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RESEARCH ARTICLE

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Impact of environmental policies on the profitability of greenhouse agriculture in southeastern Spain

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[Correction added on 6 June 2023, after first online publication: Affiliation link of Francisco Camacho-Ferre has been corrected in this version.]

Abstract

Sustainable development has become an essential criterion for structural policies of the European Union, and these policies have extended its environmental dimensions. The EU has decided that circular economy will be framed within the principles of sustainable development. Thus, the changes brought forth will affect activities like agriculture, where environmental policy can undermine the stability of agricultural systems by reducing their profitability. The objective of this study was to evaluate how the implementation of these techniques impacted the southeastern peninsula of Spain, a farming region that supports the sovereignty and food security of the European Union in terms of fruit and vegetable products. The production techniques evaluated can increase production costs by up to 5.5%, although there are no significant differences in crop profitability. It is necessary to guarantee that all producers can access the incentive system to reduce their economic pressure, due in many cases to financial losses. In this regard, it is necessary to establish a specific green architecture for this subsector that factors in the effects of inflation to balance the triple aspect of sustainability.

KEYWORDS
agriculture, circular economy, cost–benefit analysis, environmental policy, green architecture, stakeholder engagement, sustainability

1 | INTRODUCTION

Agricultural activity depends on consuming natural resources, primarily soil, and water. Over the last 50 years, resource consumption has tripled as crop productivity has increased and thus expanded the overall capacity of the planet. This dynamic has intensified food production (FAO, 2019). Agriculture has caused various environmental impacts, most notably loss of genetic diversity and the contamination of water or land by agrochemicals or soil degradation (European Union, 2019; Gil et al., 2018; Gómez-Tenorio et al., 2021; Zapata Sierra et al., 2022). At present, it is foreseen that the world's population will reach 9.7 billion inhabitants by 2050 (UN, 2022). In this context, greenhouse crops have been postulated as an alternative to expand the load capacity of our planet, due to the high crop yields obtained from them. However, protected cropping systems are characterized by a moderate to large environmental footprint. In the face of this new scenario, the agricultural activity must obtain more products with fewer inputs (European Comission, 2020a). Therefore, sustainable and resilient farming techniques must be implemented (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022).

1.1 | Greenhouse agriculture in southeastern Spain

Southeastern Spain hosts more than half of the greenhouses in the country and this is the area with the highest concentration of greenhouses in the world, with Almeria being the most relevant region. Spain is home to 76,600 ha, of which 55.6% are in the provinces of Almeria, Granada, and Murcia. Almeria accounts for 77.0% of the protected agriculture in the southeastern Iberian Peninsula (Junta de Andalucía, 2022b; MAPA, 2023a). Protected cultivation is a strategic activity for the economy of the province of Almeria, bringing about a local development system in the territory (Honoré et al., 2019; Valera-Martínez et al., 2014). Such a system generates more than 2000 million euros annually, from the sale of more than 3.5 million tons of horticultural products. In terms of production, fruit and vegetable agriculture in Almeria yields more than 22 other member states in the EU while ranking sixth in the territory (Table 1). Additionally, Almeria's agriculture, which is of vital importance for European food security exports more than 80% to the EU and the United Kingdom (Honoré et al., 2019).

Protected agricultural production in Almeria is carried out in solar greenhouses. Moreover, a large number of agroecological techniques (i.e., integrated pest and disease control, biological control, grafting, solarization, etc.) are already implemented (Belmonte-Urenã et al., 2020; Valera-Martínez et al., 2014) and demand a lower amount of energy than other European models under cover (Vanthoor et al., 2012). In recent decades, this agrosystem has expanded the use of the previously mentioned techniques. For example, biological control has been implemented in almost all crops grown in Almeria since 2009 with a particular focus on peppers. In addition, most producers in Almeria carry out their production under the integrated production standard in conjunction with other international certification standards (e.g., GLOBALGAP) (Acebedo et al., 2022; Cajamar, 2022; Junta de Andalucía, 2015). In 2021, organic production reached 2369 ha of protected crops where the addition of inputs of chemical origin is prohibited (COEXPHAL, 2022). However, some of the recent eco-innovations developed to improve the environmental sustainability of the production model may increase production costs. Nevertheless, there is still no economic study that has evaluated the impact of eco-innovations available for intensive agriculture, although it is known that some techniques can influence the decrease of production costs (i.e., self-management of agricultural waste biomass) (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022). In other sectors, the use of eco-innovations, research spending, and R&D development have small but positive effects on economic growth (Balcilar et al., 2022), something that has not yet been achieved in the Almeria model.

The ecosystems of the southeastern part of the peninsula have suffered environmental impacts due to greenhouse agriculture, such as loss of biodiversity, erosion, overexploitation, and eutrophication of aquifers, marine contamination with microplastics, and so forth. Some of the impacts have originated from excessive consumption of agrochemicals, poor or null management of agricultural waste, or excessive groundwater consumption. In recent years, negative externalities have been reduced, although they have not been completely solved (Bonisoli et al., 2019; Dahl et al., 2021; Duque-Acevedo, Belmonte-Ureña, Plaza-Úbeda, et al., 2020; Duque-Acevedo, Belmonte-Ureña, Yakovleva, et al., 2020; Galdeano-Gomez & Cespedes-Lorente, 2004; Luis Caparrós-Martínez et al., 2020).

TABLE 1 Top 10 EU member states in fruit and vegetable production (including melons and strawberries) in 2020.

Member state	Production (*t*)	Importance (%)[b]
Spain	15,099,810	23.9
Italy	13,307,520	21.0
Southeastern Spain[a]	6,847,883	10.8
France	5,566,640	8.8
Poland	5,347,200	8.5
Netherlands	5,344,590	8.5
Almeria[a]	4,082,445	6.5
Germany	4,040,160	6.4
Greece	2,535,130	4.0
Portugal	2,515,660	4.0
Romania	2,326,210	3.7
Belgium	2,231,100	3.5

Note: Fruit and vegetable agriculture of southeastern Spain and Almeria has been positioned in the ranking.
[a]Indicates a production system.
[b]Indicates importance concerning the EU-27.
Source: Own elaboration from EUROSTAT (2022), Gutiérrez-Gutiérrez (2022), and Junta de Andalucía (2022a).

1.2 | Sustainable development to avoid damaging the environment

Sustainable Development is a strategic objective of the UN member states that signed the 2030 Agenda. This document identifies agricultural sustainability as a key aspect of its second Sustainable Development Goal (SDG), which establishes five pillars: people, planet, prosperity, peace, and partnership. Agricultural policies that aim to implement the triple aspect of sustainability (i.e., social, economic, and environmental) in primary activity are supported by other SDGs such as no poverty (SDG 1), decent work and growth (SDG 8), responsible consumption and production (SDG 12) or terrestrial life (SDG 15), among others (Cojocaru et al., 2022; ONU, 2015; Streimikis & Baležentis, 2020; Tremblay et al., 2020). The European Union (EU) wants to turn its economy into a green system decoupled from environmental impacts. The digital transition aims to help achieve these goals (European Comission, 2019, 2020a). The tools of such transition can help to better manage agricultural inputs through sensor technology, big data, artificial intelligence systems, blockchain, or digital twins. Some are currently in the experimental phase (MAPA & Cajamar, 2022). The implementation of eco-innovations depends fundamentally on the process, organizational and marketing dimensions of companies in the agri-food sector (García-Granero et al., 2020; Martos-Pedrero et al., 2022).

The EU has based the implementation of sustainability on the circular economy (CE) (European Comission, 2020b). Spain is one of the European territories to face this change (Mazur-Wierzbicka, 2021). The CE principles are based on reducing, reusing, repairing, and recycling (European Comission, 2020b; Kalmykova et al., 2018). The proposed shift should neutralize net greenhouse gas emissions by 2050 (European Comission, 2019), which may drive out agricultural activities that demand bigger amounts of non-renewable inputs. This situation has generated a growing interest in developing production methods based on CE principles (Del-Águila-Arcentales et al., 2022; European Comission, 2020a; López-Serrano et al., 2023).

