A comprehensive review on impacts of COVID-19 in food preservation and cold chain: An approach towards implementing green energy technologies

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Abstract
Technology plays a crucial role in fighting COVID-19 pandemic. The COVID-19 pandemic impacts all facets of human life, including food preservation and supply chain. The changes in the food processing and preservation brings changes to the global food choice. In the age of the COVID-19 pandemic scare, the present article explores the framework for food security. It offers insights into food security with a focus on renewable energy to help rural farmers, besides, exploring the possibility of the diffusion of COVID-19 via food chain. This article indicates that the implementation of stand-alone and hybrid renewable energy systems is relatively fresh in food processing, preservation, and transportation chain. Green food preservation may be a revolutionary idea to address the challenges of the future to secure both producers and customers, besides, to improve the attractiveness of the ecological, economic, and creative sectors. This study reveals that the transformation can be achieved from a technological and economic point of view with the key steps to fulfill this goal in a cost-effective manner. The observation also shows a suitable methodology to identify the best energy, economic and environmental scenario towards fulfilling the energy needs in isolated areas.

KEYWORDS
coronavirus disease, food supply chain, hybrid energy, renewable energy, sustainability

1 | INTRODUCTION

Coronavirus disease (COVID-19) is spreading all over the world. It is not just a health problem, but also affects the world's economy, energy utilization, and environment in various ways. Many governments are involved in resolving various issues linked to Coronavirus for a sustainable society. However, the underlying expectations are severely affected either by the availability of clean energy resources or numerous financial and organizational challenges. During this global crisis, policymakers could not truly manage the strategic choices and the expenditure in the sense of ingeniously interconnected social, economic, and environmental issues. Governments are expected to get into a clean energy transformation to have a variety of options at this critical moment. Most of the green technologies can be implemented rapidly, helping to restore businesses and generate new employment. This year is expected to be a tipping point for energy and economic change, since 2020 being the culmination of a decade long progress. We still must see the outlines of the post-COVID world. The increasing loss of life is tragic, and the burden on populations and ecosystems demands careful and far-reaching solutions. A broader outlook is required, seeing energy, culture, economy, and climate as part of a complex and systemic framework. The COVID-19 pandemic has become a challenge without precedents to low-income communities, particularly those who are already insecure on energy resources. On the other hand, the pandemic also influenced renewable energy and its propagation. The notable impact
on the present situation is the investments in sustainable energy technologies.

COVID-19 pandemic is a worldwide problem that already threatens the food and livestock sectors. Immediate steps must be taken to keep food supply chains stable, both locally and worldwide. It could minimize the risk of major shocks which would have a severe effect on all, particularly the poor and the most fragile. The COVID-19 pandemic destruction will lead to significant and persistent changes in economic systems; in a way, the pandemic provides a remarkable chance to turn the current food processes into a more viable one for the future. Food security plays a significant part in combating global poverty in this way. The food industry is a highly competitive market. To thrive, it needs the use of sustainable technologies to minimize the emissions due to food processing. Green Food Processing may be a conceptual study that involves a holistic approach focused on the development of implementation of methods to eliminate fossil energy use. Green energy-based food processing may be a revolutionary model for addressing the demands of the 21st century, protecting both the environment and markets.

Stand alone and hybrid renewable energy-based food preservation is a novel area in the green energy-based food technology sector. The key suggestion identified in the food preservation and processing sector is hybrid energy based system, since they ensure high reliability in any situation. In this sense further research is needed in the combination of energy sources in the food preservation sector to minimize the economical constrains. The Hybrid Renewable Energy System (HRES) is one of the feasible options for addressing problems such as cost, and sustainability related to the usage of single energy sources. In the short term, the oil industry may need unique aid steps to address the social and economic disruptions triggered by the pandemic whereas local sources like sustainable energy and reprocessed carbon fuels should be seen in the longer term. This secured supply of energy results in substantial technological and financial advantages.

