radiation and favorable climatic conditions has a very good potential to develop Industrial partial solar dryers
- It was found that energy and GHG saving are higher for the glazed collector. However, there are other parameters to be take into account like the economic cost and the ease installation of perforated collector. In this case, the comparison will be in favor of this latter.
- Solar collector inclined at a slope equal to Biskra's latitude gives better results than the vertical one , as expected.
- Decreasing air drying temperature will save more energy and lower GHG emission (about 3% saving for 5°C decrease)
- Economic and financial analysis is necessary to complete this study.

NOMENCLATURE

Ac	Solar collector Area [m2]	W	Product moisture [%]
Cp	Air Specific hea	U_L	Solar collector overall loss coefficient [W/m^2 ◦C]
	t [kJ/kg·K]		
T	Temperature [°C]	η_c	Perforated Solar collector Efficiency
		η	Glazed solar efficiency
	Specific volume [m^3/kg]	$\alpha\tau$	Optical efficiency
V	Product mass [Kg]	q	Useful energy [J]
m		F_R	Heat removal factor
		I	Solar radiation [W/m^2]

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