The EU has proposed sharp decreases in the use of agrochemicals in agriculture, as well as increasing the area under European organic certification by 2030 (European Comission, 2020a). Several environmentally inefficient farming systems have been identified in the European territory and these can have a moderate to a high degree of intensification (Pandey & Singh, 2021). The EU also stands out for having the largest number of hectares of greenhouse crops worldwide, with Spain being the first European power in this type of agricultural system, followed by Italy, Greece, and the Netherlands (Rabobank, 2017). Hence, the EU's desire to have a neutral carbon footprint by 2050 triggers a reduction or substitution of agricultural inputs such as inorganic fertilizers, fumigants, petrochemical plastics, or non-renewable energy by other environmentally friendly alternatives: use of biomass, biodegradable plastics, photovoltaic systems, and sensoric systems (European Comission, 2019; FER, 2017; Kumar et al., 2022; MAPA & Cajamar, 2022; Marín-Guirao et al., 2022; Salinas et al., 2020; Wilson et al., 2018).

1.3 | Need to develop policies to reduce economic barriers

Nowadays, some currents demand systematic or generalized degrowth to reduce the adverse effects of anthropogenic activities (Belmonte-Ureña et al., 2021; Keyber & Lenzen, 2021; Plaza-Úbeda et al., 2020). However, we do not know precisely how the expansion of the environmental aspect of sustainability will affect social and economic subcomponents, which articulates the social development of the territories. Therefore, it would be interesting to carry out such a study to develop measures and strategies to reduce barriers, especially in fruit and vegetable production systems in the southeastern portion of the peninsula, which safeguards the sovereignty and food security of the EU (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; López-Serrano et al., 2021). The economic dimension is the most important factor for farmers in terms of managing sustainable agriculture, as opposed to socio-territorial and agroecological factors (Ngo et al., 2021). Protected cropping systems have a lower water footprint compared to those grown outdoors. However, such protected systems need to implement new cultivation techniques to reduce their energy and greenhouse gas footprint, which requires renewable inputs and energy sources (Irabien & Darton, 2016; Maureira et al., 2022). However, the isolated implementation of new sustainable cultivation techniques increases the total costs of protected agriculture, even after applying the incentive system proposed by the administration (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022).

Therefore, due to its local socioeconomic importance and the food security and sovereignty it provides to the EU, it is necessary to implement new sustainable production techniques and expand the use of other production methodologies to reduce the environmental footprint of the greenhouse farming system in southeastern Spain. Previous studies evaluating these techniques have focused on analyzing their benefits on the environmental subcomponent of the production model, but have not determined their economic impact (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022), which could provide producers with useful management information for the implementation of sustainable agriculture in this sector. Farmers consider the economic subcomponent as the most important factor in sustainable production and whether or not the implementation of eco-innovations could improve the economic growth of the most important fruit and vegetable production sector in the EU (Balcilar et al., 2022; Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Martos-Pedrero et al., 2022; Ngo et al., 2021). The objectives of this research were:

1. To evaluate the impact of production techniques framed within the principles of sustainable development and circular economy (eco-innovations) on the economic aspect of sustainability of protected agriculture in southeastern Spain, whether incentives are applied or not.
2. To establish administrative proposals to catalyze the implementation of sustainable production techniques in protected agriculture in Almeria.

2 | MATERIALS AND METHODS

2.1 | Crop model and production structure evaluated

The economic impact of sustainable food production in greenhouse agriculture based on the implementation of sustainable cultivation techniques (biodisinfection, plant debris management, use of desalinated water, use of biodegradable plastics in mulching and trellising, sensoric and photovoltaic energyin) was studied in southeastern Spain (Figure 1). These techniques were evaluated in order to assess real alternatives and not just those of experimental nature (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; FER, 2017; MAPA &

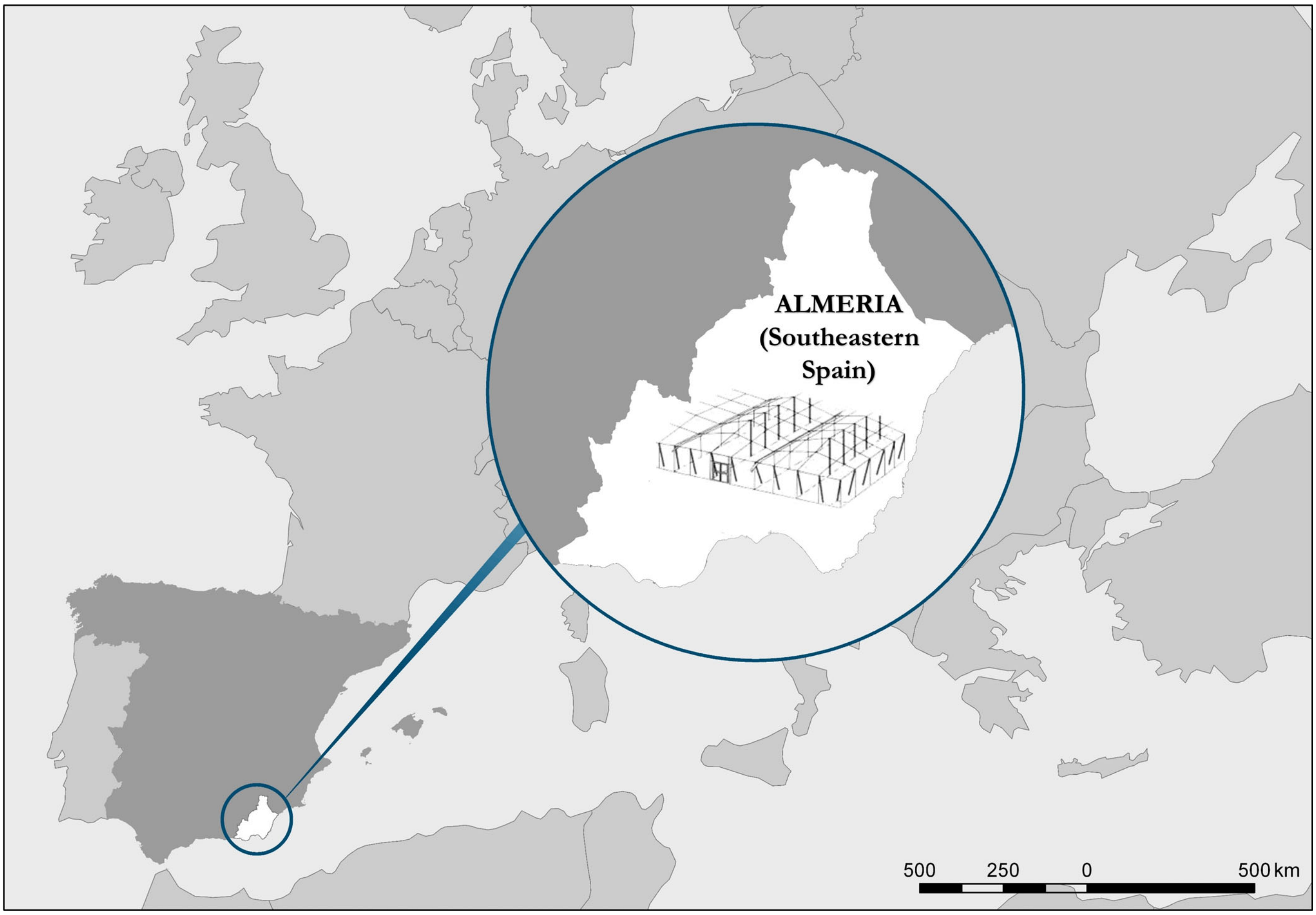

FIGURE 1 Location of southeastern Spain. *Source*: Own elaboration.

Cajamar, 2022; Marín-Guirao et al., 2022). Protected agriculture in the province of Almería (Spain) was taken as an indicator, as it is the main area of agriculture under cover in southeastern Spain (MAPA, 2021). An economic analysis was carried out in long-cycle cropping systems, a single crop with an approximate duration of 320 days after transplanting (DAT); and short-cycle, 2 cycles per year with an individual length of 160 DAT, these being the main cycles in the production model (Honoré et al., 2019; Valera-Martínez et al., 2014). The selected crop combinations appear in Table 2. Tomato, bell pepper, and watermelon crops were selected as they represent more than 60% of cultivated areas in protected horticulture in Almeria (Honoré et al., 2019). In addition, tomato and bell pepper cultivation in long cycles allows the reduction of almost 100% of inorganic fertilization by fertilizing with plant remains and compost (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Salinas et al., 2020).

