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Impact of the new measures related to the circular economy on the management of agrochemical packaging in Spanish agriculture and the use of biodegradable plastics

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Abstract

Background: Waste disposal is an activity that pollutes the environment. The European Union has developed different legislative measures which are based on the circular economy (CE) to avoid this negative externality. The management of agricultural packaging (fertilizers and phytosanitary products) is carried out through Collective Deposit, Return, and Refund Systems (CDRRS). New regulations on waste tax the consumption of non-recyclable plastic in packaging, but also reward the use of plastic by-products from packaging. The administrations recommend using biodegradable plastic in the means of production, as well as establishing a traceability system (TS) to control the proper management of all the generated waste. The proposed measures can affect producer cost accounts. This work aimed to identify and evaluate the existing agricultural packaging management system in Spain. It also studied the influence of the price of a barrel of oil, crop surface, irrigation regime, and the type of subsectors on CDRRS, and quantified the impact of the latest fiscal measures and initiatives proposed by Spanish administrations.

Results: The generation of agricultural packaging is influenced by variables including the cultivated area, irrigation regime, and agricultural subsector. The price of a barrel of oil directly influences the current by-product utilization system. Using biodegradable plastic or implementing a TS can increase production costs by up to 9.80%. The current system of subsidies to producers can soften the economic impact caused by the additional cost of biodegradable plastic (4.03%), but no subsidies have been foreseen to encourage the use of environmentally friendly alternatives.

Conclusions: Findings indicate that public administrations should be guided by the specific characteristics of the different agricultural systems when defining regulations on agricultural waste management. The fixed rate in the current system of subsidies for using plastic by-products obtained from packaging should be substituted for a variable rate. Transferring powers to autonomous communities to define by-products may lead to heterogeneity in the Spanish territory. New measures derived from the recent environmental agreements to comply with the 2030 Agenda will increase production costs even after considering the current aid scheme. The subsidy coefficient should be increased to 80% of the purchase invoice.

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Keywords: Sustainable development, Circular economy, Agriculture, Agricultural packaging, Tax incentives, Waste management, Agricultural profitability

Background

Socioeconomic importance and use of plastic inputs in food production in Spain

On a global scale, food production is mostly carried out on family farms, with small-scale producers being the key agents for the development of countries [1]. In Spain, the agri-food sector generated more than 1.1 million jobs and accounted for 5.3% of gross value added (GVA) in 2020 (57,835 million €). Agriculture and fishing contributed 59.3% of this GVA [2]. Agriculture is therefore an activity that generates wealth and employment, in addition to the labor dependence that exists in certain territories. Thus, its influence is remarkable in areas with low population density in Spain, where agriculture and the agri-food sector can reach 11% and 20% of GVA, respectively [3, 4].

During the last 50 years, agricultural systems have undergone a substantial transformation. This has led to significant increases in productivity, which helped reach the previously mentioned economic expansion, of around 240% in the case of cereals [5]. However, increased productivity has resulted in a threefold increase in the consumption of natural resources due to higher input requirements (i.e., water, agrochemicals, energy, etc.) [6] that make agriculture the main consumer of vital resources, such as water [7]. This fact has altered the functionality and organization of ecosystems [8]. The environmental impacts derived from agriculture have also increased, highlighting phenomena such as erosion [9, 10], loss of genetic diversity [11], soil degradation [9, 10], and overexploitation that includes the loss of quality in bodies of water [12]. Some of these environmental consequences are due to the excessive consumption of agrochemicals (i.e., fertilizers and phytosanitary products) and the poor management of residue from agricultural activities [13–18].

Plastics are among the most consumed materials in agricultural systems [19] and they generate large amounts of waste [16]. Their use is linked to large production structures (i.e., protected crops), production inputs (i.e., raffia, mulch, grooving rings, etc.), agrochemical packaging [16, 20] or food product containers [21]. Greenhouse crops have a high plastic footprint, up to more than 1500 kg/ha per year [16]. Spain is the principal supplier of agricultural plastic in the European market, providing 15% of the agricultural plastic consumed in the European Union. Moreover, the consumption of agricultural plastic in Spain is higher than that of the European Union (5% versus 3% of the total plastic consumed in each territory, respectively) [22]. The consumption of agrochemicals or the expansion of agriculture under plastic, mainly in the autonomous community of Andalusia, may have led to this higher consumption of plastic [16, 23, 24]. Spain is home to the largest greenhouse area in the European Union and the second largest in the world [25].

