Sustainable Food and Agriculture: Employment of Renewable Energy Technologies

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Abstract
Purpose of Review According to the Food and Agriculture Organization (FAO), a large portion of the various activities in the agriculture and food supply chain (AFSC) are extremely dependent on fossil fuels and contribute to 24% of the total global greenhouse gas (GHG) emissions.

Recent Findings There are several strategies to reduce GHG emissions and mitigate the associated destructive impacts. Among them, substituting fossil fuels with alternative low-carbon energy sources has received remarkable attention.

Summary The core concept of this study is to explore the relationship between food security, sustainable development, and renewable energy. Renewable energy has shown promising potential for integration into a wide range of agricultural activities and offers an alternative sustainable solution to current practices. In modern agriculture, the need for electrification has increased, with electric tractors and agricultural robots accounting for a large share, which represents a great opportunity for the use of renewable technologies in this sector. As new technologies emerge, investors need to familiarize themselves with them. Further technical improvements, cost reductions, and government incentives can facilitate the real-world deployment of sustainable renewable technologies in agriculture and food production.

Keywords Food security · Sustainable agriculture · Renewable energy · Carbon emissions

Introduction

Mitigating climate change and ensuring a sustainable food supply for a growing world population are two key issues that must be addressed through a linkage approach. The rise in the global population and the decline in access to fossil fuels, coupled with rising prices, have greatly increased pressure on the agricultural sector and food production. In addition, the devastating environmental consequences of fossil fuel use have exacerbated the situation [1]. Given the rising trend of world population growth, estimated to increase by more than 9 billion people by 2050, global demand for food will continue to increase, exacerbating the global problem of "food security" as one of the most important components of sustainability [2, 3••].

Although agriculture is responsible for providing people with food, it is one of the sectors that are heavily dependent on fossil fuels, which not only jeopardizes food security but also poses significant risks to its sustainability and production. Most agricultural practices are generally carried out by burning fossil fuels, which increases the risk of greenhouse gas emissions into the environment [4•, 5]. The Consultative
Group on International Agricultural Research (CGIAR) notes that agricultural and food chains alone consume about 30% of the world’s total energy, and because of the high consumption, this accounts for about one-third (19–29%) of annual greenhouse gas (GHG) emissions [6••]. Given concerns about climate change and the damaging impact of fossil fuel prices on production costs, increasing fossil fuel use in the agricultural sector will not be affordable or sustainable. This provides an incentive for the development of renewable energy sources that can supplement and replace fossil fuels.

**Agriculture and Food Security**

Food security is achieved when all people at all times have physical, social, and economic access to adequate, safe, and nutritious food that meets the dietary needs and preferences necessary for an active and healthy life [7]. Food security is a lengthy process that is exposed to a variety of risks that can directly affect different dimensions such as agricultural production and access to food. According to the United Nations (UN) report, more than 836 million people in the world live in extreme poverty. While action against hunger continues, there are still many people in the world who lack adequate food and need to lead active and healthy lives. Sustainable agriculture is an immediate solution to increase production efficiency and meet the demand of the world’s population [8]. Global demand for agricultural products is increasing, and this trend could continue for decades as the world’s population of 2.3 billion grows. Availability, stability, access, and utilization are the most important dimensions of food supply.

**Problem statement**

The increasing demand for food and the industrial revolution in agriculture has necessitated a higher energy supply. On the other hand, the environmentally harmful effects of fossil fuels have increased the importance of using renewable technologies in the agricultural sector. However, the individual use of such energies might not be sufficient. This is because these energies are not available during certain periods [1]. Considering that the population in most developing countries is growing by more than 1.7 billion people, by 2050, the energy demand is predicted to increase by more than 25%, which could lead to a global crisis. Although the development of new energy sectors reduces the demand for conventional energy sources, data show that the production of non-renewable energy sources such as coal, oil, and natural gas is increasing unceasingly [4•]. One of the most important measures to control and mitigate climate change remains energy production and consumption. Global energy demand increased by about 2.3% in 2018, driven by the strong global economic growth of 3.7%. This has led to a surge in cooling and heating demand in many parts of the world, increasing non-renewable energy consumption. Accordingly, this high demand led to a jump in carbon-based emissions from utilities by nearly 1.7% in 1 year [9].