TABLE 2 Species and crop cycles evaluated.

Type	Crop	
Long cycle	Tomato	
Short cycle	Autumn-winter	Spring-Summer
	Tomato	Watermelon
	Bell pepper	Watermelon

Source: Own elaboration.

The models evaluated were as follows:

1. Conventional system (CS): the cropping model described by Camacho-Ferre (2004).
2. Alternative system (AS): CS system that undergoes a suppression of inorganic cover crop fertilization for 217 DAT, a reduction of irrigation and disinfection water of 37.2%, a substitution of petrochemical plastics for biodegradable polymers in mulch and raffia, a substitution of groundwater from aquifers for desalinated water, a change in the acquisition of electric energy by self-consumption systems in photovoltaic electric energy farms, the use of sensors to monitor the water and nutritional status of the soil with cloud storage and consultation services, the use of a digital field notebook for document management, and a traceability system to detect spills. (Aznar-Sánchez et al., 2021; Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Kumar et al., 2022; MAPA & Cajamar, 2022).
3. Alternative Subsidized System (ASS): incentives are applied in biodegradable plastics, digitalization and photovoltaic energy in the

TABLE 3 Specification of production techniques used in the different crop alternatives evaluated with or without sustainable production techniques.

	Conventional production				Implementation of sustainable techniques[a]			
Crop	Long-cycle tomato	Short-cycle tomato	Short-cycle pepper	Wztermelon	Long-cycle tomato	Short-cycle tomato	Short-cycle pepper	Watermelon
Seedling raising	In seedbed for 33 days in trays of 150 cells	In seedbed for 33 days in trays of 150 cells	In seedbed for 40 days in trays of 96 cells	In seedbed for 40 days in trays of 40 cells	In seedbed for 33 days in trays of 150 cells	In seedbed for 33 days in trays of 150 cells	In seedbed for 40 days in trays of 96 cells	In seedbed for 40 days in trays of 40 cells
Planting density	16,000 plants/ha	16,000 plants/ha	20,000 plants/ha	2500 plants/ha	16,000 plants/ha	16,000 plants/ha	20,000 plants/ha	2500 plants/ha
Vegetal material	Adapted to the conditions of the farm without grafting	Adapted to the conditions of the farm without grafting	Adapted to the conditions of the farm without grafting	Adapted to the conditions of the farm, grafted on a rootstock of *Cucurbita maxima* × *Cucurbita moschata*	Adapted to the conditions of the farm without grafting	Adapted to the conditions of the farm without grafting	Adaptado a las condiciones de la explotación sin injertar	Adapted to the conditions of the farm, grafted on a rootstock of *Cucurbita maxima* × *Cucurbita moschata*
Labor	Manual for each cultivation task							
Pollination	Forced with bumblebees (5 hives/ha). Renewal every 2 months	Forced with bumblebees (5 hives/ha). Renewal every 2 months	With air	Forced with bees (4 hives/ha)	Forced with bumblebees (5 hives/ha). Renewal every 2 months	Forced with bumblebees (5 hives/ha). Renewal every 2 months	With air	Forced with bees (4 hives/ha)
Pruning	Single-arm, pinching the secondary shoots. Clamping of the clusters to 7 fruits	Single-arm, pinching the secondary shoots. Clamping of the clusters to 7 fruits	Cleaning of internal sprouting	—	Single-arm, pinching the secondary shoots. Clamping of the clusters to 7 fruits	Single-arm, pinching the secondary shoots. Clamping of the clusters to 7 fruits	Cleaning of internal sprouting	—
Trellising	Trellising system using hangers, raffia and clips	Trellising system using hangers, raffia and clips	Traditional Almeria trellising (banding)	No trellising	Trellising system using hangers, raffia and clips	Trellising system using hangers, raffia and clips	Traditional Almeria trellising (banding)	No trellising
Mulching	Polietileno	Polietileno	Polietileno	Polietileno	Polímero biodegradable	Polímero biodegradable	Polímero biodegradable	Polímero biodegradable
Cover whitewashing	Dosage of 5 g/L of lime	Dosage of 5 g/L of lime	Dosage of 5 g/L of lime	—	Dosage of 5 g/L of lime	Dosage of 5 g/L of lime	Dosage of 5 g/L of lime	—
Fertilization	Inorganic calculated from Steiner's ideal nutrient solution				60% reduction in inorganic fertilization calculated from Steiner's ideal nutrient solution + plant debris	Plant debris incorporated in veneers	Plant debris incorporated in veneers	60% reduction in inorganic fertilization calculated from Steiner's ideal nutrient solution + plant debris

(Continues)

TABLE 3 (Continued)

Crop	Conventional production				Implementation of sustainable techniques[a]			
	Long-cycle tomato	Short-cycle tomato	Short-cycle pepper	Wztermelon	Long-cycle tomato	Short-cycle tomato	Short-cycle pepper	Watermelon
					incorporated in veneers			incorporated in veneers
Irrigation water	Aquifer water				Desalinated water			
Protección del cultivo	Integrated production, on demand under the specific conditions of each production season							
Soil disinfection	Solarization + chemical disinfection				Biodesinfection			
Harvesting	Manual and unitary							
Sale of the product	Cooperative							
Transport of plant waste	Truck with a transport distance of less than 100 km				–			
Vegetable waste management	Authorized management (30 m^3)				Use on the farm			
Transport of plastic waste	Truck with transport of less than 100 km							
Plastic waste management	Authorized management							
Energy	Energy obtained from the commercial grid				Photovoltaic energy + spot support with energy obtained from the commercial grid			
Greenhouse	Scraping and tilling with a ridge height of 6 and 5 m for tilling							
Irrigation system	High-frequency irrigation system composed of an irrigation programmer, which incorporates five tanks for the preparation of nutrient solutions applied to the different crops							
Sensoric	–	–	–	–	*datalogger* with 2 tensiometers and capacitive EC sensor, nitrates, potassium, and pH			

[a]A third alternative has been evaluated, which consists of applying the subsidies offered by the Administration to the crop that implements production techniques based on the principles of sustainable development.

AS alternative (Junta de Andalucía, 2021; MAPA, 2018, 2019; MINECO, 2021).

The greenhouse structure used in this analysis was the "raspa y amagado" type with a sanding system. For the long production cycle, the structure had a height of 6.0, 5.0, and 4.7 m in the scrape, harrowing and banding, respectively. For the short production cycles, structures had a height of 4.5, 3.5, and 3.0 m in the scrape, damping-off and strips, respectively. This type of greenhouse is the most used in intensive production in southeastern Spain and, specifically, in Almeria, where more than 75% of the greenhouses are of the "raspa y amagado" type (Valera-Martínez et al., 2014). The amortization period of the greenhouses was 15 years. The greenhouse covers and banding plastic was three-layer and anti-strip netting with a useful life of 4 and 15 years, respectively. The greenhouses had a high-frequency drip irrigation system with emitters of 3 L/h per emitter driven by an irrigation programmer. In addition, they had a plastic water storage tank with a 10-year payback period. These techniques were evaluated in order to assess real alternatives and not just those of experimental character (Castillo-Díaz et al., 2022a, 2022b; FER, 2017; MAPA & Cajamar, 2022; Marín-Guirao et al., 2022). The photovoltaic self-consumption system and sensors for water status (*datalogger* with 2 tensiometers and capacitive electrical conductivity sensor) and soil nutrients (nitrates, potassium, and pH) had a payback period of 7 and 5 years, respectively. Table 3 summarizes the production and subsidy techniques applied in the analysis performed.

2.2 | Economic evaluation technique

To evaluate the impact of the techniques identified in Section 2.1 on the economic sustainability of agriculture in the southeastern part of the peninsula at the scale of production units, fixed costs, variable partial costs, total costs, and pre-tax profit were analyzed (i.e., cost–benefit analysis). These parameters have been used and recommended in previous research specializing in the evaluation of the impact of environmentally friendly alternatives for economic sustainability compared to conventional techniques (Batlles-delaFuente et al., 2022b; Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Celiktopuz et al., 2023; Colla, 2017; Heinrich et al., 2023; López-Serrano et al., 2021, 2023; Morselli et al., 2023; Roberts et al., 2023; Streimikis & Baležentis, 2020; Subhashree et al., 2023; Xu et al., 2023; Zhuo et al., 2023).