Negative externalities of plastic: the need for sustainable development

Plastic has been described as one of the major physical and chemical pollutants in ecosystems [26, 27]. They can fragment into small particles (i.e., microplastics and nanoplastics) [28], which can interact with the lipid membranes of living organisms [29]. They can also emit chemicals that are added during their manufacturing process (additives) to improve their quality (e.g., bisphenol) [27], while acting as vectors of pollutants [26]. Unfortunately, plastic spills damage the environment, including marine ecosystems [30], although their effects also extend to terrestrial ecosystems [28]. Poor management of the material can lead to its accumulation in soils, the emission of greenhouse gases into the atmosphere (e.g., methane, ethylene, etc.) [31], new conglomerate rock formations [32], the spillage of chemicals into ecosystems [33, 34], the internal infestation and death of living organisms [19, 35], and the accumulation of substances that act as endocrine disruptors (e.g., bisphenol) that end up being transmitted to the food chain [27, 36].

The UN principles of sustainable or lasting development seek to correct the instability caused by anthropogenic activities that may influence the development of future generations, as in the case of bad practices related to the usage of plastic. In 2015, UN member states adopted the 2030 Agenda, which contains 17 Sustainable Development Goals. The Agenda addresses the most relevant social, economic, and environmental issues on a global scale while aiming to achieve sustainability and durability of societies and economic activities through sustainable and resilient development [37]. The European Union has based its new policy update on the CE principles (i.e., reuse, reduce, and recycle) to minimize waste and its environmental effects [38, 39]. This new policy aims to achieve economic growth decoupled from the consumption of natural resources and greenhouse gases [40]. Production systems must be transformed into sustainable and resilient production models. To this end, production processes need to "close the loop" and make use of the by-products obtained while minimizing waste generation and preserving the biodiversity of ecosystems [41–44]. The European Union has also formulated a specific strategy to "close the loop" in the life cycle of plastic, highlighting specific measures for the management of agricultural plastic to avoid undesirable environmental effects [41, 45].

The management of agricultural packaging has created problems on agricultural systems due to the indiscriminate dumping of toxic substances and plastic packaging on ecosystems [46, 47]. In Spain, the problem was detected during the 1990s [20, 46, 47]. According to Nature and SIGFITO [34], more than 6% of the poor practices regarding agricultural waste relate to the packaging of agrochemicals. The most common issues include burning, burying, and abandonment. Some authors recommend establishing a TS to detect negative farmer practices regarding the disposal of containers and other types of plastic waste [16, 48] since these practices carried out with agricultural containers can also be extended to other agricultural plastic [16, 49].

In addition, new initiatives proposed to solve the problems surrounding agricultural plastic may have a negative impact on producer costs as a result of higher input prices (e.g., use of biodegradable plastics, a traceability system, tax on non-recyclable plastic packaging, etc.) [16, 50], mainly in high-yield agricultural systems that demand a high amount of agrochemicals (i.e., agricultural models under greenhouses) [23, 51]. The stability recorded in the price of agricultural products and the increase in production costs have lowered producer margins in the last decade [52, 53]. The situation may also worsen by the introduction of biodegradable polymers, which in many cases involve an emerging technology [16], stemming from the high price of inputs.

In this scenario, the objectives were as follows:

- To identify the regulatory framework associated with the management of agricultural packaging (fertilizer and phytosanitary products) in Spain and the functioning of the initiatives generated around it.
- To determine the type of agricultural systems and subsectors that generate the highest number of agricultural containers.
- To evaluate the influence of Brent crude oil barrel (in dollars per barrel of oil) on the performance of the container recycling system.
- To study the economic impact in the greenhouse agriculture expense account of the following variables: taxes on the consumption of non-recyclable containers, bonuses to encourage the use of plastic by-products from containers, aids for the consumption of biodegradable polymers, and the implementation of a TS for the waste generated.
- To establish administrative proposals to improve the waste management operation and encourage the consumption of by-products and biodegradable polymers.

