# Role of Solar Drying Systems to Mitigate $CO_2$ Emissions in Food Processing Industries

**K. Rajarajeswari, B. Hemalatha and A. Sreekumar**

**Abstract** This chapter sheds light on the role of solar drying systems in food processing industries to mitigate carbon dioxide emissions. The industrializing world is encircled by scads of environmental problems. Greenhouse gas emission leading to climate change is a major concern for which there are many policies emerging among the countries. India, ranking sixth in the world in energy-related carbon dioxide emission, pledged to decrease the emission in Nationally Determined Contributions (NDC). Industries gobble major portion of the energy produced in a country. Food processing is the largest sector in India, which has segments like dairy, fruit and vegetable processing, grain processing, meat processing, poultry processing, fisheries, etc. Drying is an important processing method for food preservation. A conventional type of drying process in industries uses electricity and fossil fuels. Replacing the existing drying systems to alternate energy-driven drying systems helps to reduce the total energy consumption. Solar drying system is remarkable in energy efficiency and product quality. A considerable amount of carbon dioxide emission reduction can be attained by using solar drying systems since they derive energy from the sun, a freely available source of energy. Details on energy consumed by food sectors, energy consumed by other drying systems, and solar drying systems are discussed in this chapter.

**Keywords** Solar dryer · Greenhouse gas · Carbon dioxide · Food quality Energy

K. Rajarajeswari · A. Sreekumar (✉)
Centre for Green Energy Technology, Pondicherry University, Puducherry 605014, India
e-mail: sreekmra@gmail.com

B. Hemalatha
Department of Biotechnology, Bharathidasan University, Tiruchirappalli 620024, India

 
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## 1 Energy-Related $CO_2$ Emission

Global warming is a widely spoken problem since last few decades. The emission of greenhouse gases like $CO_2$, $N_2O$, $CH_4$, CO, etc., into the atmosphere resulted in heating up the Earth. The infrared absorption per molecule is more for greenhouse gases (GHG). The increase in temperature of the globe provides away to climate change and melting of glaciers. Out of all the GHG, 80% of contribution to global warming is by carbon dioxide (Lashof and Ahuja 1990). To mitigate $CO_2$ emission the world countries have adopted the global warming limit of 2 °C or below. But the probability of exceeding 2 °C is 53–87% if the emission of GHGs is increasing more (Meinshausen et al. 2009). The fossil fuel resource that accumulates carbon for years together, when burnt releases an enormous amount of carbon into the atmosphere. Combustion of coal is the major source of electricity across the globe which is also the source of carbon dioxide emissions into the atmosphere. India relies on coal reserves for its 70% of electricity generation. The carbon dioxide emission factor for electricity production in India was 901.7 $gCO_2$/kWh in 2005 and increased to 926 $gCO_2$/kWh in 2012. The emission factor is much higher than the global average energy-related $CO_2$ emission which was 542 and 533 $gCO_2$/kWh in the year 2005 and 2012, respectively (IEA 2015). The growing population and energy demand may increase the trace of carbon in the atmosphere. India pledged to reduce the overall emission intensity by 35% in its NDC (Nationally Determined Contributions) (Shearer et al. 2017).

The average carbon dioxide emission factor for different parts of the world is given in Table 1. In India, the emission factor varies with different states, among which Jharkhand has the highest emission factor of 1.21 $kgCO_2e$/kWh and the average electricity generation emission factor of India is 0.89 $kgCO_2e$/kWh (cBalance Solutions Pvt. Ltd. 2009). The emission factor varies with different energy sources. It is obvious from Table 2 that the emission is high for lignite and coal-based thermal power plants. The renewable energy resources emit less carbon into the atmosphere compared to conventional energy resources.

The major energy consumption is by industrial and transport sectors. The industries use different forms of energy like heat, light, water, etc. The heating

**Table 1** Carbon dioxide emission factor (IEA 2015)

| | $CO_2$ emission factor from electricity ($kgCO_2e$/kWh) |
|---|---|
| Africa | 0.70 |
| Asia | 0.77 |
| Europe | 0.36 |
| Latin America | 0.18 |
| Middle East | 0.67 |
| North America | 0.567 |
| Pacific | 0.46 |
| Former USSR | 0.36 |

**Table 2** Carbon dioxide emission of different sources (World Nuclear Association 2011)

| Source | Carbon dioxide emission (tons $CO_2e$/GWh) |
|---|---|
| Lignite | 1,054 |
| Coal | 888 |
| Oil | 733 |
| Natural gas | 499 |
| Solar PV | 85 |
| Biomass | 45 |
| Nuclear | 29 |
| Hydroelectric | 26 |
| Wind | 26 |

sector is one of the potential consumers of energy. Heat generation consumes more than 50% of global energy consumption. Heating sector uses a considerable percentage of total energy and it is met with the fossil fuel reserves. This production of heat accounts for one-third of energy-related carbon dioxide emissions according to International Energy Agency (IEA). One-third of energy accounts for 10 Gtonne emission of carbon dioxide per year (Eisentraut and Adam 2014). Despite its huge energy consumption, the heating sector receives less attention. Heat production using alternative energy provides a way to boost energy security and turn down energy-related $CO_2$ emissions in the economically viable way. Heat generation is a very important process in many industries for processing, melting, boiling, evaporation, etc., among which food processing industries rely on heat generation for producing quality food products.