2.2.1 | Cost structure

The cost structure used by the "Catedrático Eduardo Fernández" Experimental Farm of the UAL-ANECOOP Foundation was used. Production costs were obtained from the work done by Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al. (2022); Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al. (2022), who obtained them from the analysis carried out by Torresano and Camacho-Ferre (2012) for Agroseguros, S.A.-España. These data are used by the said agency for the calculation of compensation after productivity losses due to pests, diseases, or climatic events. Agroseguros, S.A.-España is an entity that specializes in managing agricultural insurance on behalf of the insurance companies that are part of the coinsurance pool (Agroseguro, 2023). The values were updated to June 2022 from the ECOICOP index (European Classification of Individual Consumption by Purpose; ICP) (INE, 2022). Consultations were made in supply centers specialized in the distribution of agricultural inputs in the province of Almeria (i.e., cost of the sensor system, field notebook, cloud platform, photovoltaic system, etc.). This process was carried out using a closed questionnaire where the input or service and the cost associated with it were identified.

Variable costs

The cost of consulting was similar among all the crops, because they all demand similar labor. The land preparation item was modulated according to the duration of each crop (i.e., short cycle and long cycle). This item refers to the work of re-sodding carried out on a four-year basis. The agricultural biomass and plastics management items refer to the cost of handling the waste inside the greenhouse, transporting it and managing it at the treatment plant. The disinfection item refers to the cost of solarizing the greenhouse soil with a chemical disinfectant or organic amendments. Chemical disinfection was carried out every 4 years and physical disinfection every 2 years, while biodisinfection was applied annually. The addition of plant debris took place once a year. The plant remains were kept in mulch and shredded on the farm in the short-cycle alternatives. Under covering and structure, the costs of whitewashing are included, along with double roofs, tunnels, and mulching. Seeds and seedling production refer to the cost of seed, seedbed, and transport of seedlings to the farm. The cost of labor, phytosanitary products, and biological control and transportation of the merchandize to the cooperative appears under the heading "labor and inputs." Finally, water and fertilizer expenses for the indicated crops are identified.

Fixed costs

The item structures and irrigation system identifies the cost of the type of structures described above for short and long cycles. The soil maintenance item refers to the annual cost of implementing a sanding system. The heading cover and structure includes the expense incurred for the three-layer plastic cover of the greenhouse bands and the maintenance of the structure. The expenditure on insurance, management, and financial services includes the annual cost of the insurance of the campaign and structure, the cost of processing payroll, and taxes demanded by management and loans. Finally, the cost of energy and fixed supplies is identical.

The values of variable expenses were expressed in euros per hectare of crop and year. Finally, the total expenditure was obtained from the following mathematical expression:

$$TC = VC + FC \tag{1}$$

Where, TC: total costs (€/ha·year); VC: variable costs (€/ha·year); FC: fixed costs (€/ha·year).

Additionally, the variation rate was calculated:

$$RC = \frac{FV - IV}{IV} \quad (2)$$

Where, RC: variation rate (%); IV: initial value (€/ha·year); FV: final value (€/ha·year).

2.2.2 | Profit structure

Subsequently, an analysis of the producer pre-tax profit was carried out. The profit was calculated from the productivity and average price reported by the Junta de Andalucía from the 2016/2017 to the 2021/2022 campaigns to avoid climatological influences (Andalucía, 2021; Junta de Andalucía, 2022a). Values were then adjusted from the evaluated production methodologies (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; MAPA & Cajamar, 2022; Valera-Martínez et al., 2017). For this purpose, the following mathematical formulas were used:

$$TNR = P \cdot Pr \quad (3)$$

$$NPbt = TNR - TC \quad (4)$$

Where, TNR: total annual revenues (€/ha·year); *P*: Productivity (kg/m^2); Pr: Selling price (€/kg); NPbt: profit before tax (€/ha·year); TC: total cost (€/ha·year).

Finally, the CRB ratio was calculated. This is one of the most utilized coefficients for the establishment of management strategies. It is defined as the ratio between the monetary value of the total annual revenues and the monetary value of costs. For the calculation to be acceptable, the result of this operation must be higher than 1 (Celiktopuz et al., 2023; Kuwornu et al., 2018). The mathematical formula used was as follows:

$$CRB = \frac{TNR}{TC} \quad (5)$$

Where, TNR: total annual revenues (€/ha·year); TC: total costs (€/ha·year).

2.3 | Statistical treatment

After processing the information, an analysis of variance was applied to the total cost, profit, and other financial parameters evaluating the use of the one-way ANOVA test. A post hoc analysis was performed using the Least Significant Difference (LSD) test with a confidence level of 95%. The assumptions of normality and homoscedasticity were previously tested using the Shapiro–Wilk and Bartlett test. The analyses were performed with the STATGRAPHIC CENTURION XVIII statistical package (Manugistic Incorporate, Rockville, MD) for Windows.

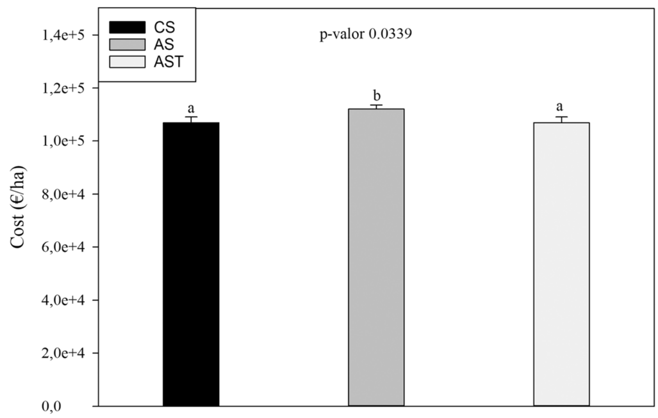

FIGURE 2 Total economic costs of cultivation of the evaluated methodologies ($n = 3$). CS: conventional system; AS: implementation of sustainable cultivation techniques; ATS: implementation of sustainable cultivation techniques with incentives. Different letters above the bars indicate statistically significant differences (one-way ANOVA; *p*-value ≤ .05; LDS test).

3 | RESULTS AND DISCUSSION

3.1 | Economic analysis

3.1.1 | Effect on total costs

Figure 2 shows the total farming costs of the three farming systems evaluated. It can be seen how the operating costs triggered by CS and ATS are significantly lower than those obtained by AS (one-way ANOVA; *p*-value ≤ .05).

Table 4 shows the economic appraisal of the crop alternatives evaluated. The production costs per annual alternative in CS vary from 104,905.9 to 109,223.6 €/ha. The rapid rise in Individual Consumption by Purpose (ICP) suffered by both Spain and the EU has increased production costs by almost 6000 €/ha beginning in the 2017/2018 season (Honoré et al., 2019; INE, 2022). In the AS methodology, the results showed a higher percentage increase in fixed costs versus variable costs. Another issue that could influence the results obtained would be the increase in interest rates by the European Central Bank due to the fact that half of the producers in the crop model evaluated have loans with credit institutions (Valera-Martínez et al., 2014).

Producers who grow two crops per season (i.e., two short cycles of 160 DAT per cycle) may experience higher increases in production costs than those who cultivate only during 1 cycle per season (i.e., long cycles of 320 DAT) if their production is not subsidized. The lower input use that long-cycle crops (i.e., mulching) may experience

TABLE 4 Economic impact on production costs (€/ha/year) due to the implementation of new sustainable production techniques.