Regulatory framework for the management of agricultural packaging (fertilizer and phytosanitary products) in Spain

Spain defined its law regarding packaging management after incorporating Directive 94/62/EC into its regulatory code under Law 11/1997 of 24 April 1997 and Royal Decree 782/1998 of 30 April 1998 [54, 55]. However, it only took three years to detect the ineffectiveness of the regulations for some of the commercial or industrial packaging, including the containers of phytosanitary products [33, 56].

For this reason, Law 14/2000 of 29 December 2000 on fiscal, administrative, and social measures introduced a legal framework that eliminated the possibility of exemption from the extended producer responsibility regime (EPR) for some commercial or industrial hazardous packaging, thus preventing the consumer from owning the entire treatment obligation [56]. Through Royal Decree 1416/2001, of December 14, 2001, the Spanish Government incorporated a specific regulatory body to deal with the management of phytosanitary products packaging. This law requires producers to establish a Deposit, Return, and Return to Individual System (DRRIS), or alternatively Collective Deposit, Return, and Refund Systems (CDRRS), where the producers of agrochemicals could be indexed voluntarily. A DRRIS is a system for the collection of containers by a single agrochemical producer, the purpose of which is to collect the containers sold by this manufacturer. A CDRRS is a system formed by several agrochemical producers, whose purpose is to collect the containers sold by the manufacturers indexed in the CDRRS. The packaging of fertilizers was excluded. The cost should be incorporated into the selling price of the agrochemical [33]. Through Directive 852/2018, of May 18, the obligations of producers of phytosanitary products and fertilizers were equated, establishing an EPR for all packaging manufacturers. Fertilizer producers must establish a DRRIS or adhere to CDRRS [57, 58]. This new regulation mandates the reuse of secondary elements (i.e., by-products) obtained from production processes. This measure aims to introduce CE principles into the packaging management standard [58].

Spain has recently reformulated its waste regulation. This can be considered the first CE regulation in Spain, and it has had a crucial influence on plastic packaging. It introduces an indirect tax on the consumption of non-recyclable plastic with a taxable base of €0.45/kg for non-reusable packaging. To reduce the regulatory barriers to the process, this law also includes a modification of the procedure for the declaration of a by-product. Autonomous communities will have the competence to evaluate and authorize the requests to take advantage of the by-products that are generated and consumed within their borders and also outside the limit of their regions when a favorable report has been submitted by the receiving autonomous community within a period of one month. It will be understood that a favorable report has been issued if a negative report has not been generated within this period. An autonomous community may request the national authorization of by-products from the Coordination Commission, and no by-product can be declared legal if it has been previously declared illegal by the Coordination Commission. The above-mentioned law also establishes the proximity principle. That is, waste must be treated in the closest treatment plant to the point where the waste was generated, and which uses the most appropriate technologies and methods for this purpose [50]. It also proposes a 15% reduction in the generation of waste in Spain by 2030, praises the EPR, and creates the possibility of establishing a Deposit, Return, and Return System to collect food packaging or an electronic waste information system to perform an analysis of the waste management and contaminated soil [50].

The Spanish government is currently updating its legislation on packaging. It has transposed Directive 852/2018, of May 18 [58] and will unify the different regulations dealing with packaging management in the national territory under the same legal text. The procedure for the management of agricultural packaging will be similar to that already in place since 2001. However, the law determines a minimum content of recycled plastic in the composition of containers (Table 1) and a system of bonuses (Table 2) to encourage the use of plastic by-products in packaging, as long as an extra 10% of the minimum required content is incorporated and the plastic used comes from packaging. In addition, it identifies the possibility of granting an additional 10% bonus if the packaging incorporates the amount and type of plastic included in its composition. It highlights that the minimum collection rate of EPRs should be 75% in 2025, 85% in 2030, and 95% in 2035 [57].