Renewable energy is energy derived from renewable resources that are naturally recharged. These include sources such as sunlight, wind, water, tides, waves, and geothermal heat. They have a high potential for use as an energy source in rural and remote areas. Concerns about climate change have led governments to switch from fossil fuels to renewable energy. Some indicators are used to evaluate and analyze the impact of renewable energy on the economy [10]:

- Number of employees in the renewable energy sector, which must be studied in full-time equivalents or person-years
- Fiscal impact, which represents the local or national government’s financial share of the renewable energy industry
- Salary of employees provides information on the quality of jobs created in the industry, where high-paying and low-paying employees differ, with high-paying jobs having a greater impact on the economy
- Landowner benefits in the form of lease payments from the system operators to the landowner, which are especially the case for wind turbines and other land-intensive technologies such as photovoltaic systems

Although there are several studies on the use of renewable energy in agriculture, a thorough evaluation considering the three important aspects of technology, economics, and policy and regulation is essential. This paper examines previous research in this area to identify the most relevant information. The core concept of this study is to address the following issues: integration between food security, sustainable development in agriculture, and renewable energy technologies. In addition, the current state of agriculture and food production and related challenges from a global perspective were discussed. In addition, the applications of renewable energy in agriculture, related barriers, challenges in scaling up the use, and global policies are explored. Some suitable technologies for application and possible future directions are also presented and the prospects for their development are discussed. This study aims to provide new insights and information on recent advances in renewable energy and its specific applications in agriculture and food production. It provides an overview of renewable energy and discusses its principles, developments, and applications. In this context, a wide range of renewable energy technologies are presented and discussed, and recent developments are highlighted.
Sustainable Development in Agriculture

Agri-Food Supply Chains (AFSCs)

Agri-food supply chains (AFSCs) encompass all stages of production, processing, and distribution of food until its final consumption. In general, an AFSC is a branching network consisting of a series of activities that extend from "farm to the fork" [11]. AFSCs often encounter large and complex barriers to long-term sustainability, including economic, environmental, and social impacts [12]. With increasing public interest, food safety has become an important issue for both consumers and producers. Improving food quality is the main goal of collaboration in the agri-food industry, and customer approval is critical to long-term profitability. In the agri-food industry, these supply chains include post-consumption and pre-production operations. Agricultural companies strive to deliver safe and shelf-stable food. In many countries, traceability is required to improve customer food safety and ensure the safety of the food supply [13]. In general, there are two main classifications of AFSCs: (i) fresh produce supply chains, which include fresh fruits, vegetables, and flowers, and (ii) highly processed supply chains, which include canned foods, desserts, and so on. The production, storage, packaging, transportation, and sale of these products are the main operations.

Greenhouse Gas Emissions from AFSCs

AFSC’s energy use is heavily dependent on fossil fuels at all stages, which is a major source of GHG emissions as a result of agricultural processing and production. Thus, in terms of reducing GHG emissions, there are opportunities to reduce them, and this can be understood by examining the contribution of agricultural practices to current emission levels.

Figure 1 shows the major participants in global GHG emissions in 2019, with a particular focus on agricultural activities. As shown in this figure, agriculture plays an important role in GHG emissions with the highest contribution of 55% and 45% for methane (CH₄) and nitrous oxide (N₂O), respectively. In addition, gut fermentation, i.e., digestion of carbohydrates by ruminants, is the largest source of CH₄ production in agricultural systems, while manure is the second most important stimulus for the release of CH₄ and N₂O. Artificial nitrogen fertilizers, as the third participant accounting for 13% of GHG emissions, release N₂O gas when microbes begin to process residual nitrogen from crops [14].