	Alternative 1			Alternative 2			Alternative 3		
	CS	AS	ATS	CS	AS	ATS	CS	AS	ATS
Total variable cost	83,950.7	88,172.5	82,505.3	82,239.0	86,608.6	80,941.4	84,328.8	87,296.8	84,100.0
1. Technical assessment	356.5	356.5	356.5	356.5	356.5	356.5	356.5	356.5	356.5
2. Soil preparation	8991.9	6574.7	6574.7	8993.0	6575.5	6575.5	4495.9	3288.1	3288.1
3. Waste Management	2741.9	374.8	374.8	2742.4	374.8	374.8	1582.7	374.8	374.8
3.1. Agricultural biomass	2318.4	0.0	0.0	2318.8	0.0	0.0	1159.2	0.0	0.0
3.2. Plastic waste	423.5	374.8	374.8	423.5	374.8	374.8	423.5	374.8	374.8
4. Soil disinfection	1362.1	4229.0	4229.0	1362.1	4229.0	4229.0	1362.2	2815.4	2815.4
4.1. Plastic for solarization	995.3	1990.5	1990.5	995.3	1990.5	1990.5	995.3	1990.5	1990.5
4.2. Water for solarization	132.7	166.7	166.7	132.7	166.7	166.7	132.7	166.7	166.7
4.3. Chemical disinfectant	234.2	0.0	0.0	234.2	0.0	0.0	234.2	0.0	0.0
4.4. Incorporation of agricultural biomass	0.0	2071.8	2071.8	0.0	2071.8	2071.8	0.0	658.2	658.2
5. Covering and structure	5474.3	13,333.7	8393.0	5474.3	13,333.7	8393.0	2737.1	6666.9	4196.5
5.1. Mulching plastic	2022.0	9881.4	9881.4	2022.0	9881.4	9881.4	1011.0	4940.7	4940.7
5.2. Biodegradable plastic subsidy	0.0	0.0	−4940.7	0.0	0.0	−4940.7	0.0	0.0	−2470.4
5.3. Remaining covering and structure inputs	3452.3	3452.3	3452.3	3452.3	3452.3	3452.3	1726.1	1726.1	1726.1
6. Seeds and seedling production	8937.2	8937.2	8937.2	10,417.7	10,417.7	10,417.7	6616.3	6616.3	6616.3
7. Labor and other inputs	56,086.9	53,912.0	53,185.6	52,893.0	50,866.8	50,140.4	67,178.0	66,724.4	65,997.9
7.1. Trellising raffia	129.6	581.5	581.5	129.6	581.5	581.5	129.6	581.5	581.5
7.2. Trellising raffia subsidy	0.0	0.0	−383.8	0.0	0.0	−383.8	0.0	0.0	−383.8
7.3. Trellising rings	155.3	685.2	685.2	155.3	685.2	685.2	155.3	685.2	685.2
7.4. Trellising ring subsidy	0.0	0.0	−342.6	0.0	0.0	−342.6	0.0	0.0	−342.6
7.5. Water	1869.0	1956.2	1956.2	1821.0	1906.0	1906.0	1800.0	1884.0	1884.0
7.6. Fertilizers	4832.2	1588.3	1588.3	4681.3	1588.3	1588.3	2240.8	721.3	721.3
7.7. Labor and remaining inputs	49,100.8	49,100.8	49,100.8	46,105.8	46,105.8	46,105.8	62,852.4	62,852.4	62,852.4
8. Traceability system	0.0	454.5	454.5	0.0	454.5	454.5	0.0	454.5	454.5
Total fixed costs	22,666.9	24,039.4	23,125.2	22,666.9	24,039.4	23,125.2	24,894.8	26,267.4	25353.1

(Continues)

TABLE 4 (Continued)

	Alternative 1			Alternative 2			Alternative 3		
	CS	AS	ATS	CS	AS	ATS	CS	AS	ATS
1. Soil maintenance	2375.4	2375.4	2375.4	2375.4	2375.4	2375.4	2446.9	2446.9	2446.9
2. Covering and structure	4753.8	4753.8	4753.8	4753.8	4753.8	4753.8	4898.4	4898.4	4898.4
3. Energy	1753.3	447.6[a]	447.6[a]	1753.3	447.6[a]	447.6[a]	1753.3	447.6[a]	447.6[a]
4. Fixed supplies	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6	123.6
4. Insurance. management and financial services	4134.3	4134.3	4134.3	4134.3	4134.3	4134.3	4259.4	4259.4	4259.4
5. Equipment and irrigation system	9526.5	9526.5	9526.5	9526.5	9526.5	9526.5	11,413.2	11,413.2	11,413.2
6. Sensorics	0.0	916.0	516.0	0.0	916.0	516.0	0.0	916.0	516.0
6.1. Irrigation	0.0	448.0	448.0	0.0	448.0	448.0	0.0	448.0	448.0
6.2. Soil nutrients	0.0	468.0	468.0	0.0	468.0	468.0	0.0	468.0	468.0
6.3. Subsidies	0.0	0.0	−400.0	0.0	0.0	−400.0	0.0	0.0	−400.0
7. Digital field notebook	0.0	48.0	48.0	0.0	48.0	48.0	0.0	48.0	48.0
8. Photovoltaic system	0.0	1714.3	1200.0	0.0	1714.3	1200.0	0.0	1714.3	1200.0
8.1. Cost	0.0	1714.3	1714.3	0.0	1714.3	1714.3	0.0	1714.3	1714.3
8.2. Subsidy	0.0	0.0	−514.3	0.0	0.0	−514.3	0.0	0.0	−514.3
Total expenses	106,617.6	112,211.9	105,630.5	104,905.9	110,648.0	104,066.6	109,223.6	113,564.2	109,453.2
Increase in production costs (%)	0.0	5.2	−0.9	0.0	5.5	−0.8	0.0	4.0	0.2

[a]Minimum electricity tariff.
Source: Own elaboration based on primary data and Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Garcia-Caparros et al., 2017; Junta de Andalucía, 2021; MAPA, 2018, 2019; MINECO, 2021.

triggers this behavior. Mulches made with biodegradable polymers deteriorate more easily than the conventional composite during the normal development of a production cycle (Marín-Guirao et al., 2022). The deterioration that the material may suffer during the pre-cultivation work for the spring-summer cycle in the first two alternatives may lead to replacing the plastic mulch. Proper conservation and reuse of mulch between the fall-winter and spring-summer cycles can reduce production costs.

The incentive scheme proposed by the administrations and the decrease in production costs offered by some sustainable techniques neutralizes the increase in production costs. The short-cycle alternatives decreased total production costs by −0.9% and −0.8%, respectively, while the long-cycle tomato crop increased total costs by only 1.0%. The expected output is that most farmers do not benefit from the total number of subsidies. The incentive system is framed in specific action plans, with limited resources allocated to these systems Therefore, the total production costs of greenhouse agriculture in the southeastern peninsular can vary from −0.9% to 5.5% per production campaign because of the sustainability policies derived from Agenda 2030 and the CE. On the other hand, as mentioned above, the implementation of these techniques expands the environmental sustainability of the system by framing the local development system of the southeastern peninsular in the CE. This fact sustains the social aspect of the model and helps to balance the production system.

Figure 3 shows the increase in total production costs in the evaluated vegetable species. Watermelon is the crop that experienced the higher increment in production costs (8.7%), followed by long-cycle tomato (4.0%), short-cycle tomato (3.7%), and sweet bell pepper (1.5%). Thus, the existing differences in the rate of cost increase may be due to the requirements of the plant species. The reduced production costs due to the use of biodisinfection with agricultural biomass lowered the economic impact of sustainable production techniques by reducing the demand for inputs. The environmental footprint of the greenhouse agricultural system in the southwest of the Iberian Peninsula is significantly reduced with the use of the production techniques evaluated, reducing the carbon, energy, and water footprint of crops, which is a capital issue (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Kumar et al., 2022; Maureira et al., 2022; Salinas et al., 2020). At the same time, the local development system in