Table 2 Bonuses granted by the Government of Spain for the use of recycled plastic

Type of recycled polymer	Bonus (€/kg)
Polyethylene terephthalate (PET)	0.05
Low-density polyethylene (LDPE)	0.40
Flexible high-density polyethylene (FHDPE)	0.45
Rigid high-density polyethylene (RHDPE)	0.20
Polypropylene (PP)	0.45
Polystyrene (PS) and expanded polystyrene (EPS)	0.55

Source: own elaboration based on MITECO [57]

Initiatives for the management of agricultural packaging (fertilizer and phytosanitary products) in Spain

In Spain, initiatives for the management of agricultural packaging based on the CE principles have been in place since the beginning of the twenty-first century [59], which is facilitating the transition to a sustainable and resilient production model and making Spain one of the eight most advanced countries in the European Union in facing this transition [60].

In 2002, following the publication and enforcement of the agricultural packaging management regulations [33, 56], a CDRRS was formed: “Sigfito Agroenvases” (SIGFITO) [59], although it did not obtain all the necessary authorizations to operate nationwide until 2005 [61]. Until 2013, the operational capacity of this CDRRS was limited to collecting phytosanitary product containers. From this date forward, it obtained the necessary

Table 1 Minimum content of by-products in the composition of packaging in Spain.

Date	Objetive	
Starting in 2025	25% of the total mass of packaging placed on the market made of polyethylene terephthalate (PET)	
Starting in 2030	30% of the total mass of packaging introduced into the market	
	Specific	
	Jars, jugs, and similar articles up to 5 L capacity, including caps and lids	35% of the total mass of packaging introduced into the market
	Plastic cans, jars, tubs, trays, baskets, and other similar plastic items	15% of the total mass of packaging introduced into the market
	Plastic films used in primary packaging applications, including pouches, liners, peel-off lids or wraps	25% of the total mass of packaging introduced into the market
	Plastic films used in secondary packaging applications, such as shrink wrapping, liners, sacks, bubble wrap, envelopes	50% of the total mass of packaging introduced into the market

Source: own elaboration based on Ministry for the Ecological Transition and the Demographic challenge (MITECO) [57] accreditation to collect fertilizer containers, bio-stimulants, and nutritional products. It was also after this date that the first voluntary adhesion of manufacturers of this type of products was achieved. A second CDRRS was created in Spain in 2015: Spanish Association for the Recovery of Packaging (AEVAE) [62]. SIGFITO is the CDRRS that integrates the largest number of agrochemical manufacturers [63, 63].

Operation of the CDRRS

In 2021, 92.6% of agrochemical manufacturers were associated with the CDRRS available in Spain [63, 63]. In 2020, 11,730 tons of agricultural packaging was collected by the CDRRS (Fig. 1). The packaging was made of plastic, paper, cardboard, and metal, with plastic being the material mostly used [64]. However, the collection rate of agricultural packaging barely exceeded 60% in 2020. This parameter shows a similar level to the 2013 value. The value registered a decrease of 23.7% in the period comprised between 2013 and 2015 and slightly increased in the 2016–2020 period.

Between 2003 and 2020, SIGFITO increased the amount of packaging collected nationwide by a factor of fifteen. In 2016, the model's management capacity was increased with the creation of a new CDRRS (Fig. 1). The amount of plastic and metal agricultural packaging collected in 2021 was collected at 100% and was reintroduced into production processes for the synthesis of new plastic and metallic products. Agricultural cardboard packaging was 100% recovered for energy recovery [65]. However, uncollected agricultural packaging can be disposed of in the environment [34].

Methods

Geographic area and production models analyzed

The evaluated territory has a Useful Agricultural Area (UAA) that exceeds 23 million hectares (45.9% of the area of Spain) (Table 3). The Autonomous Communities of Andalusia, Castile-La Mancha, and Castile and Leon have UAAs exceeding 3 million hectares each (Fig. 2) [66]. The irrigated area was 3,862,811 hectares in 2021 [24].