## 2 Energy Consumed by Food Sector

Industrial sector uses more energy amounting to 54% of world's total energy consumption. Industries are classified into two according to their energy usage, namely, energy-intensive manufacturing, non-energy-intensive manufacturing, and nonmanufacturing (U.S. Energy Information Administration 2014). Industrial sector uses energy for different applications such as assembly, cogeneration, steam, lighting, heating, air-conditioning, process heating, and cooling. Food and beverage production falls under energy-intensive manufacturing sector. The different food processing industries in India are dairy, fruits, vegetables, grain, meat, poultry processing, and fisheries. The country produces a large number of food products out of which only 2% undergoes processing (I. Brand Equity Foundation). This is due to lack of food processing techniques and the high cost of existing techniques. A packed food or processed food undergoes many stages from the day of cultivation till it reaches consumers. Each and every stage requires energy in the form of electricity, thermal energy, and water. The food industry in Taiwan is the largest consumer of electricity among the manufacturing sectors. 95% of total energy used is petroleum and electricity. The intensity of GHG emission is increased due to large amount energy consumption among of food sectors. The energy consumption of 76 food sectors in Taiwan is 685,002 MWh of electricity, 69,540 L of fuel oil, 2,136 ton of LPG and 2,853 $km^3$ of natural gas (Ma et al. 2012). The food industry was the fifth largest energy-consuming sector in the USA in the year 1994 (Drescher et al. 1997). The energy requirement was mainly met with electricity. Food sector depends on energy for food processing, safe package, and storage. Heating processes such as roasting, cooking, frying, and boiling use fuels and electricity. Cooling and refrigeration process depend on electricity. Packaging is a very important step, which is more energy-consuming process. Freezing and drying are the most pivotal methods of food storage. Freezing requires more energy and drying is mostly met with fossil fuel reserves.

Atmospheric forced hot air dryers are the commonly used method for drying food products. The major problem that deals with the hot air drying is the large energy requirement and low drying efficiency. During the drying process, the evaporation occurs at a rapid rate and the outer skin gets dried faster with wet interior leading to case-hardening which is a quality defect. If the products are exposed to high temperature for longer time, the color and flavor of the product degrade. So the conventional method of drying does not result in good quality. The methods that result in high-quality food products consume more energy and the traditional open sun drying consumes zero energy but suffers from food loss and low quality.

## 3 Fundamentals of Drying

Drying is one of the oldest methods of food preservation. Drying prevents the growth of microbes in the food and helps the food for longer storage. This is because the microbial growth and multiplication get deteriorated in the absence of water. Drying of the food product is removing excess moisture content by vaporizing the water present in the product. This process of drying requires energy to vaporize the water. There are two processes that are responsible for the unit operation of energy required for drying:

- The energy required to remove the bound water from the product, i.e., heat transfer to provide necessary latent heat of fusion.
- The energy required to remove the water vapor from the product, i.e., flow of hot air to remove the moisture.

The drying systems are mostly provided with electricity and another fossil fuel has driven systems to generate the heat required for drying. There are many types of drying. They are:

*Hot air drying*: In this type of drying the moisture is removed by supplying hot air.

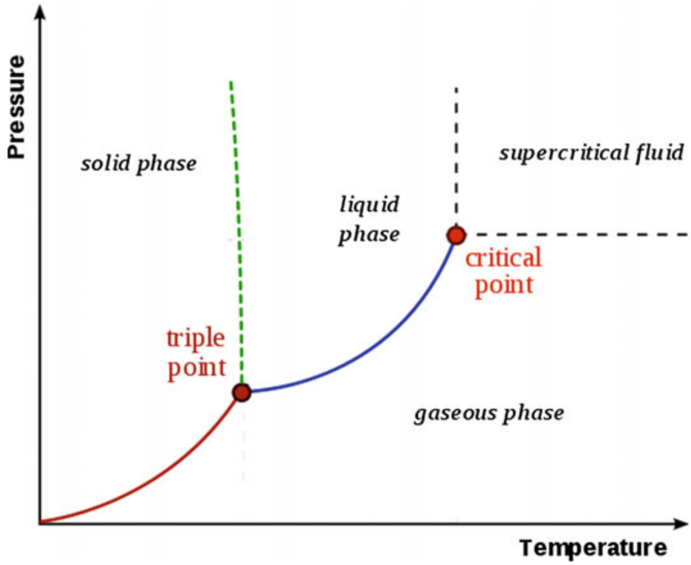


**Fig. 1** Phase diagram of water

*Freeze drying*: This is the process in which the product is frozen and the moisture is removed by the process of sublimation. The food structure is maintained superior in this type of drying.
*Vacuum drying*: In this type, the pressure is reduced by means of the vacuum pump, and the heat transfer is done by conduction by passing the steam over the products.