Sustainable Food and Agriculture (SFA)

Society, economy, and environment are the most important dimensions of sustainable agriculture. To be sustainable, the agricultural sector should meet the nutritional needs of present and future descendants while ensuring profitability, environmental sustainability, and socioeconomic equity [15]. Sustainable food and agriculture (SFA) include all dimensions of food security and sustainability. Using a group of farmers, Laurett et al. [16], concluded that nature-based agriculture, research in innovation and technology, and environmental features could define sustainable development in agriculture. But the lack of knowledge and planning are the main obstacles to the implementation of this conclusion.

Nevertheless, sustainable development in agriculture is a challenge in which the increasing demand for food must be met by more sustainable agricultural activities [17]. Due to the rapidly increasing competition for land use, an international framework to protect food production is needed. This means that a revolution in energy efficiency and a change in the energy sources used in the agricultural sector
is required [18]. Over time, the use of low-carbon energy sources to replace fossil fuels in agriculture has increased rapidly. Sustainable agricultural production systems and smart energy AFSCs with more access to modern energy services can be practical and affordable solutions to ensure energy security and achieve sustainable development. In this regard, using renewable energy sources (RES) to meet the total energy needs of AFSCs can help improve access to energy resources, reduce energy security problems, and reduce dependence on fossil fuels [19].

Applications of Renewable Energies in Agriculture

Distributed Electricity Generation

Solar energy as one of the renewable energy sources is considered not only for the production of food in agriculture but also for the production of electricity, which is widely used in agriculture as a substitute for conventional fossil fuels [20]. As shown in Fig. 2 agrivoltaic systems, which include photovoltaic (PV) modules installed on agricultural land and optimally distribute sunlight to crops, maximize food and energy yields within reasonable limits [21]. In addition to the various factors affecting rice cultivation, such as fertilization, temperature, and solar radiation, Gonocruz et al. [22] evaluated the shading rates of PV modules installed over rice crops in Japan. The results showed that the maximum allowable shading rate limit for agricultural photovoltaic installation varies from 27 to 39%, which can preserve at least 80% of the rice yield and generate almost 30% of the total electricity demand for rice production when such systems are applied over rice fields in Japan.

Agrivoltaic systems have the potential to reduce water demand and increase the overall water productivity of certain crops. Al-Agele et al. [23] studied the growth characteristics of tomato plants at different locations in an agrivoltaic field and found that water productivity was greater in inter-row treatments than in the control deficit and that total crop yield decreased with increasing shade. Their results indicate the potential of photovoltaic systems to improve water productivity even in crops traditionally considered shade intolerant. Trommsdorff et al. [24] cultivated four arable and vegetable crops under the designed agrivoltaic system, which allows for a wide range of machine inputs due to vertical and wide spacing of 5 m and up to 19 m, respectively. The measured land-use efficiency showed that the agrivoltaic system resulted in a 90% increase in land productivity. Considering the angle of insolation, climate change, and increasing land scarcity, the overall results show a high potential of agrivoltaics as a sustainable and efficient technology to address the major challenges of the last century.

The potential of wind energy systems and biomass-based hybrid configurations with wind and their various design factors were analyzed by Amjith and Bavanish [25]. In this study, the performance of the power systems driven by various biofuels such as bioethanol, biodiesel, biomethane, biohydrogen, and biomethane from biomass was critically evaluated, and the performance of wind energy and wind turbine systems was studied. The results showed that biomass-based hybrid energy systems can be a cost-effective and environmentally friendly alternative for off-grid rural and agricultural electrification.