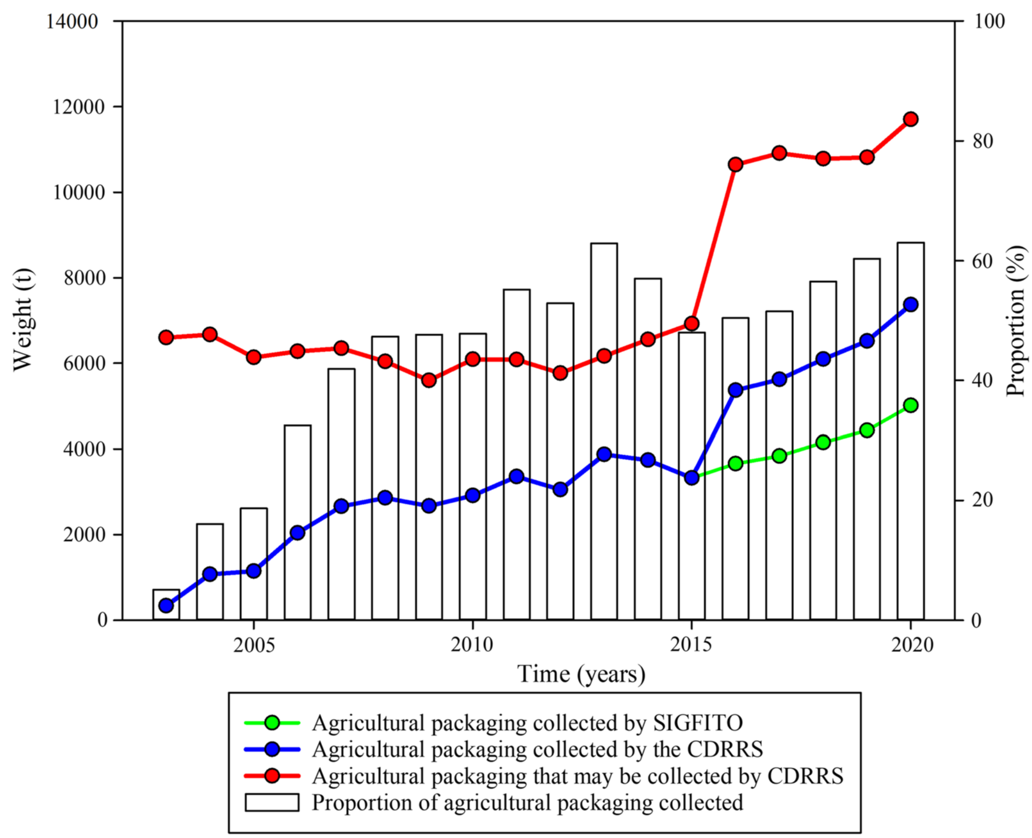

Fig. 1 Total production of agricultural packaging, agricultural packaging collected by the CDRRS, and collection rate of agricultural packaging in Spain. Source: own elaboration based on SIGFITO [65]. The value of the volume of packaging currently managed and that could be managed by the CDRRS was obtained from the collection of packaging generated by a SIGFITO member manufacturer [65] and CDRRS members [63, 65]

Table 3 Main indicators of Spanish agriculture.

Cultivated area (ha)		Consumption of agrochemicals (t)	
Useful agricultural area	23,913,682	Phytosanitary products	
Ecological surface	2,354,916	Fungicides and bactericides	37,950
Irrigated area	3,831,181	Herbicides	20,199
Greenhouse area	73,115	Insecticides and acaricides	8381
Major subsectors[a]		Growth regulators, molluscicides and others	9494
Grain cereals	6,170,885	Total, phytosanitary products	76,024
Olive groves	2,770,424	Fertilizers	
Non-citrus fruit trees	1,260,762	Total, nitrogenous	2,495,037
Fodder crops	973,161	Simple phosphates	179,992
Vineyard	957,857	Simple potassic	295,398
Industrial crops	918,754	Monoammonium and diammonium phosphates	381,592
Grain legumes	313,959	NP + NK + PK fertilizers	218,351
Citrus fruit trees	307,343	NPK fertilizers	1,556,046
Vegetables and flowers	254,402	Total, complex fertilizers	2,155,989
Tubers	48,060	Total, fertilizers	5,126,461