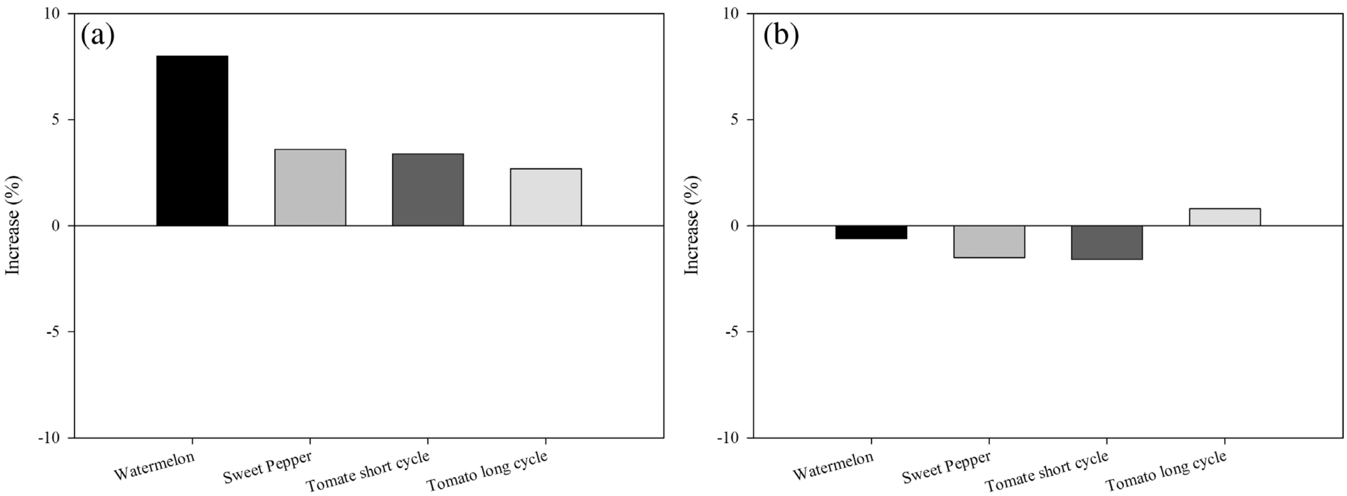

FIGURE 3 Increase in total costs of the crops evaluated. (a) Without subsidies; (b) Including subsidies. *Source*: Own elaboration from primary data and based on other authors. (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Garcia-Caparros et al., 2017; Junta de Andalucía, 2021; MAPA, 2018, 2019; MINECO, 2021).

Almeria, generated by greenhouse agriculture, is fully framed within the CE principles and helps to achieve the SDGs. The use of biodegradable plastics favors the management of the material, avoiding the generation of environmental impacts on Almeria's ecosystems (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022). The use of desalinated water reduces the pressure on Almeria's aquifers and can significantly increase the production of horticultural crops compared to well water. This fact is not known by many of the farmers and misinformation acts as a barrier to the implementation of new sustainable production techniques (Aznar-Sánchez et al., 2021; Valera-Martínez et al., 2017). Sensors and the digital field notebook allow decision-making based on accurate crop data, improving the management of inputs such as water and fertilizers (MAPA & Cajamar, 2022). The traceability system makes it possible to detect waste discharges. Self-consumption of energy with the photovoltaic system reduces the demand for non-renewable energy. At the same time, inorganic fertilizers are reduced to a greater extent than required by the EU in the current time frame of the European Green Pact (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; European Comission, 2020a). The benefits of the evaluated techniques allow further positioning of the protected agriculture of southwestern Spain as one of the leading production systems in the EU in terms of sustainability, compared to its international competitors (Vanthoor et al., 2012). Some research has reported that energy and fertilizer savings enable the best economic scenario in agriculture in southeastern Spain. The techniques evaluated facilitate this scenario (Torrellas et al., 2012). Other techniques, such as water and nutrient recirculation systems, can also be implemented. These systems cause substantial decreases in crop water and nutrient demand. However, they demand the implementation of new production infrastructures, with the consequent expansion of the environmental footprint. This behavior would significantly affect greenhouse agriculture in southeastern Spain, which makes intensive use of soil (Rufí-Salís et al., 2020; Valera-Martínez et al., 2014). In the future, the combined implementation of other production techniques that are currently experimental, such as digital twins or robotization, could further increase production costs and drastically decrease the economic profitability of the activity (Ariesen-Verschuur et al., 2022; MAPA & Cajamar, 2022; Pearson et al., 2022).

3.1.2 | Partial costs

Figure 4 shows the partial increase in production costs resulting from the sustainable and circular production techniques on the specific subheadings of each technique, with and without subsidies. Only the biodisinfection technique, using agricultural biomass, resulted in a partial decrease in production costs (−29.3%). This method facilitates a total reduction of chemical fumigants, a partial suppression of inorganic fertilization in cycles of 320 DAT and a reduction in water supply by improving soil fertility. At the same time, the problems related to the management of agricultural biomass are reduced (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Duque-Acevedo, Belmonte-Ureña, Plaza-Úbeda, et al., 2020; Duque-Acevedo, Belmonte-Ureña, Yakovleva, et al., 2020; Salinas et al., 2020). The use of desalinated water, biodegradable plastics, and photovoltaic energy increased the partial production costs in water (66.7%), mulching plastics, raffia and trellising rings (389.2%), and energy (23.3%) (Figure 2a). The application of the incentive system mitigated the partial rise in production costs (Figure 4b). The use of subsidized photovoltaic energy resulted in a partial decrease in production costs of 6.0%, which could be amplified by the increase in energy prices due to the political instability in Eastern Europe and the

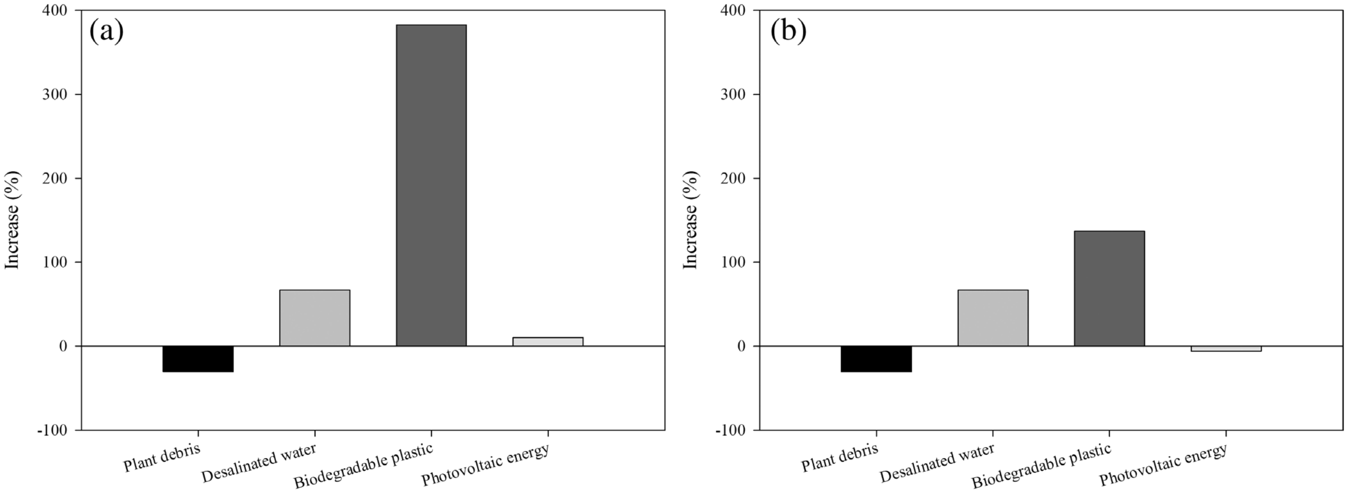

FIGURE 4 Partial rate of change of production costs. (a) Without subsidies; (b) Including subsidies. For the calculation of the partial variation rate, only the items involved in the application or not of each particular technique have been considered, namely: Plant debris: external management of agricultural biomass, solarization plastic, chemical disinfectant, incorporation of agricultural biomass, water and fertilizers; Desalinated wáter: cost of water; Biodegradable plastic: cost of mulching plastic, rings and trellising raffia; Photovoltaic energy: cost of energy, minimum energy service and self-consumption system. It was not possible to calculate the variation rate of digitization and the traceability system because there were no items in CS. *Source*: Own elaboration from primary data and based on other authors. (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Garcia-Caparros et al., 2017; Junta de Andalucía, 2021; MAPA, 2018, 2019; MINECO, 2021).