The phase diagram of water shown in Fig. 1 gives the physical states at different temperatures and pressures. At room temperature and pressure, it takes the liquid form. It becomes solid when the temperature is lowered below 273 K and above 373 K, it gets vaporized at the same pressure. The point at which all the three phases coexist is called triple point. The energy required to evaporate a particular mass of water ($m_w$) is given as

$E$ (kJ) = $m_w$ × Latent heat of vaporization of water

$$m_w = \frac{M(m_i - m_f)}{100 - m_f}$$

where $m_w$ is the mass of water to be removed (kg), $m_i$ is the initial moisture content (%), $m_f$ is the final moisture content (%), and $M$ is the total mass of product (kg).

The percentage moisture content of a sample can be given as

$$\%\,\text{moisture} = \frac{\text{weight of wet sample} - \text{weight of dried sample}}{\text{weight of wet sample}} \times 100$$

Drying of food products is more energy consuming due to the high moisture content. The moisture content varies with different products. The product has to be dried to equivalent moisture content for storage. Low moisture content tends to prevent the microbial attack and preserve the product for a longer duration. The major parameters that are concerned about drying process are:

*Time period*: The products with high moisture content require more time to be dried. This may invite the microbial attack during the process of drying.
*Energy*: It requires more energy to remove water that is bound to the food products than the liquid water due to the high latent heat of vaporization. Hence, drying is a more energy-consuming process.
*Economics*: The storage process is most expensive than the cost required for producing the food products, particularly the food producers cannot afford.
*Quality*: The quality of dried products enables the consumer to attract toward the market. So quality is the most important parameter which cannot be compromised.

The drying technology must be able to meet the above parameters of the drying process. There are many technological advances in recent times to produce high-quality products.

## 4 Energy Consumed by Different Drying Technology

Microwave drying is a technique in which microwave energy is applied to the products to increase the temperature of the product which increases the rate of water removal. Soysal et al. used microwave convective drying to enhance the quality of dried red pepper. Color, texture, and sensory properties were analyzed and presented. The drying system comprised of two 900 W microwave oven, a 100 W radial fan with volume flow rate 180 $m^3$ $h^{-1}$ (Soysal et al. 2009). If the operation of the equipment is for 2 h, then it requires 1.8 kWh of energy. This process releases 1.6 kg of carbon dioxide into the atmosphere for 2 h if the average emission is considered to be 0.89 $kgCO_2e/kWh$. If the equipment is operated continuously in a food processing industry, it leads to 529 kg of $CO_2$ emissions per year for drying single product. The energy-related carbon dioxide emission changes with different products. Mortaza et al. developed a laboratory-scale hot air dryer for drying berberis fruit and compared it to the sun drying. The specific energy requirement for thin drying of berries is given as 20.93–1,110.07 (kWh/kg) (Aghbashlo et al. 2008). The energy-related carbon dioxide emission is 17 kg to 910 kg per kg of fresh product.

Lucio et al. investigated the energy consumption and analysis of industrial drying plants for fresh pasta process. They discussed the energy needs and $CO_2$ emissions resulting from a small factory producing fresh pasta located in Molise, Italy. According to the study, 50% of electricity is consumed by two processes, namely, pasteurization, and drying. There are five steps in processing before the product is packed: (i) picking up and storage of raw materials, (ii) mixing of ingredients, (iii) shaping, (iv) pasteurization and pre-drying of pasta, and (v) drying. Energy resources like electricity, thermal, and water were used. Electrical energy is used in the whole plant and thermal energy is used for pasteurization and drying. Monthly pasta production consists of 5,846 kg of pasta, 175 kg of dry pasta. The amount of energy used is (i) 1,100 kWh of electricity, 44.77 kWh of which was used for dry pasta, (ii) 6,231.8 kWh of thermal energy, 366.2 kWh was used for the production of dry pasta. Every kg of monthly produced pasta requires 0.18 kWh of electricity, equivalent to almost 78 g of $CO_2$ emission and 1.1 kWh thermal energy equivalent to almost 220 g of $CO_2$ emissions.