Numerous articles relating to the COVID-19 outbreak and its effect on the human health in global level have been published in the field of medicine. Even so, its effects on the environment and energy sector are not completely defined. A few other sources claim that outbreak of COVID-19 decreases air degradation, whereas others argue that substantial ecological impact awaits everyone. While a lot of researches have been already reported on the subject, no comprehensive study, regarding the impact of COVID-19 on food preservation chain has been undertaken. It is evident from the published research that the losses of food products can be reduced significantly due to renewable energy-based food preservation. The current study fills this gap by presenting a critical analysis of the nexus between the COVID-19 and the food security, based on hybrid and renewable energy.

This paper is organized into six sections. Section 1 is introductory part. Section 2 presents the energy demand analysis at the pandemic period. Section 3 presents the statistics and influences of COVID-19 on ongoing renewable energy activities. Section 4 describes influences of COVID-19 in food preservation chain. Section 5 presents the studies on renewable energy based food preservation. Section 6 presents the possibilities and analysis on HRES based food preservation chain. Finally, Section 7 summarizes the conclusions of this work.

2 | MATERIALS AND METHODOLOGY

The objective of this work is to measure and analyze the scientific investigations and activities around green food preservation, as well as to identify the factors of renewable energy activities and food preservation during the COVID-19 period. In order to address this problem, this work first conducts a bibliometric analysis of this topic in terms of both performance evaluation and scientific mapping. Then, the most related studies on the green food preservation are next reviewed, and an in-depth qualitative analysis is implemented.

2.1 | Data source and collection

The bibliometric studies conducted were mostly based on the online database Science Citation Index Expanded (SCI-E), Web of Science (WoS), which compiles a broad and interdisciplinary set of bibliographic records from leading scientific journals. Initially, four major key criteria were used in the search: 1) “Covid-19” AND “Renewable energy”; 2) “Food preservation”; 3) “Covid-19” AND “Renewable energy” AND “Food preservation”; 4) “Covid-19” AND “Hybrid renewable energy” AND “Food preservation.” Search terms were searched in the title, abstract, author's keyword, and WoS keyword fields. A search of the Web of Science (WoS) database and the articles and documents has been collected from the internet source and web search engine found 270 publications published between 2011 and December 2021. Meanwhile, various qualitative reviews and assessments were conducted on each publication to verify relevance to the green food preservation and covid field. As a result, 145 of the chosen publications were concerned with the green food preservation and covid consequences. Figure 1 depicts the research framework methodology of search parameters.

3 | ENERGY DEMAND ANALYSIS

The energy market, as a crucial enabler of modern life, is severely jolted by COVID-19 crisis, which is still vital to regional and national relief and rehabilitation initiatives. Energy stability is a significant source of concern. The disaster shows the vital importance of power networks and comprehends the underlying answer to the coronavirus pandemic. Owing to major shifts in energy demand, the activity of the power grid has become crucial. An obligation program for consumers as well as utility providers has been provided by government to tackle the situation. Table 1 outlines the effect of COVID-19 lockout on the power grid in different countries.

According to the International Energy Agency (IEA) report, the pandemic has caused the massive historical decline in global energy demand. The expenditure forecast predicts a collapse in major sectors...
this year, from power to renewable energy conservation. Energy market investment is expected to decrease by 10% by 2020, with the troubling implications for the production of more stable and reliable energy systems. Prior energy crises offer an overview of what occurs when the price of oil collapses and how the use of fossil energy has consequently recovered. But this recession is different since it is