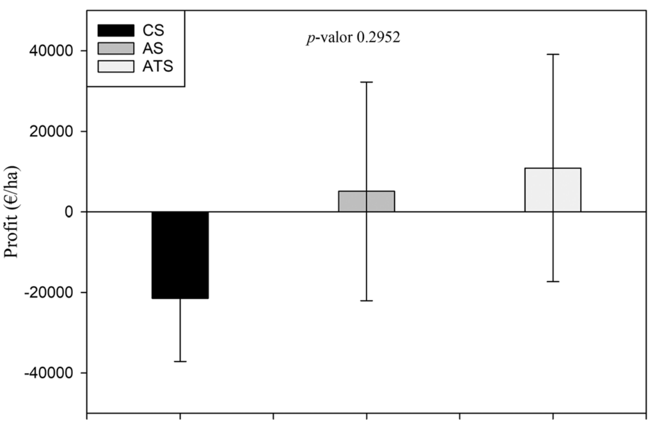

FIGURE 5 Pre-tax economic benefit (NPbt) of the cultivation methodologies evaluated ($n = 3$). CS: conventional system; AS: implementation of sustainable cultivation techniques; ATS: implementation of sustainable cultivation techniques with incentives. Different letters above bars indicate statistically significant differences (one-way ANOVA; p-value ≤ .05; LDS test).

current adverse climatic phenomena in the EU (European Commission, 2022b; Hernández de Cos, 2022). Photovoltaic energy can be self-sufficient for farmers. Also, this system could jointly implement cogeneration or geothermal systems to obtain energy and thus improve the efficiency of the process (Kumar et al., 2022; Torrellas et al., 2012). The traceability system increases production costs by 454.5 €/ha per year but allows the identification of producers with poor waste management practices (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022). The digital field notebook cost 48 €/ha per year. However, this digital tool facilitates the documentary management of farms and the generation of the necessary documentation to certify production, thereby reducing the time spent on this task, where the traceability system could be placed (MAPA & Cajamar, 2022). The aid granted by the Spanish government through the Digital Kit can reduce the partial cost of adopting sensor technology by 43.7% in microenterprises and, consequently, reduce one of its barriers: the cost of adoption (MAPA & Cajamar, 2022; MINECO, 2021).

3.1.3 | Profit before taxes

Profit

Figure 5 shows the economic benefit of the cultivation methodologies evaluated. There are no statistically significant differences between the pre-tax profit of CS, AS, and ATS (one-way ANOVA; p-value ≥ .05) because of the high dispersion shown by NPtb. This result may be due to the variability of the cases studied in this work, which could be associated with the risk of the economic operation of expanding the environmental aspect of sustainability. However, it can be noticed that the cultivation methodology that implements sustainable strategies (AS) increases the average value of NPtb by 123.8%. This value reaches 150.6% for the alternative that enjoys subsidies established by different administrations (ATS) in addition to implementing sustainable cultivation techniques. Both methodologies obtained a positive balance, although this decrease is not statistically significant given the high variability of the evaluated parameter. Therefore, the implementation of eco-innovations could slightly improve the profitability of

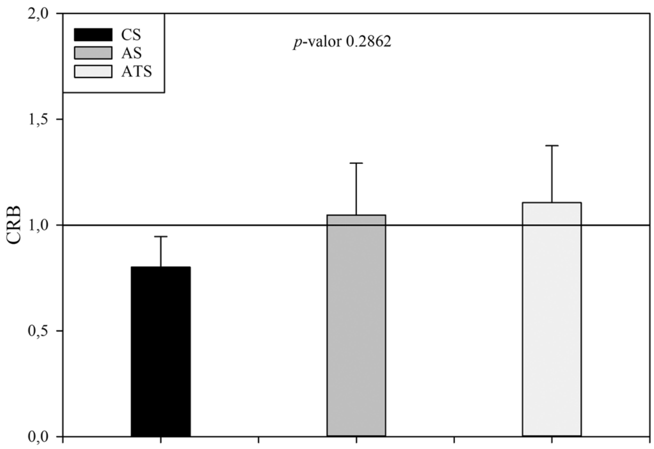

FIGURE 6 CRB ratio triggered by the cultivation methodologies evaluated ($n = 3$). CS: conventional system; AS: implementation of sustainable cultivation techniques; ATS: implementation of sustainable cultivation techniques with incentives. Different letters above the bars indicate statistically significant differences (one-way ANOVA; p-value ≤ .05; LDS test).

the sector, a result similar to that obtained by other research in protected agriculture in southeastern Spain (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Honoré et al., 2019; Martos-Pedrero et al., 2022) and in other sectors, such as energy (Balcilar et al., 2022).

It should be noted that some of the traditional crop alternatives evaluated under the different production methodologies registered economic losses (Figure 5). Previous research on the profitability of the most representative crop alternatives in southeastern Spanish agriculture between 2016 and 2021 has reported similar results. They indicate the need to diversify the range of protected crops to other plant species, such as papaya or figs, or to implement production techniques that can expand crop productivity and increase the economic sustainability of the greenhouse production model (Aznar-Sánchez et al., 2021; Batlles-delaFuente et al., 2022a; Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Honoré et al., 2019; Valera-Martínez et al., 2017). This is due to the expansion of production costs in recent years where the pressure to implement techniques framed in sustainable development and the circular economy (i.e., environmental policy) may favor such an increase. However, when interpreting the results one must consider that the producers of the protected model of the southeastern portion of the peninsula resort to family labor during economic downturns and they sacrifice their profit while reducing financial losses due to reduced expense accounts (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Honoré et al., 2019). Therefore, these are two factors to remember when assessing this work. However, food production and the implementation of eco-innovations, sustainable development, and environmental policies should not benefit from the casuistry indicated above. An attractive, competitive, diversified, and modern agricultural sector must be created. This sector should provide opportunities for society and, above all, for young people. Attracting human capital to the agriculture sector and rejuvenating the workforce of primary producers in the Spanish agri-food sector would help sustain the sovereignty and food security of its territory and the EU.

3.1.4 | Ratio CRB

Figure 6 shows the CRB ratio that illustrates the total annual revenues and the total costs of each cultivation methodology. This figure shows no significant differences between CS, AS, and ATS (one-way ANOVA; p-value ≥ .05). However, it can be noted that the cultivation methodologies that expand the use of cultural practices framed in the principles of sustainable development and circular economy (AS and ATS) obtain an average CRB higher than 1, although this result is not statistically significant due to the dispersion of the parameter. This variability could be related to the risk that farmers may face when implementing sustainable techniques since their implementation requires a change in the idiosyncrasies of producers, a training exercise to ensure that these cultivation techniques are applied correctly, and also the knowledge of the technology and/or sustainable practices. Therefore, the success of expanding the environmental aspect of sustainability while maintaining acceptable levels of the economic subcomponent may depend on these factors and will put farmers in a position that may help or harm efforts to sustain the economic profitability of their farm (Batlles-delaFuente et al., 2022a; Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Galati et al., 2020; Honoré et al., 2019). It is also necessary to highlight that the results of this research suggest the need to change the direction of the conventional alternative of protected agriculture in the southeastern peninsula to maintain its economic sustainability.

3.2 | Possible corrective measures

The results of this research suggest that sustainability policies within the principles of sustainable development and the circular economy may harm the cost account of protected horticulture farmers in southeastern Spain. However, the incentive system and the implementation of the production techniques evaluated in this research can dilute this effect by improving the pre-tax profit of the parties involved. Management plays an essential role in maintaining the balance between the different strands of sustainability of agricultural systems and other economic activities to meet the SDGs (Filho et al., 2020; Madu & Kuei, 2012). In this sense, the inflation that strikes both Spain and the other EU Member States can compromise the achievement of the environmental objectives by progressively increasing the production costs of farmers who have seen their economic benefit reduced during the last decade due to the stability of prices at the origin. The combined effect of inflation and sustainable production techniques can reduce the socioeconomic development of some local production systems in southwestern Spain (Table 4 and Figures 5 and 6), as is the case in protected agriculture in Almeria (Honoré et al., 2019). In addition, all the action plans that define incentive systems must consider inflation as a factor that modulates the amount to be granted (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022). The subsidies offered in the matter of digitization offer a fixed amount. Inflation, in combination with the low supply of microchips in the EU, may limit the possibilities of implementing new technological solutions, such as sensor technology, which can reduce the environmental footprint (European Commission, 2022a).