Source: own elaboration based on the Agrarian Census [66] and Ministry of Agriculture, Fisheries and Food (MAPA) [23, 24]

[a] Natural pastures and home gardens have been excluded from the classification

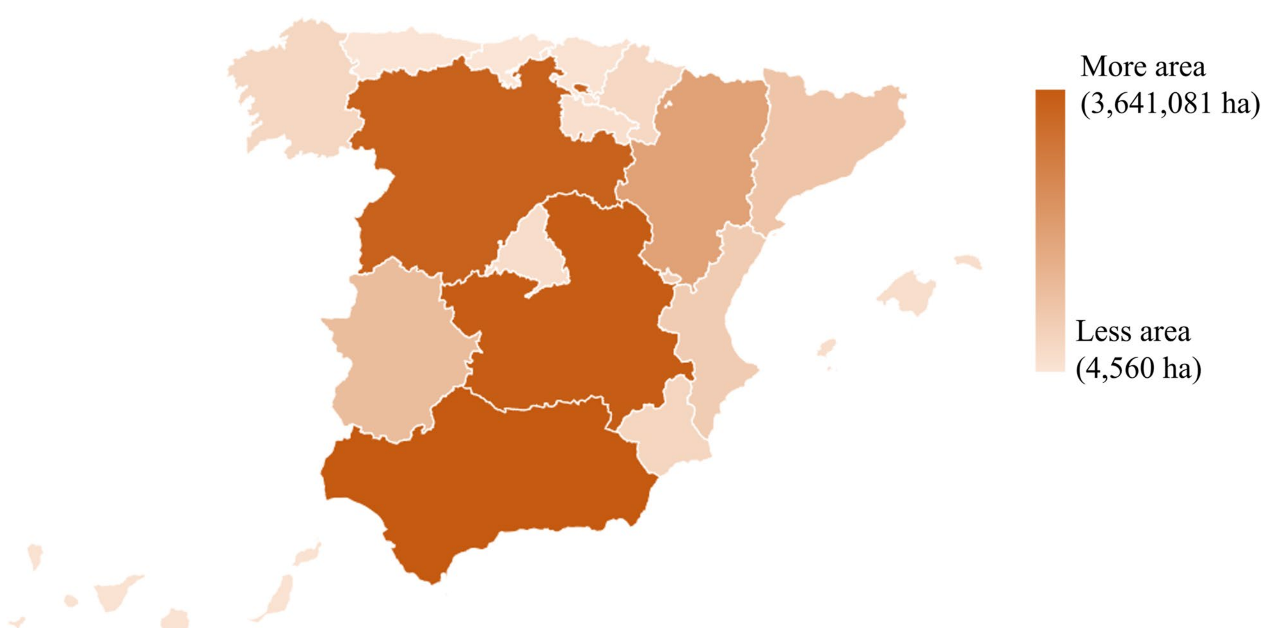

Fig. 2 Existing agricultural land in the different Autonomous Communities of Spain. Source: own elaboration based on MAPA [24]

Grains, non-citrus fruit trees, fodder crops, vineyards, industrial crops, grain legumes, citrus fruit trees, vegetables and flowers, and tubers are the principal subsectors. The national area of protected crops was 73,115 hectares in 2021 (Table 3). The autonomous communities of Andalusia, Region of Murcia, and Community of Valencia concentrate the largest area of crops under cover in the whole nation. The province of Almeria accounts for almost half of Spain's greenhouse area [24].

Analysis of the information

During the research process of this study, we carried out a compilation, classification, verification, and in-depth analysis of information from different sources.

These included studies, technical reports, regulations, and official statistics from different public and private organizations related to the management of agricultural packaging in Spain. A telephone consultation, which consisted of a closed questionnaire, was made with the departments in charge of managing the data used to verify the information and statistics obtained. This procedure has already been used in other research in the field of agriculture [14, 16].