**FIGURE 1** Research framework methodology of search parameters

**TABLE 1** Impact of COVID-19 on the energy sector in various countries

| Sl. No | Country   | Lockdown period   | Impacts in energy sector                                                                 | Ref  |
|-------|-----------|-------------------|----------------------------------------------------------------------------------------|------|
| 1     | India     | March 2020–June 2020 | Indian distribution grid will experience a sales deficit of US$ 4 billion and a financial crisis of US$ 7.2 billion during the shutdown. | 33,34 |
| 2     | United States | March 2020–May 2020 | Residential electricity consumption in certain parts of the USA has risen by 20%. It is projected that there will be a 4.2% decrease in the retail selling of power to the market in 2020. | 35   |
| 3     | China     | Jan 2020–March 2020 | The overall demand for electricity was 8% lower than in 2019 over the same duration. | 36   |
| 4     | United Kingdom | March 2020–May 2020 | Energy consumption at the transmission stage dropped by 10% after March 2020. | 33,37 |
| 5     | Italy     | March 2020–May 2020 | Electricity consumption fell by 10–22% from March 2020 relative to the same market in 2019. Production of renewable electricity rose by 3.5%. | 38   |
| 6     | Spain     | March 2020–May 2020 | Power consumption fell by 3% and 24% in the months of March and April 2020 relative to the same market in 2019. More electricity produced by renewables; PV production increased by 72%. | 33,39 |
| 7     | France    | March 2020–May 2020 | The energy sector faced a reduction of about 70% of its sales in March 2020 relative to March 2019. | 33   |
| 8     | Germany   | March 2020–May 2020 | Throughout COVID, the share of renewables rose to 41%, with a commitment of 302 TWh. | 33   |
driven by energy demand. With the reduction in demand, renewable energies (mainly wind and solar) have seen a large rise in their share of energy at record rates in many countries as shown in Figure 2. It shows that, India and US raised their renewable energy share by 45% and 40%, respectively, followed by the other European countries which are a new record for renewable energy integration to the grid. Enhancing demand, COVID-19 climate revival support, technology, and development prospects in low-carbon and emerging technologies are expected to prevent the renewable energy path from straightening. The economy will bounce back after the COVID-19 era, however suitable policies and actions are needed from the governments and policy makers to increase the implementation of renewable energy before any such outbreak comes in the future.29 Sustainable strategies may reduce the demand and pollution of global energy resources besides, satisfy energy needs at relatively reduced financial costs. Nonetheless, these prospects do not discuss worldwide economic inequality, while the influences of food security could be harmful to the most vulnerable in society.30 At the beginning of 2020, it was predicted that that the global energy capital spending will increase by 2%. This has been the largest uptick in global energy expenditure since 2014. However, the propagation of the COVID-19 pandemic revised the expectations in 2020.31 As shown in Figure 3, the biggest decrease of 20% in capital energy expenditure relative to the previous year is experienced. The greater impact on capital expenditure, particularly in oil, stems from sales growth due to reduced energy needs and costs, as well as more unpredictable prospects for such variables in the upcoming years.32

4 | INFLUENCES OF COVID-19 ON ONGOING RENEWABLE ENERGY ACTIVITIES

Climate and energy are the two world’s main issues that have been taken as an interconnected topic in the recent era. The connection between the two policy issues is derived from the fact that oil contributes for 60% of global emissions. Therefore, tackling carbon pollution is the key to climate mitigation and adaptation strategies. The coronavirus pandemic is expected to intensify the transition from spending on fossil fuels to investment in renewable energies.30 As the full impact of the COVID-19 pandemic struck in March 2020, the clean energy market, which is at the forefront of new development, abruptly slowed down with shelter demands, labour shortages and product line disturbances.41 COVID-19’s strongest detrimental effect is supply chain instability and utilization of renewable energy technology since the origins of these technologies such as China, the United States, and Germany, diverted their focus towards preventing the pandemic.42 COVID-19 has a significant negative impact on the renewable energy sector. China is the world’s largest manufacturer of various renewable energy products, including solar panels, wind turbines (WT), and batteries, and is one of the countries most affected by the corona virus. Since the corona virus has hampered imports from China, green energy companies have been more diligent in meeting equipment deployment deadlines.43 The COVID-19 pandemic has caused estimates of renewable energy to drop by 28% in 2020.44