Firouzi S et al. analyzed energy consumption for drying paddy using the newly designed horizontal rotary dryer. Two types of the dryers, namely, industrial horizontal rotary dryer (IHRD) and industrial batch type bed dryer (IBBD), are analyzed in terms of energy consumption and drying performance. Specific energy is defined as the energy used to evaporate unit mass of water from the bulk grain in a dryer. Specific electrical energy consumption (SEEC) and specific thermal energy consumption (STEC) are studied for both the dryers. SEEC varied between 2.64 and 7.48 MJ/kg for IBBD and 5.50 and 17.41 MJ/kg for IHRD for different levels of moisture content. It was reported that the energy requirement increased with decreasing moisture content. It required more energy to remove the moisture from the inside of grains that is bound to the solid. Specific thermal energy consumption varied from 7.78 to 22.09 MJ/kg and 11.5 to 36.44 MJ/kg of water removed while drying with IBBD and IHRD, respectively. The total specific energy consumption is given in Fig. 2, which shows that the energy consumption varied between 10.41 and 29.58 MJ/kg and 17.00–53.86 MJ/kg while drying with IBBD and IHRD, respectively. In this case, the $CO_2$ emission is a maximum of 7,289 $gCO_2e$ per kg of water removed using IBBD and 13,261 $gCO_2e$/kg of water removed using IHRD.

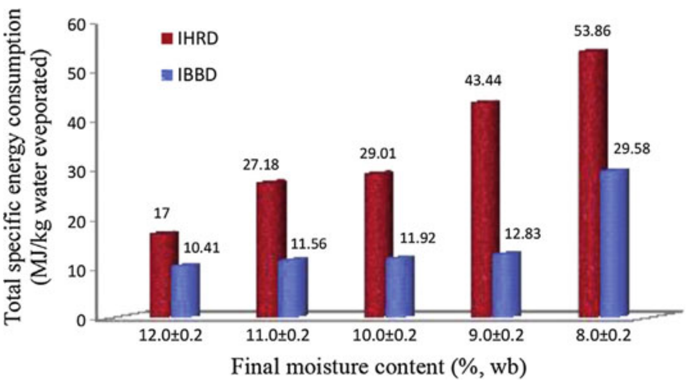


**Fig. 2** Total energy consumption during drying of paddy with industrial batch dryer and industrial horizontal rotary dryer in Northern Iran (Firouzi et al. 2017)

A laboratory-scale microwave-vacuum oven was developed for drying cranberries by Yongswatdigul and Gunasekaran. Cranberries were pretreated and dried to bring down the moisture to 15% (wet basis). Drying efficiency was calculated using the parameters: total energy input which is the multiplication of microwave power and total power-on time, energy absorbed which is calculated by changes in sensible and latent heat, and heat of vaporization of water. The drying process was operated in continuous mode and a pulsed microwave-vacuum drying mode. Drying efficiency in continuous mode ranges from 3.59 to 5.02 MJ/kg of water which emits a maximum of 1,237 $gCO_2e$/kg of water removed and drying efficiency in pulsed microwave-vacuum drying is 2.51–4.49 MJ/kg which contributes a maximum of 1,103 $gCO_2e$/kg of water removed. Pulsed microwave-vacuum drying consumes less energy than the continuous mode drying (Yongsawatdigul and Gunasekaran 1996). The specific energy consumption for batch drying, spray drying, freeze drying, fluidized bed drying is 40, 5,300, 18,000, and 11,400 kJ/kg, respectively (Huang et al. 2017).

Tohidi et al. studied energy and quality aspects of deep bed drying of paddy grains. Drying experiment of paddy with different temperatures and velocities was performed. The total energy consumption ranged between 0.37 and 1.85 kWh at temperatures 80 and 40 °C, respectively. The corresponding carbon dioxide emissions would be between 329.3 and 1,646 $gCO_2$. It was found that energy efficiency was more at higher drying temperatures, lower velocity, and lower relative humidity (Tohidi et al. 2017).

Microwave, vacuum, and convective drying of nettle leaves were compared in terms of energy consumption and color characteristics. The energy consumption at different conditions and different drying methods is shown in Fig. 3. The maximum energy consumed during convective drying is 0.35 kWh at the lowest temperature which corresponds to 311.5 $gCO_2$ emission. The maximum energy consumed during vacuum drying is 0.9 kWh at highest pressure and lowest temperature which corresponds to 801 $gCO_2$ emissions. The maximum energy consumed during microwave drying is 0.06 kWh which corresponds to 53 $gCO_2$ emissions. Among different drying methods, microwave drying is energy efficient for drying nettle leaves. The color change was less in microwave drying followed by vacuum and convective drying methods (Alibas 2007).

**Solar Drying**

Sun is the major source of energy for the Earth. The solar intensity outside the atmosphere is 1,367 W/m$^2$. On an average, the radiation falling on the ground is between 800 and 1,000 W/m$^2$. This huge amount of energy can be more effectively utilized by the intervention of appropriate technology (Rajarajeswari and Sreekumar 2016; Aravindh and Sreekumar 2016). The solar energy sector is growing rapidly with innovative technology and materials in recent years for generating electrical energy and thermal energy from Sun. Solar drying technology is the one that utilizes heat radiation from the sun for drying variety of food products, marine products, agricultural products, meat, poultry products, etc. This method of food drying is a better replacement for the traditional method of drying