To avoid the above situation, administrations must create a green and digital architecture of incentives, which help to maintain the EU's food security and sovereignty for greenhouse systems (Honoré et al., 2019). In such a structure, they should develop incentive packages related to inflation to reduce administrative hurdles and the number of applications made by producers. Also, combined incentive packages can help to expand the implementation of all sustainable production techniques equally, take away the fact that some of the technologies evaluated in the past have a reduced rate of implementation (Castillo-Díaz, Belmonte-Ureña, Batlles-Delafuente, et al., 2022; Castillo-Díaz, Belmonte-Ureña, Camacho-Ferre, et al., 2022; Valera-Martínez et al., 2014). As of now, a similar architecture could be established based on the actions framed in the operational programs of the Fruit and Vegetable Producer Organizations (OPFH). The freedom of selection in these programs may result in some of the best available practices being ignored, which could lead to their asymmetrical implementation. Therefore, selection should be limited to specific packages of measures, such as the one proposed in this work, to achieve a symmetrical adherence of farming techniques. In addition, operational programs limit the percentage of the economic concession offered to the actions they consider of interest, which can reduce the aid that producers grouped in FVPOs can receive (MAPA, 2022). In addition, the new Community Agricultural Policy (CAP) (2023–2027) has identified the need to create a selective green architecture composed of sustainable practices chosen by each country based on the analysis of the best available practices, which will make it possible to reduce the environmental footprint of primary production. This green architecture is linked to one of the support packages identified in the first pillar of the CAP. This measure represents a continuist line of the CAP in the face of the measures included in other historical periods. In the previous period (2014–2020) a green payment for the application of environmentally friendly agricultural practices was identified (MAPA, 2023b).

In the case of the subsidies evaluated in this work, farmers must carry out three different procedures in different administrations or organizations, which can lead these agents to confusion (Junta de Andalucía, 2021; MAPA, 2018, 2019; MINECO, 2021). This architecture must contemplate the training of primary agents in sustainability, sustainable production techniques, the implementation of organic agriculture, and the creation of a differentiated quality distinction for fruit and vegetable products generated in the southeastern peninsular (Figure 7). A similar model to the one implemented to improve the

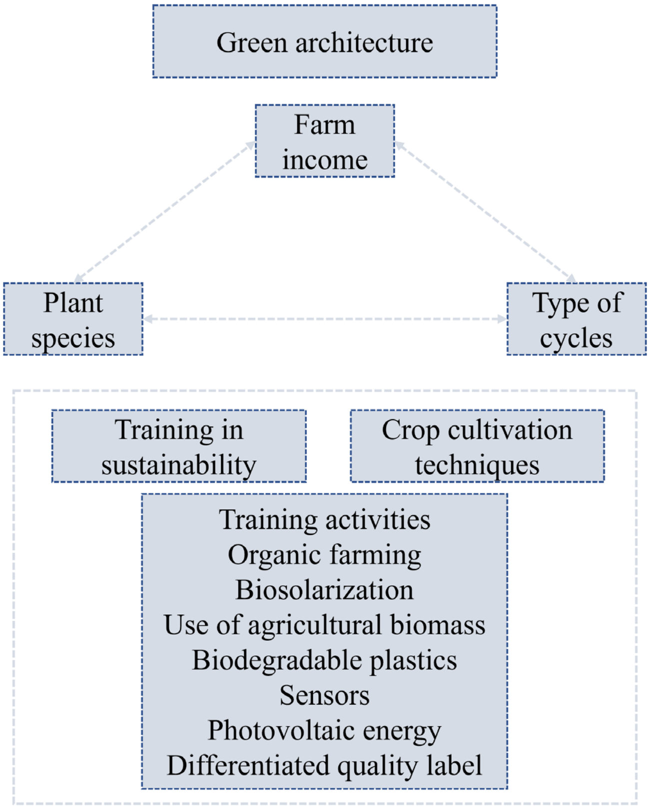

FIGURE 7 Projection of the proposed green architecture for greenhouse agriculture in Almeria. *Source*: Own elaboration.

training of farmers in the application of phytosanitary products could be used, offering a certificate of competence in sustainability in circular production techniques. Conducting on-site demonstration activities is critical to show farmers first-hand the benefits of the techniques (European Comission, 2020b; MAPA & Cajamar, 2022; Ministerio de la Presidencia, 2012). This sustainability training can expand the environmental culture of agri-food agents in the southeastern peninsular, which is directly related to the increased implementation of eco-innovations, particularly in companies with a customer orientation to meet their needs, as is the case of agri-food companies (García-Granero et al., 2020). The action plans implemented to date do not take into account the singularities of each territory, the local development systems, or some of the particularities of the crop systems, such as the plant species cultivated or the type of crop cycle that influence the increase in production costs (Figures 3 and 4 and Table 4). In some cases, local decentralization of agricultural policy should occur to take into account these or other variables specific to each territory. However, applying for aid should be made through a single agency. An exclusion variable should be the income obtained per campaign. The incentives to be granted in the green architecture of Almeria's agriculture should be 5.5% of agricultural expenditure (Table 4).

The proposal to concentrate the totality of incentives in a subsidy package to reduce the number of procedures would require that institutions can condense a large number of farmers. Producer organizations play an essential role. On the other hand, producers often require external capital to finance their agricultural activity. In greenhouse agriculture in Almeria, almost half of the producers turn to credit institutions for funding to develop their activity (Valera-Martínez et al., 2014). These entities can play an essential role in achieving environmental objectives and sustainable development by granting financing only to agricultural activities with a low environmental footprint or those committed to improving the environmental efficiency through sustainable production techniques. The inclusion of the triple aspect of sustainability in the risk analysis carried out by these entities is a key aspect for achieving the SDGs (CFS, 2011; Gambetta et al., 2021). Green architecture should be a means to address sustainable development from multiple perspectives, implement new quality certifications, or extend the regulatory content of the current ones, and not only be limited to an administrative level for the granting of subsidies or procedures.

4 | CONCLUSIONS, LIMITATIONS, AND FUTURE LINE OF RESEARCH

The results of this research suggest that the implementation of cultivation techniques framed in the principles of sustainable development and circular economy can significantly increase the production costs of greenhouse agriculture in the southeastern peninsula. This potential increase could reach a percentage value of up to 5.5%. However, the pre-tax profit obtained among the cultivation methodologies evaluated (CS, AS, and ATS) was statistically similar to each other due to the high variability in the parameter. Despite this, the methodology that implemented the cultivation techniques framed in the principles of sustainable development and circular economy without subsidies expanded the economic benefit to obtain a positive average balance. The implementation of eco-innovations can slightly improve the profitability of the sector, although this requires proper and joint application of the techniques.

Sustainable development is an essential criterion for any economic activity. It balances the triple aspect of the sustainability of the local development system generated by agriculture in the southwest of the peninsula. However, the synergistic effect between the rise in production costs and the rapid rise in the ICP in recent times due to political instability can be devastating. Subsidies proposed by governments can mitigate the economic impact. The public sector must act as a balancing agent of the three sides of sustainability in different economic activities but, above all, of the primary activity, which preserves the sovereignty and food security of the countries and is the pillar of local development in many of the Spanish territories. For this, incentives should be bundled in packages through a green architecture adapted to the conditions of each agricultural system, helping to expand the combined implementation of production techniques, the training of stakeholders, and reducing the administrative hurdles of the application. The proposed system could be taken as a reference by the Common Agricultural Policy of the European Union for future modifications of the latter in the case of the evaluated subsector.

Despite the contributions of this work, it is not without limitations. These may be due to the methodology applied and the fact that it uses average costs and incomes of the sector, so the results of this study may not express the particular reality of each farmer. However, this work provides clarity on the effect of production techniques framed in the previously mentioned principles on economic sustainability in one of the farming models that sustains food security and sovereignty in food production in the EU. The possible management strategies can be applied to catalyze its implementation, so the economic subcomponent of sustainability is not reduced due to expanding the environmental dynamic.

Future research should analyze the current implementation of the production techniques evaluated to quantify the sustainability of the greenhouse farming system in the southwestern peninsular. In addition, future research should assess the impact of these or other sustainable production techniques on the profitability of other agricultural subsectors, such as open-air horticultural production, to determine the effect of environmental policy on the socio-economic development of the territories.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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