Agricultural Cultivation Greenhouses

One of the forms of modern agriculture is greenhouse cultivation, in which the growth of plants is controlled to obtain better yields in quantity and quality. Kumar et al. [26] conducted a study to investigate solar technology for greenhouses. The promising results of PV modules provide the required electrical energy and ensure sufficient crop production. However, the shading effect led to a reduction in
crop yield as the photosynthetic efficiency of greenhouse plants decreased. It was also shown that photovoltaic-thermal (PVT) modules are interesting due to the generation of electrical and thermal energy from a single module and their high efficiency. Finally, it was demonstrated that the use of these solar technologies in greenhouses can increase the quantity and quality of the product. Gorjian et al. [27••] gave an overview of the advances in solar technologies in greenhouses and investigated the solution to problems such as shading by using sun trackers and concentrating modules. Thermal energy storage (TES) was also investigated as a critical component for secure energy supply (without instability in supply) in solar greenhouses. The use of TES systems can improve the thermal performance of solar greenhouses by 29%. The use of wind turbines as well as solar energy technologies has many economic and environmental benefits and is highly desirable. Crete in Greece with high average annual wind speeds and as a location with a high concentration of greenhouses was noted by Vourdoubas [28]. In this study, small wind turbines were installed to meet the electricity demand of greenhouses, and it was found that the generation of wind electricity in an area with high annual electricity demand is economically viable and environmentally attractive.

Sánchez-Molina et al. [29] presented a novel technique for heating, CO₂ storage, and enrichment systems using biomass. In this case, a biomass-based dual-mode system was provided to reduce the need for gasoline-based fuels and costs by using low-cost pellets (from tomatoes and peppers). The system consisted of a boiler with CO₂ recovery from flue gases to enrich the greenhouse and provide heat by using wood chip fuel in the form of pellets (Fig. 3a). The results indicated an improvement in energy efficiency in both nighttime temperature and daily CO₂ concentration, as both biomass from agricultural waste and CO₂ released by the heater were recycled.

Space Cooling and Heating Applications

An alternative thermal model integrating a semi-transparent PVT system (GiSPVT) in conjunction with a ground-air heat exchanger (GAHE) was developed by Yadav et al. [30] for a greenhouse, as shown in Fig. 3b. The effect of various factors, including air mass flow rate, heat capacity, greenhouse air temperature, and GiSPVT system temperature, was investigated for harsh winter conditions. The results showed that only the use of the GAHE system during sunny hours is economically feasible. The greenhouse and plant temperature values were increased by 4 °C and 5 °C, respectively, and the mass flow rate of air passing through GAHE increased by 0.5 kg/s. In a study by Faridi et al. [31], the possibility of using soil-air heat exchangers for agricultural buildings was investigated using soil temperature modeling. In this context, the behavior of soil temperature at different depths was modeled and the results suggested that the potential of soil could be used to heat or cool agricultural buildings such as greenhouses. The performance of heating a south-facing greenhouse using a solar copper coil heating system was investigated by Ihoume et al. [32]. In this system, water was circulated as a heat transfer medium in a closed loop on the greenhouse roof to store heat during the day and return it to the greenhouse at night. A parametric study provided useful information to optimize the heating system and estimate the amount of water that would flow through the copper coil heat exchanger as the air temperature changed. This sustainable heating system was found to have a payback period of fewer than two years and a low environmental impact with a CO₂ emission rate of 176 g/day compared to 41,000 g/
day\textsuperscript{1} for a boiler. To maintain the optimal growing environment for plants, Gourdo et al. [33] developed a system to store solar energy in the rock bed to warm the atmosphere in the greenhouse. This system stores additional heat from the greenhouse during the day and releases it at night. The data from the experiments show that the air temperature in the greenhouse with a rock bed is on average 1.9 °C lower during the day and 3 °C higher at night than in the conventional greenhouse. In addition, this system has a positive effect on tomato yield by about 22% compared to the conventional greenhouse.