COVID-19 presents a challenge to the investment of individual, small and medium-sized businesses in clean energy technologies such as solar PV, solar thermal and biomass boilers.45 The prediction in renewable energy in the electricity generation for 2019 is very relevant to normal results. New installations of 191 GW are ultimately connected to the grid last year with a rise of 7% relative to 2018, which is shown in Figure 4. The COVID-19 pandemic impacted clean energy production plants, distribution networks and industries, and delayed the transformation to the sustainable and green energy. The international drop in the value supported by the financial system could affect the rising growth of advances in environment-friendly and low-carbon energy. According to data, renewable energy contributed for 72% of total power growth in 2019, with wind and solar energies increasing by 60 GW and 90 GW, respectively, and accounting for 90% of renewable energy supplies.46 The pandemic tipped the balance in favor of renewables for safer and cheaper resources. This influence on the renewable energy market is not yet apparent. Whether it would promote carbon reduction and ‘start rebuilding stronger’ solutions, or the economic effects would substantially impede further innovation, works will be crucial.47

5 | INFLUENCES OF COVID-19 IN FOOD PRESERVATION SECTOR

The food supply chain is a dynamic system, involves various activities between the manufacturers and consumers. It consists of many related functions like agriculture, fisheries, processing, preservation, transport, marketing, etc.48 The COVID-19 pandemic is affecting all four pillars of food security: availability, access, utilization, and stability. Food security issues are often the result of rapid reductions in food production due to pandemics like avian influenza or African swine fever. COVID-19 is expected to have fewer direct effects on food development than other impacts. It influences the food security in a number of ways, depending on the commodity and the region.49
The COVID-19 pandemic is a public health threat that also has catastrophic consequences on the global economy in both direct and indirect aspects. Agriculture and food sectors also feel those impacts. Power stability appears to be the main subject.

Global food security programme states that the food security and supply chains are directly affected by the effect of food production and consumption; the critical issues for this impact may be the reduction of buying power, food processing and delivery efficiency, and the entrenchment of treatment activities. The level of food and agro waste is disastrous for farmers in poor and middle-income nations, where agriculture provides a bigger part of GDP than in affluent countries. According to the New York Times, due to the lack of preservation and transport facilities, farmers in US spill up to 3.7 million gallons of milk per day. A single chicken producer breaks 750,000 flushed eggs a week. Although food availability is currently adequate, labour shortage to cope with late summer cultivation is a major issue for the upcoming weeks. Because of the advent of social distancing and travel limits, handling the temporary, migrant labor would be problematic. This increasing risk increases the production expense rather than processing and distribution. High-value goods, such as fruit and vegetables, are at an increased risk of logistical instability due to the perishability.

The COVID-19 pandemic has brought immense burden on food value chain, with obstacles in farm labour, manufacturing, preservation, distribution, and volatile market. Many of these disturbances are caused from measures that have been implemented to curb the virus’ dissemination. COVID-19 delayed the normal activities of food manufacturing sectors. The major reasons are the social distancing laws, the labor crises, and the virus-spread lockdowns. Although the pandemic presents some significant short-term problems for the food supply chain, it is also an impetus to drive changes in the food and agriculture industry in order to create sustainability against a series of issues like environmental threats. This pandemic is also raising the alarm about the crucial need to change food preservation chain around the world. Moreover, it leads to the need for diverse, safe, and sustainable systems for the development of processes, preservation methods, distribution networks and waste disposal.

6 | RENEWABLE ENERGY IN FOOD PRESERVATION

The COVID-19 pandemic is a public health crisis that already has serious effects for the global economy—both directly and indirectly. The food and agriculture industry also experiences those impacts. The COVID-19 pandemic has put the immense burden on food preservation chains to overcome the obstacles in processing, preservation, transport, and storage in accordance with the major market changes. Food production and preservation chains have shown incredible resistance to certain strains. Research communities should rapidly describe the key threats to the food preservation chain during a pandemic to execute preventive actions. The existing food systems, however, are not viable. In fact, one-third of the food produced globally is wasted. This 1.3 billion tons/year wastage can generate 3300 metric
tons of CO₂ emissions per year. More recent data indicate that about 14% of food is lost in preretail stages like agriculture, harvesting, slaughtering, etc. Research scientists and food-industry analysts are expected to address the significant obstacles such as food quality, food health, and food wastages. The current chapter discusses the key options of food preservation systems based on renewable energy technologies during the era of COVID-19 pandemic.