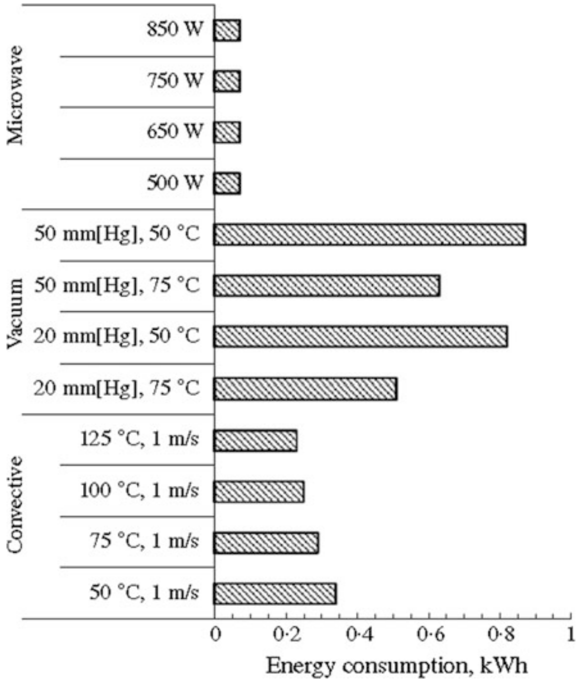


**Fig. 3** Energy consumption for nettle leaves drying at three different drying methods (Alibas 2007)

which suffers from poor quality of dried products. Electrical drying results in a good quality product, but it consumes more energy even though. The energy consumption is almost zero in a solar dryer.

Advantages of solar drying over open sun drying are

- Higher temperature and lower humidity increase the rate of drying.
- The casing protects the food from weathering, dust, and birds, and hence, the postharvest loss is low.
- The drying area is small as compared to open sun drying area due to high drying rate.
- The shelf life is longer due to complete drying.
- The product quality is very high as compared to the branded products.

The three important parts of a solar collector are glazing that transmits the solar radiation, absorber plate which absorbs the incoming radiation, and insulation that suppresses the heat losses. Solar dryers are classified into

Direct solar dryer: In this type, the food products are exposed to solar radiation. The moisture is removed by the incoming solar radiation and also by the hot air that is allowed to pass through the drying chamber.

Indirect solar dryer: In indirect solar drier, the moisture is removed only by passing hot air through the drying chamber. The atmospheric air is passed through the solar collector; the absorber plate which is heated by the solar radiation transfers the heat

to the flowing fluid. The air temperature thus increases and passed on to drying chamber (Aravindh and Sreekumar 2014; Aravindh and Sreekumar 2015; Sreekumar and Aravindh 2014; Rajarajeswari and Sreekumar 2014).
Mixed mode dryer: In this type, food is dried by both the solar radiation and by the hot air.
Hybrid dryer: Both solar energy and conventional energy are used for drying in the hybrid dryer.

## 5 Solar Dryers—A Case Study

*Commercial solar dryers*
SEED (Society for Energy, Environment and Development) developed various solar food processing dryers.

The dehydrated food products using developed solar dryers include fruits, vegetables, green leafy vegetables, spices, forest products, medicinal products, herbal products, food items, and chemicals. The products can be dehydrated with pretreatment for longer shelf life with zero energy cost using the developed solar dryers. The specifications of various capacity solar dryers are shown in Table 3. All the dryers are completely solar driven with electrical energy backup that can be utilized during nonsolar hours. The photograph of the commercially developed solar dryer is shown in Fig. 4.

Frito lay, a chip manufacturing company in the USA, uses concentrated solar collectors for five acres, which consist of 384 solar collectors. The solar collectors are designed to absorb sunlight which produces steam that is used to heat the cooking oil used for frying chips. This predominantly reduced the use of natural gas. The company contributes in mitigating 1.7 million pounds of $CO_2$ emissions every year (Eswara and Ramakrishnarao 2012).

Abhay et al. developed an indirect solar dryer for drying banana slices. Solar air heater with corrugated absorber plate connected with the drying chamber forms the drying system. The moisture content of banana reduced from 56% (db) to 16.3%, 19.4%, 21.15%, 31.15%, and 42.3% in tray 1, tray 2, tray 3, tray 4, and open sun. The drying time was more in the open sun than the solar dryer. It was concluded that the solar drying was more efficient than open sun drying (Lingayat et al. 2017; Rajarajeswari 2016).