Data source and processing

Relationship 1

To establish the relationship between agricultural packaging delivered (t) (fertilizer and phytosanitary products), types of agricultural systems (ha), and the ten main agricultural subsectors (ha; Table 3), a review and analysis of the information published by MAPA [67] and SIGFITO [65] was carried out. The existing data series from the Autonomous Communities dating from 2015 to 2020 was used. This set of values was the complete data series for the 17 autonomous communities in Spain.

Relationship 2

Data from the Energy Information Administration (EIA) [68] and SIGFITO [65] were obtained for the period comprised between 2003 and 2020 to establish the relationship between the price of a barrel of Brent oil ($/barrel), the collection rate of agricultural packaging (%) (fertilizer and phytosanitary products), and recycling of agricultural plastic packaging (t/container) (fertilizer and phytosanitary products). The complete data series was used for all the variables studied in relationship 2. In this case, the analysis could be expanded from 2003 to 2020, in contrast to relationship 1. To avoid the influence of the increment in number of containers on the increase in container recycling, the parameter "recycling per container" was used. After obtaining the Brent price of a barrel of crude oil (C), the annual average value was calculated with a monthly time lag from t − 12 to t + 12, using the same procedure reported by other authors [16]:

$$\overline{C_{t-n}} = \frac{\sum_t^n C}{12}, \quad (1)$$

$$\overline{C_{t+n}} = \frac{\sum_t^n C}{12}, \quad (2)$$

where $\bar{C}$: average price of a barrel of crude oil($/barrel)' t: time (months), n: number of months of lag time ($-12 \leq t \leq 12$).

Cost structure of greenhouse operations

Data source A lack of information regarding the plastic waste generated, mainly from plastic containers, was detected in subsectors with a wide scope in Spanish agriculture that made it impossible to calculate its economic impact on some crops, such as grains, olive groves, non-citrus fruit trees, fodder crops, vineyards, industrial crops, grain legumes, citrus fruit trees, and tubers. Only the greenhouse crop subsector showed information about the generation of plastic waste in agrochemical containers [16, 48, 70–72]. Therefore, the analysis was carried out only in this sector.

Production costs were obtained from those reported by Honore et al. [53] and Castillo-Díaz et al. [52] for eggplant, zucchini, green bean, melon, cucumber, bell pepper, watermelon, and tomato crops, each being primary in the Almeria Model [73]. The number of containers, mulching requirements, trellising elements, and the cost of TS were obtained from values reported by Ufarte [70], Ufarte [48], García [71], García [72], Sayadi-Gmada et al. [69] and Castillo-Díaz et al. [16].

Cost structure The cost structure used follows the configuration applied by the Experimental Farm "Catedrático Eduardo Fernández" of the Experimental Foundation UAL-ANECOOP. The values provided have been updated annually under the general national index ECOICOP (European Classification of Individual Consumption by Purpose).

The production costs were obtained from "Raspa y Amagado" type greenhouses with a height of 4.50, 3.50 and 3.00 m, respectively. This structure is the typical one in the Almeria Model [74].

The variable operating costs comprised the following items: technical advice preparation, soil preparation, agricultural biomass management, seeds and production services, cover and structure inputs, and labor and production inputs. They were obtained from the methodologies described by Honore et al. [53] and Castillo-Díaz et al. [52]. However, some additional sub-concepts were incorporated, such as fertilizer and phytosanitary containers, bonuses for the reuse of plastic by-products from fertilizer and phytosanitary containers, taxes for non-reusable plastic from fertilizer and phytosanitary containers, trellising raffia, trellising clips, and subsidies for non-biodegradable plastic.