Desalination of Saltwater

An environmentally friendly strategy was proposed by Guo et al. [34] to reuse discarded face masks during the COVID-19 pandemic to construct photothermal evaporators and use them for solar desalination with high efficiency and autonomous solar ocean farming. The face mask fabricated with polyvinyl alcohol and polypyrrole resulted in the evaporator having an increased solar efficiency of 91.5% and long-term stability for salt retention. The extracted clean water is suitable for plant growth to be able to do agriculture on the sea surface. The proposed strategy to convert facial mask waste into sea-level clean water production and cultivation is likely to be a promising solution for environmental sustainability with several advantages. Ling et al. [35] developed a desalination system coupled with tidal energy to use the mechanical energy generated by tidal energy directly with the reverse osmosis system (RO) through a hydraulic turbine. The performance of the system and the water cost of the conventional and tidal energy RO systems were compared, and it was found that the tidal energy RO equipped system can save water costs in the order of 31–42% compared to the conventional RO system. In addition, as a technology that will be an effective alternative desalination method in the future, the tidal system RO can save more money when the feed pressure or water extraction rate is high. To find solutions to challenges such as fossil fuel limitation, high pollution, and high energy demand on our globe, eight different renewable biofuel blends were presented and investigated by Elfasakhany [36] as energy sources for desalination plants. The results showed that both gasoline-bioethanol and gasoline-biomethanol provided high heat recovery and sensitive emissions of CO and UHC. Finally, gasoline-bioacetone was the best of all blends and was, therefore, the most recommended for desalination plants in terms of both heat recovery and emissions. Bio-fuel cells, their types, and their role in desalination were discussed by Banerjee et al. [37]. They confirmed that a (microbial) biofuel desalination cell, which is a combination of a microbial biofuel cell and electrodialysis, can be used for seawater desalination as well as renewable power generation and wastewater treatment. They showed that in a typical microbial desalination cell (MDC), wastewater substrate and exoelectrogenic microorganisms are used for water desalination.

Water Pumping and Irrigation systems

Khan et al. [38] presented a feasibility analysis of a water pumping system based on an off-grid hybrid renewable energy source for irrigation applications in Sudan. The techno-economic optimization analysis of this system was carried out in 12 different locations in Sudan, and several hybridization cases of the photovoltaic, wind turbine, and battery storage were simulated, evaluated, and compared considering the water demand of different crops for planning and design. The results showed that the choice of the system strongly depends on the cost, wind speed variations, solar radiation, and system size.

In Spain, the island of El Hierro is already on its way to becoming a 100% renewable energy island, and a wind-hydro power plant has been installed that could provide almost 60% of the annual electricity demand in 2018. The hydrological cycle of this island, which includes groundwater extraction, seawater desalination, and water pumping and distribution and provides about 35% of the island’s annual electricity demand, was studied by Melián-Martel et al. [39], as shown in Fig. 4. The objective was to investigate the possibility of running the entire hydrological cycle with the surplus of wind energy alone. The results show that the total contribution of renewable energy on the island could be increased.

The selection of portable solar-powered pumps and their performance were studied by Parmar [40], analyzing centrifugal and piston pumps. After evaluating the data in terms of the volume of water pumped at a given head and analyzing

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\textsuperscript{1} Emission rate in gram per day.
the performance of the pumping systems, it was found that the piston pump offered the best system performance, with a maximum efficiency of 48.97% at a head of 8.5 m and an input power of 88.31 W.

**Drying of Agricultural Products**

Sethi et al. [41] studied different solar drying techniques for drying various marine products. After numerical and experimental analysis, the results indicated that the high speed and low-temperature dyeing method is more suitable to preserve the original color of fish. Since moisture reduction of marine products takes more time, hybrid solar dryers perform better than other conventional dryers. According to health standards, low salt concentration (about 5%) in dried products is suitable. In India, the drying of marine products using solar technologies also has great potential in some areas, such as coastal regions. Asnaz and Dolcek [42] investigated various low-cost solar dryers, including the natural displacement dryer (NCD), forced displacement dryer (FCD), and integrated heat pump dryer (HPD). The experiments were conducted on a thin layer of mushrooms at an average daily solar radiation of about 790 W/m². The results showed that cutting thin slices reduced the drying time and the average thermal efficiencies for HPD, FCD, and NCD were 77.45%, 67.66%, and 59.74%, respectively.