**Table 3** Specification of solar dryers developed by SEED (TERI 2014)

| Model | Loading capacity (kg) | Drying area ($m^2$) | Solar photovoltaic panel 12 VDC (W) | Electrical backup (kW) |
|---|---|---|---|---|
| SDM-8 | 8 | 0.56 | 3.5 | 1 |
| SDM-50 | 50 | 3.6 | 20 | 4 |
| SDM-100 | 100 | 7.2 | 50 | 8 |
| SDM-200 | 200 | 14.4 | 100 | 16 |

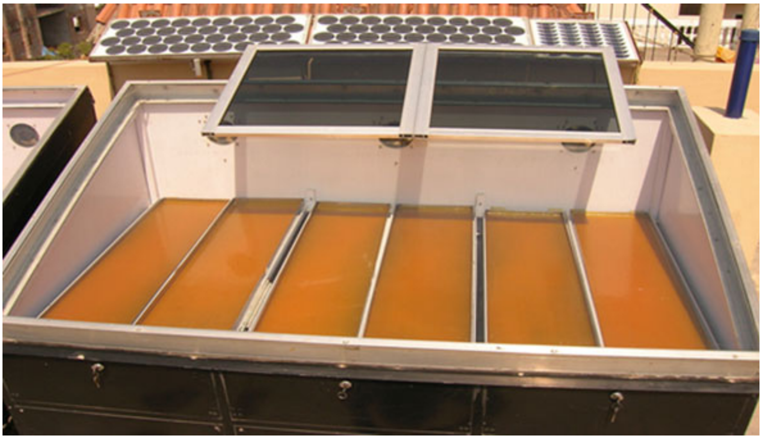

**Fig. 4** Commercial solar dryer developed by SEED (Eswara and Ramakrishnarao 2012)

**Fig. 5** Direct type solar dryer (Castillo-Téllez et al. 2017)

*Direct and indirect dryer*

Solar dryers for chili drying shown in Figs. 5 and 6 were designed and installed in Mexico. Drying experiment was carried at solar radiation between 200 and 950 W/m$^2$ with the ambient air temperature ranging from 26 to 33 °C and drying temperature ranged from 31 to 45 °C. Drying air velocity ranged between 0.7 and 2.6 m/s. The initial moisture content of chilies varied between 80.65 and 88.83%. The final moisture content of dried chilies varied between 5.46 and 8.29% wet basis. The total drying time was 16 h. The thermal efficiency of solar dryer ranged from 67 to 72%. The energy required for drying was taken from solar radiation.

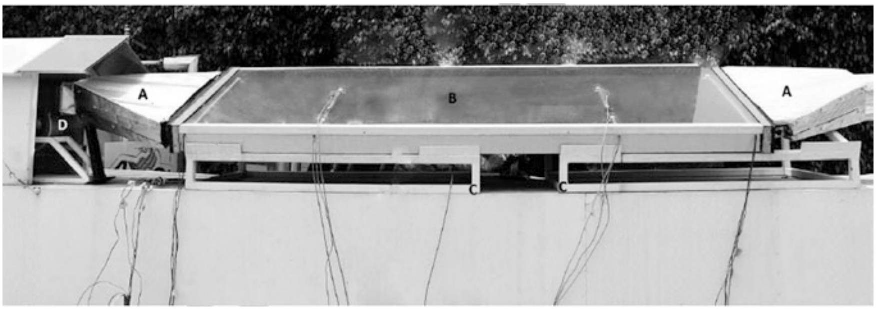


**Fig. 6** Indirect type solar dryer (Castillo-Téllez et al. 2017)

**Fig. 7** Chilli in solar dryer at different drying stages (Castillo-Téllez et al. 2017)

The energy consumed was only for running centrifugal blowers. The product at different stages of drying is shown in Fig. 7 (Castillo-Téllez et al. 2017).

*Greenhouse type solar dryer*
The greenhouse type solar dryer shown in Fig. 8 is installed at a small-scale food industry in Thailand. The loading capacity is 1,000 kg of fruits. The size of the dryer is 20 m length, 8 m width, and 3.5 m height. DC fans with three 50 W solar panels were used to circulate the air. A 100 kW LPG burner was present to heat the air during nonsolar hours. Tomatoes were chosen for drying experiment. The moisture content of 57% (wet basis) reduced to 17% (wet basis) in 4 days while in the open sun drying it was 29% for the same period. The drying time is reduced in a solar dryer. Retention of original color in the solar dryer was appreciable as compared to open sun drying which had a pale yellow color whereas in the solar dryer it occurred in reddish brown color. The total electricity consumed was 252 kWh per year (Janjai 2012). The carbon dioxide emissions will be 148 kg $CO_2$ per year if conventional fuel was used. Since the fuel consumed is zero, the $CO_2$ emission due to the fuel consumption is zero. For drying 1,000 kg of tomatoes, the electricity required would emit 269.67 kg$CO_2$. For a year, it would emit 53,934 kg $CO_2$ if 200 days of operation and 0.89 kg$CO_2$e per kWh is considered.

*Direct type solar tunnel dryer*
A prototype of solar tunnel dryer of 12 kg capacity of fresh product shown in Fig. 9 was installed in the Centre for Green Energy Technology, Pondicherry University. The dryer is of direct type, where the products are exposed to sunlight. The energy

**Fig. 8** Greenhouse solar drying system (Janjai 2012)

**Fig. 9** Solar tunnel dryer (Rajarajeswari et al. 2016)

for vaporization of water is taken directly from solar radiation and also from the heated air inside the chamber. The DC fans that circulate air inside the chamber are powered by solar panels. The drying experiments were carried at latitude 11.91°N and longitude 79.81°E between 9:30 a.m. and 5:30 p.m. in the month of April where the solar radiation ranged between 300 and 900 W/m$^2$. The temperature profile of solar dryer is shown in Fig. 10. The drying temperature was between 35 and 48 °C. The ambient temperature ranged from 30 to 35 °C.