Preserving food is among the most ignored aspects of food security in the humanitarian sense. Currently, more than one-third of the food produced globally is lost to waste or spoilage. In low-income countries food is lost long before it reaches consumers, mainly because of financial, technical, and other barriers. Harvesting methods, transportation, cooling facilities, supply chain facilities and packaging are scarce in low-income countries. As the food commodities differ based on a particular climate, the effective use of renewable energy technology depends on the geographical location. There is a potential of using wood, agricultural waste and animal waste as sources of energy. Such sources can provide a constant electrical energy for a farm through direct combustion of biomass or biogas operated power plants. Case studies have demonstrated the steady transformation in food waste management to a sustainable future. Food waste is being used as a resource through emerging green technologies such as anaerobic digestion-based green energy supply. On the level of economic viability and efficiency, current techniques for converting food waste to electricity are insufficient. In developing countries, a sustainable green approach based on food waste for the long-term production of fuels, as well as the inclusion of these processes into future bio refineries, will be critical.

Co-operative societies at village-level milk collection centres are operated by bulk milk coolers running on traditional grid electricity. In the absence of electric power, diesel generators are operated for milk cooling. Solar-based cooling system and diesel generator sets are the viable solutions for milk cooling to overcome irregular supply of grid electricity. The commercial use of sustainable energy is not yet popular, as there are numerous issues in this field that give rise to uncertainty. Finally, in order to illustrate the feasibility of replacing traditional fossil fuels with solar energy in the dairy sector, it could be claimed that 71% of the utilization of natural gas could be offset by a solar energy. The studies on a solar PV milk processing plant for a large farm, supported by the grid shows that it is viable for the cooling and preservation of a wide assortment of consumable goods, particularly agricultural, and dairy products. The solar-powered milk chilling system presents an exceptional way to on-farm solar milk processing. It can provide value addition to the produce and income for farming communities. Solar milk pasteurization is a viable option, but the payback period (PBP) is 10–11 years and if cost of maintenance is added, PBP may exceed 20 years. Therefore, to address the rise in energy and PBP, a sustainable solution is needed. The PV-powered flash intercooled compression device is the most effective configuration for each food storage temperature but is economically feasible only for the highest food preservation temperature.