In a study by Yahya et al. [43], to reduce the dependence on fossil fuels for paddy drying, a pilot-scale biomass-based mixed flow drying system with a drying capacity of 400 kg/h was developed, installed, and tested (Fig. 5). The thermal energy required to heat the drying air was provided solely by biomass. The specific energy consumption, specific thermal energy consumption, specific moisture evaporation rate, thermal efficiency, exergy efficiency of the drying section, and potential improvement of the dryer were evaluated. The experimental results show that the moisture content of the paddy is reduced from 20.90 to 13.30% on a wet basis, and

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2 Dry the rice paddy immediately after harvest.
the consumed energy from biomass is about 47.77% of the total energy.

**Solar-Powered Agricultural Machinery and Farm Robots**

To encourage different subsectors of the agriculture sector and to promote the integration of PV technology with modern electric agricultural machinery, Gorjian et al. [44] conducted a comprehensive study on the advent of solar-powered electric farm tractors and agricultural robots. In this study, most commercial pieces of equipment were studied and discussed. Additionally, the necessity for the transition from fossil-based farm machinery to solar-powered electric tractors was discussed, while the successful commercial solar-powered field robots along with their main challenges and barriers were discussed. They asserted that the two main barriers against the global deployment of solar-powered electric agricultural machinery are their high initial cost, mainly due to the use of PV modules and battery storage units, and their sensitivity to environmental parameters such as air temperature, dust accumulation, shadowing, and humidity of the air, which can significantly affect the electric yield of PV modules. The photos of two commercial farm robots are shown in Fig. 6.

In addition to emission reduction, precise control, stepless speed control, and overload capability are the key factors presented by Ghobadpour et al. [45] which have to be considered when renewable-powered electric farm machinery is employed. They asserted that electric machinery can pave the way for the emergence of independently networked vehicles that increase the quality of work and the comfort of drivers. They also confirmed that in addition to the electrification of agricultural vehicles, the generation of on-site renewable energy to provide the required power will enhance the benefits of higher energy efficiency and independency as a forward-looking approach. In a study by Carroquino et al. [46], the power generated from a PV farm was utilized to drive a drip irrigation system and other ancillary uses, and through the electrolysis of water, the excess energy was utilized to generate hydrogen (H₂) on site. The produced H₂ was then used to power a hybrid fuel cell electric vehicle which was employed for worker mobility in the city. To meet the energy requirements, electricity and hydrogen were produced on-site entirely from renewable sources.

In another study by Gonzalez-de-Soto et al. [47] to reduce the fuel consumption of agricultural robots and thus reduce the emissions of these automated machines, a hybrid energy system was modeled for driving weed and pest control farm robots. In this study, exhaust emissions were compared to those of machines driven by an internal combustion engine. The hybrid energy system was a combination of a tractor’s internal combustion engine with a new electric system based on a hydrogen fuel cell. The results indicated that the hybrid energy system reduces emissions by about half. For precision agriculture, Quaglia et al. [48] investigated a novel unmanned ground vehicle (UGV) with seven degrees of freedom equipped with a robotic arm and vision sensors. This robot could be mounted on a drone landing platform composed of solar cells, enabling the solar power to be stored. This device can play a key role in a more complex automated agricultural system for coordinated field monitoring and maintenance.

**Challenges and Prospects**

Renewable energy has made significant progress in developing countries. Fossil fuel-based food production systems are unstable over the long term and account for about a quarter of total greenhouse gas emissions. Therefore, governments have embraced achieving a sustainable agricultural supply system using clean energy technologies. Raising awareness, building the capacity of financial institutions and equipment suppliers, gender equality in management and technical work, and providing training are important issues that need to be addressed [49]. Increasing the capacity and potential of renewable energy depends on factors such as cost and investor, social, environmental, policy, and support. For the acceptance of the technology by an entrepreneur or farmer,
the issues of technology awareness, profit and loss assessment, and local conditions must be considered.