The products selected for drying are apple, tapioca, pineapple, and tomato. The initial moisture content of each product was found by hot air oven method. The products were kept for drying in the hot air oven at 110 °C for 24 h. The difference in the initial and final weight gives the percentage water content present in the products. The initial moisture content of apple, onion, and tomato are 86.2, 82.7, and 93.1%, respectively. Three types of drying were compared in terms of drying efficiency, energy consumed, and quality of dried products. The moisture content of apple dried in solar drier got reduced to 10.3% from 86.2% in three solar hours.

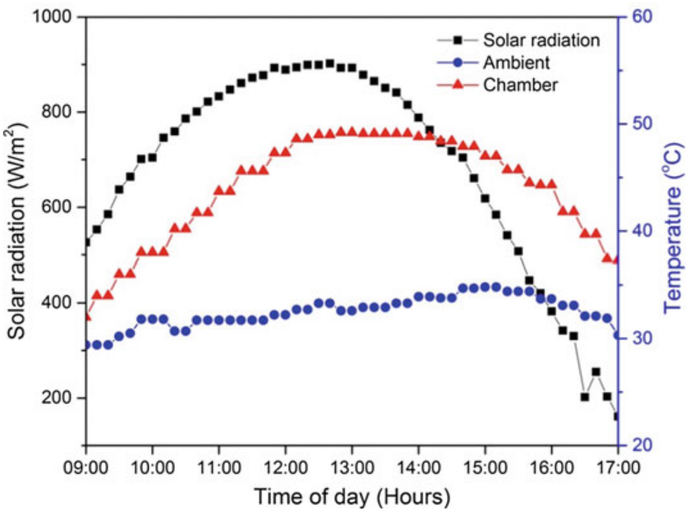


**Fig. 10** Drying temperature and solar radiation on day of experiment

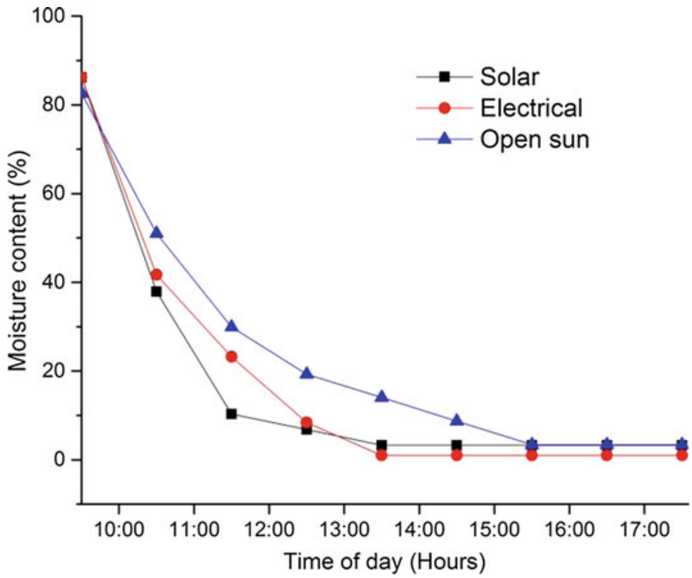


**Fig. 11** Moisture reduction curve for apple

The same time was taken in the electrical drier. In open sun drying, it took a little longer for drying as shown in Fig. 11. The moisture content of onion got reduced to 10.4% from 82.7% in four solar hours in a solar tunnel dryer. The drying was faster