Less than 2% of India’s total vegetables are processed for commercial purposes, compared to 70% in Brazil and 65% in the United States. Long-term fruit and vegetable processing is based on the substantial use of controlled atmosphere storage. The cost of operating cold storage rises every time electricity and fuel prices rise. To address the above specified inconveniences, vapor absorption plants are an excellent alternative for cold storage applications. Biomass based cold storage systems using direct-fired absorption technology with environment-friendly working fluids have been developed for rural area applications. Due to the absence of dairy chilling infrastructure, milk producers in regions with no access to adequate electricity experience greater milk spoilage. Biogas-based technologies provide the most attractive alternative, with an internal rate of return around 25%, a net present value of around $9000 and a rise of 78% monthly income of farmers. Biogas-powered evaporative cooler using zeolite as an absorbent is used for preservation of milk in rural dairy farmers. In recent days, geothermal energy has been suggested as an innovative option for rural milk processing. These applications are a big game changer for the societal benefit in the field of thermal energy applications. The exergetic output of the milk pasteurization aided by geothermal energy with a total exergy destruction rate of 13.66 kW was estimated as 56.81%. The novel technologies such as microwave heating, vacuum cooling, high-pressure processing, pulsed electric field, and solar energy are attractive for producing high-quality and safe food products. The limitation of these technologies is high investment costs, complicated controls associated with the operation, lack of regulatory approval and consumer acceptance. The authors conducted the case study for the existing supply chain management in sub-Saharan region. It concludes that the poor handling practises along the supply chain from farm to market and from rural to urban areas, as well as inadequate facilities, including transportation and market infrastructure, and a lack of refrigeration capacity in a tropical environment, threatening food safety and public health. Adopting appropriate agricultural practises, as well as improving post-harvest management, can help to ensure food safety across the fresh produce supply chain. The authors conducted the case study for the existing supply chains of in the state of Punjab, India. It was revealed that the green supply chain management is a novel idea that many people are inexperienced with, but it has a lot of potential in the future. However, the rise in operating and production expenses should never be considered in isolation because there are many other advantages. Even in the face of rising prices, environmental protection and commercial benefits will be a major impetus for acceptance of the idea. Extensive study in this subject is essential, as is a commitment on the side of businesses to accept it. Green supply chain management projects that are carefully planned and implemented usually generate excellent benefits for the key stakeholders. Firms must ensure that the faster they solve this problem, the better, because they will ultimately have to transition to green initiatives in supply chain management.

7 | HYBRID RENEWABLE ENERGY IN FOOD PRESERVATION

In the past decades, renewable energies have gained a great attraction in power generations, primarily due to the threats such as price
fluctuations, climatic impacts, and environmental degradation anticipated from the use of fossil fuels. Single technology-based renewable energy systems are a feasible choice for increasing access to electricity from rural and inaccessible areas.\textsuperscript{75} However, due to site variability and the irregular nature of certain renewable sources (solar and wind), stand-alone solutions are expensive, besides continuous power supply may not be possible. A feasible alternative to this is to integrate various renewable energy systems to create a hybrid system in which one system’s shortfall in production is enhanced by another. They also boost energy efficiency, cost benefits, and system reliability.\textsuperscript{76} For these reasons hybrid renewable energy systems are chosen for applications related to food security in remote places.

The grid-connected photovoltaic systems are best suited for farms in northern coastal regions. On the other hand, a grid-connected wind energy system is more appropriate for highland farms. However, a hybrid grid connected PV/wind system is determined to be the optimal configuration for the Ghardaia region, which has exceptional potential for renewable energy.\textsuperscript{77} Moreover, Hybrid renewable energy methods have been developed to resolve the fluctuation and unpredictability of a specific source of energy sources such as solar and wind power.\textsuperscript{78} Considering that the solar, wind and biomass resources are usually abundant in remote rural areas across west China, therefore the utilization of hybrid renewable energy system can be a suitable option to provide power to the remote rural communities. Moreover, the sustainability of remote rural electrification projects is not only reflected in economy and environment aspects, but also integrated with other dimensions like social and cultural benefits.\textsuperscript{79} The researchers evaluated the feasibility study in the hybrid renewable energy system using biomass to meet local energy requirements while reducing the amount of domestic solid waste.\textsuperscript{80} The main impact of biomass subsystem is its greater contribution to the system’s energy and exergy efficiencies than that of the solar subsystem. Moreover, a high biomass energy ratio always corresponds to higher energy efficiency.\textsuperscript{81} Solar and biomass powered poly-generation system, which is used to cool the food commodities in the remote farms satisfies the power and clean water needs in the dairy. The energy and exergy efficiencies of the solar and biomass hybrid poly-generation system is found to be 49.85\% and 20.94\%, respectively.\textsuperscript{82} It is identified that the 100\% hybrid renewable energy system with solar/wind/biomass shows the least NPC compared with the system with 100\% natural gas and natural gas/renewable combinations.\textsuperscript{83} The study reveals that the full utilization of biomass will enhance the COP, while the gobar gas decreases the investment cost, operating costs and the payback time.\textsuperscript{84} In the coastal area, vapor absorption refrigeration system operate with the energy combination of biomass/biogas/gobar gas along with the solar energy has been identified as the optimum combination will meet the cooling needs for dairy products.\textsuperscript{85} The absence of diesel in hybrid energy decreases the economics of the systems, whereas it favors the energy sustainability and environmental friendliness.\textsuperscript{86} Hybridization of wave/solar/wind is a reliable way to provide electricity for fish preservation in coastal regions. Moreover, a techno-economic analysis of this hybrid renewable energy system, to provide electricity for 3000 households in seashore places in Iran shows the lowest energy cost of $0.219/kWh.\textsuperscript{87}