**Global Policies and Regulations**

Today, significant progress has been made worldwide in renewable energy. Policy plays a very important role in this technology. The role of regulators is to manage the market so that renewable energy generation is cost-effective. For this reason, it is necessary to set policies. Deployment policies can support the creation of the market, facilitating the scaling-up, lowering technology costs, and increasing investment levels in line with energy transition requirements [50]. Without an appropriate policy, it is not possible to introduce a technology despite high profitability. Careful evaluation of policies is necessary before implementation. Policies are especially important for renewable energy technologies that are in the process of development. Key policies include market-based approaches, financial mechanisms, and consumer and business programs. In the financial sector and reducing investment risk is an important issue where governments can solve many problems and pave the way with the right policies.

**Financial and Economic Support**

Global renewable energy investment increased 2% in 2020 compared to 2019, reaching $303.5 billion. This increase is far below the required level. With this progress, the overall growth rate of renewable energy investment will be 22% by 2030, which should increase to 200%. However, fossil fuel investment is six times higher than renewable energy investment. Moreover, fossil fuel subsidies are much higher than renewable energy subsidies. The shift of financial resources from fossil fuels to renewable energy by investors and institutions is changing, leading to increased investment in renewable energy [51]. According to IRENA, to limit global warming to 1.5 °C by 2050, $131 trillion should be allocated to energy transfer technologies. Currently, the current plan allocates $98 trillion for energy generation by 2050. Thanks to planned energy (PES), investments reached $2.1 trillion in 2019, doubling the previous year’s investments [52]. Attracting attractive investments in sustainable energy requires financial and economic analysis. The main purpose of the initial financial analysis is to study the financial returns to justify project stakeholders and attract investors. The first step is to compare two technologies (one old and one to be replaced in the future). Investment financial analysis is a comparison between two technologies. The second step is to identify the types of capital and operating costs and monetary benefits. Initial capital costs are typically high, and life-cycle costs should be considered, including equipment capital costs, operation, and maintenance costs and fuel costs. The third step is to calculate the return on investment of the technology, which is the result of comparing the costs and benefits of the two technologies [53].

**Conclusions**

With the advent of new technologies, investors need to be knowledgeable about the technology. Lack of knowledge hinders the development and investment of technology. Doubts can be removed through training, seminars, conferences, participation in projects, and information campaigns. In addition, training can provide the necessary skills, including those needed to install, set up, and maintain systems, and create a skilled workforce.

Given the increasing demand for food and the onset of mechanization in agriculture, energy must be supplied at a higher level. The agricultural sector, with its wide variety of applications and energy resources, is one of the leading users of renewable energy systems. On the other hand, concerns about the environmental impacts of conventional energy suppliers highlight the importance of using renewable technologies in the agricultural sector, which provides the impetus for an energy transition toward renewable energy. Despite the many benefits that solar-powered tractors and agricultural robots offer in terms of energy savings and reducing hazardous emissions, they suffer from high initial costs, which is why few of them have been commercialized and entered the market. Further cost reductions in sensors and control units, as well as PV modules, can largely solve this problem. More solar-powered robots and tractors can therefore be expected to make their way onto farms. Therefore, it is expected that an increase in the unit price of fuel or a decrease in battery costs will be the main incentive for the commercialization of solar tractors.

The literature review in this paper indicates that integrating farms with renewable energy technologies increases reliability and efficiency while helping to reduce fossil fuel consumption and thus carbon emissions. In addition, some studies report that the use of energy storage systems increases both efficiency and reliability, but economic considerations should also be taken into account. It is recommended to consider a fixed set of key indicators for energy interventions in agricultural food chains to reduce the complexity of the work. Small-scale technologies should be preferred as they would increase the welfare and income of farmers and families as well as local food producers. In addition, access to electricity in remote areas can lead to the creation of new businesses.
Declarations

Conflict of Interest The authors declare no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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• Of importance
•• Of major importance

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