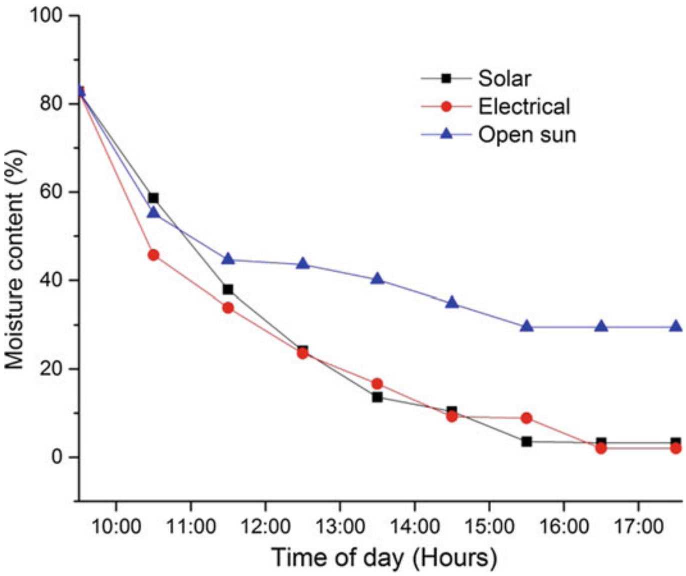


**Fig. 12** Moisture reduction curve for onion

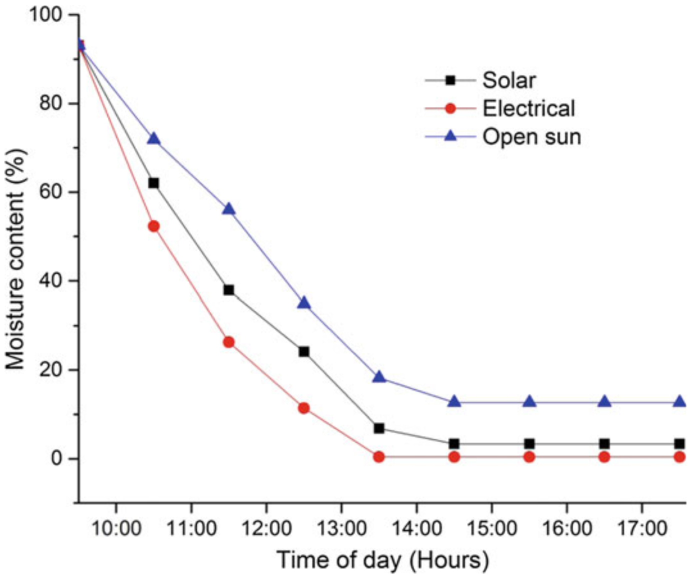


**Fig. 13** Moisture reduction curve for tomato

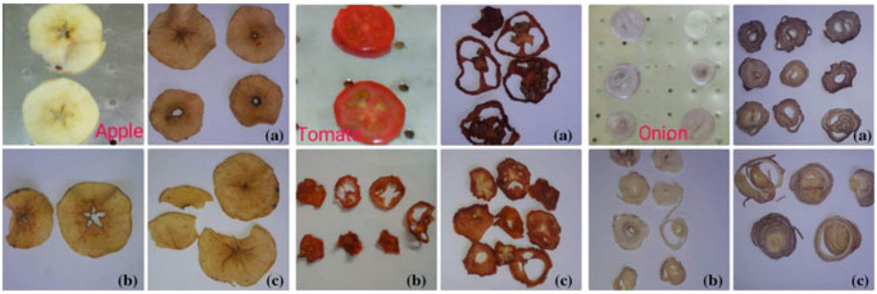


**Fig. 14** Images of fresh and dried products: **a** solar dryer, **b** electric dryer, and **c** open sun

in electrical drying and in four hours the moisture percentage in open sun drying was 45%. The drying duration was longer in open sun drying as shown in Fig. 12. The moisture content of tomato reduced to 20% in three drying hours in the solar dryer. In electrical drying, the drying was faster as compared to the solar dryer as shown in Fig. 13. The drying duration was reduced in solar dryer comparing to open sun drying while in the electric dryer, it was faster than solar dryer due to a constant temperature. The images of fresh and dried products are shown in Fig. 14.

## 6 Reduction of $CO_2$ Emission

The solar dryer uses the energy from the solar radiation to vaporize the water present in the products. In the electric dryer, the energy is supplied by electricity. The energy required to remove per kg of water from each product is given in Table 4. Using solar dryers prevents 434 $gCO_2e/kg$ of drying fresh apple, 467 $gCO_2e/kg$ of fresh tomato, 410 $gCO_2e/kg$ of onion, 480 $gCO_2e/kg$ of pineapple, and 382 $gCO_2e/kg$ of tapioca.

**Table 4** Carbon dioxide mitigation using solar dryer

| Product | Initial moisture content (%) | Final moisture content (%) | Energy required per kg (kWh) | $CO_2$ mitigation (g) |
|---|---|---|---|---|
| Apple | 86.2 | 10.3 | 0.53 | 434 |
| Tomato | 93.1 | 20 | 0.57 | 467 |
| Onion | 82.7 | 10.4 | 0.50 | 410 |
| Pineapple | 86.5 | 23.5 | 0.54 | 480 |
| Tapioca | 72.4 | 6.8 | 0.43 | 382 |

## 7 Conclusion

Realizing the adverse impact of climate change each country must tread toward in mitigating the emission of greenhouse gases. This can be done by adopting clean and green energy resources that are less harmful to the environment. Since food industry is a major consumer of electricity and other conventional fuels, it is endorsed to stick to technology that is run by alternate energy. Solar dryer is an intriguing, ancient, and alternate technology that consumes zero fuel for the drying process. Large-scale promotion of solar drying technology helps to reduce $CO_2$ emissions up to a certain extent in food processing industries. The environmental cost of fuel also should be considered while making the economics of conventional and renewable energy systems. Influential amount of energy-related carbon dioxide emissions can be mitigated by proclaiming the technology among the food processing industries and small-scale food producers.

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