The combination of sustainable energy and zero emission solutions is a potential approach to solve the rising global warming problem. This strategy increases power efficiency and decreases carbon emissions by designing the system’s elements for solar, wind, fermentation, gasification, pyrolysis, and power storage. More comprehensive system modeling, such as designing models for biomass conversion, can be implemented to make the entire system more comprehensive and optimistic. In addition to the financial and environmental targets, other experiments that include certain considerations, such as social and ecological impacts, may also be taken out by incorporating various limitations priorities to the design.\textsuperscript{88}

As far as sustainable and recycled carbon fuels are concerned, in connection with the bio-based economy and in a long-term environmental context, the COVID-19 pandemic will promote the importance of energy sustainability by leveraging the benefits provided by a high presence of alternative fuels. Thus, the post-pandemic reboot should be an incentive to guide the energy system towards more robust, stable, efficient and sustainable, else COVID-19 would reflect a really negative outcome of the missing chance to reconsider our successful structures.\textsuperscript{89}

8 | CONCLUSION

This comprehensive study analyses the impacts in food preservation due to the consequence of COVID-19. The unexpected impact of COVID-19 highlights the need for a change from “life as usual” strategies to a more forward-looking policy framework that engages in the efficiency, sustainability and resilience of the global food system. The critical review of several studies shows that the COVID-19 pandemic has threatened the renewable energy sector as well as the food security.

Green food processing would be a subject of study which involves a holistic plan focused on the development and implementation of methods to minimize the use of energy. The concept of green food processing is to meet the demand of the end user with greener resources. A comprehensive study would be needed to understand its advantages to the end users. The food preservation focused on renewable energy is therefore a crucial research area for the development of energy-efficient food systems in remote places. This review demonstrates that the renewable energy in food preservation technology is presently one of the most promising and cost-effective solutions.

In the post-COVID-19 era, when the economy bounces back, countries should intensify the initiatives of green energy policies to manage the global economy in such disasters in the future. This green approach should be the outcome of an entire chain of principles in all the meanings of the term: financial and sustainable, beginning with the cultivation and harvesting of raw agricultural products, technologies of preservation, refining and processing, along with the design and distribution methods.
In general, the following aspects require immediate attention and can be considered as directions for future research: (1) The need to understand the effect of these processing methods (renewable energy based cooling and hybrid energy based cooling) on different climatic regions. Since, the renewable energy production may vary with the climatic conditions. (2) Cost and economics of different green energy based cooling techniques, revealing insights about the technology’s sustainability and commercial possibilities. (3) The potential for cost, process time, and quality synergies when adopting combinational (hybrid) processing techniques. (4) Detailed analysis on the sustainability of these processing methods. (5) Implications of these renewable and hybrid processing methods on the nutritional and functional components of agro products. Given the rising markets and growing consumer acceptability of green energy-based preservation systems, these proposals highlight the possibility for processing agro food goods utilizing such developing technologies.

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The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS
M. Edwin: Conceptualization (lead); data curation (lead); investigation (lead); methodology (lead); resources (lead); writing – original draft (lead). M. Saranya Nair: Investigation (equal); writing – review and editing (equal). S. Joseph Sekhar: Supervision (equal); writing – review and editing (equal).

DATA AVAILABILITY STATEMENT
Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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