The fixed costs reflected in the analysis were soil maintenance (sanding), cover and structure, energy and fixed supplies, insurance, management and financial services, and equipment and irrigation system. These were obtained from the methodologies described by Honore et al. [53] and Castillo-Díaz et al. [52]. Finally, the variable and fixed cost items were added to obtain the total cost:

$$TC = VC + FC, \quad (3)$$

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

Alternatives evaluated Three alternatives were evaluated in this work (Table 4) to determine the impact of the new actions proposed by the administrations:

- Alternative 1: conventional farming system.
- Alternative 2: the effect of the tax on non-reusable plastic from packaging, the lower price of recycled plastic by-products on the conventional cultivation system, and the bonus for the use of plastic by-products from packaging are applied. It was assumed that the costs incurred by packaging manufacturers were passed on to farmers through the value chain and that packaging comprised 90% plastic by-products and 10% virgin material. The tax on non-reusable plastic was calculated using the following mathematical expression:

$$W = Y \cdot TI \cdot \left(1 - \frac{CCR}{100}\right), \quad (4)$$

  where W: consumption tax on non-recyclable plastics for packaging (€/ha·year), Y: amount of packaging generated (kg/ha), TI: taxable amount (€/kg), CCR: national packaging collection rate (%)
- Alternative 3: the effect of the use and bonuses for using biodegradable plastics in trellising and mulching inputs, as well as a TS on the expense account of alternative 2 are applied. The subsidies utilized are those proposed by the Government of Spain for the use of raffia and biodegradable plastic in the operational programs of the Fruit and Vegetable Producers Organizations (FVPOs). These subsidize 50% and 66% of biodegradable plastics and biodegradable raffias, respectively [76–77].

Table 4 Alternatives evaluated in the economic analysis

Alternative	System
1	Conventional system
2	Alternative 1 + tax − decrease in the cost of production of agricultural packaging (fertilizer and phytosanitary products)
3	Alternative 2 + biodegradable plastics in raffia, rings and mulching + TS − subsidy to biodegradable plastics

Source: own elaboration

[a] The sign indicates the effect on the expense account

Statistical treatment

The coefficient of determination (R^2) with the F-test was used to evaluate the first relationship between the area by crop type (ha) and the area of the ten main subsectors (ha). The 2015–2020 series were employed with a total number of values (n) of 85. Pearson's coefficient (r) with the F-test was applied to evaluate the relationships between Brent oil barrel price ($/barrel), collection rate (%), and amount of plastic waste recycled (t/container). The 2003–2020 series were used for the first relationship, and also the 2013–2020 ones with n of 18 and 8, respectively. The IBM SPSS Statistics v.27 statistical package was used to evaluate the relationships between the variables.

Results and discussion

Relationship 1: agricultural packaging, types of farming systems, and subsectors

Our results suggest the existence of directly proportional relationships between the amount of agricultural packaging delivered (fertilizer and phytosanitary products), the types of agricultural systems, the irrigation regime, and the agricultural subsectors (Fig. 3). A low relationship ($R^2 = 0.2541$) was observed between total cropland and the amount of agricultural packaging delivered by the autonomous communities. The relationship increased when the number of agricultural containers was related to the types of agricultural systems implemented in the different territories. Irrigated agriculture ($R^2 = 0.8523$) or agriculture under greenhouses ($R^2 = 0.7205$) registered a high relationship with the amount of agricultural packaging delivered to the CDRRS, while agriculture under rainfed systems reported the lowest relationship ($R^2 = 0.1641$). The degree of intensification shown by crops grown in irrigated or greenhouse systems is usually higher, which leads to stronger demand for agricultural inputs and containers [23, 78]. The use of irrigation systems facilitates the addition of fertilizers to crops [79] and can increase the demand for these products [23, 78]. However, agrochemicals are also used in rainfed crops to alleviate pests, diseases, and weeds that affect farms [80]. The ratio obtained in this work between the amount of agricultural containers delivered and the area under rainfed regime is very low. This behavior could be due to greater waste dumping, the use of inputs in larger capacity purchasing units (e.g., fertilizers) or the use of fertilizer by-products in bulk as organic amendments.

The factor "subsector" also showed a direct relationship with the amount of agricultural packaging delivered (Fig. 4). Olive groves, non-citrus fruit crops, industrial crops, and vegetables and flowers showed the highest relationship with the amount of agricultural packaging

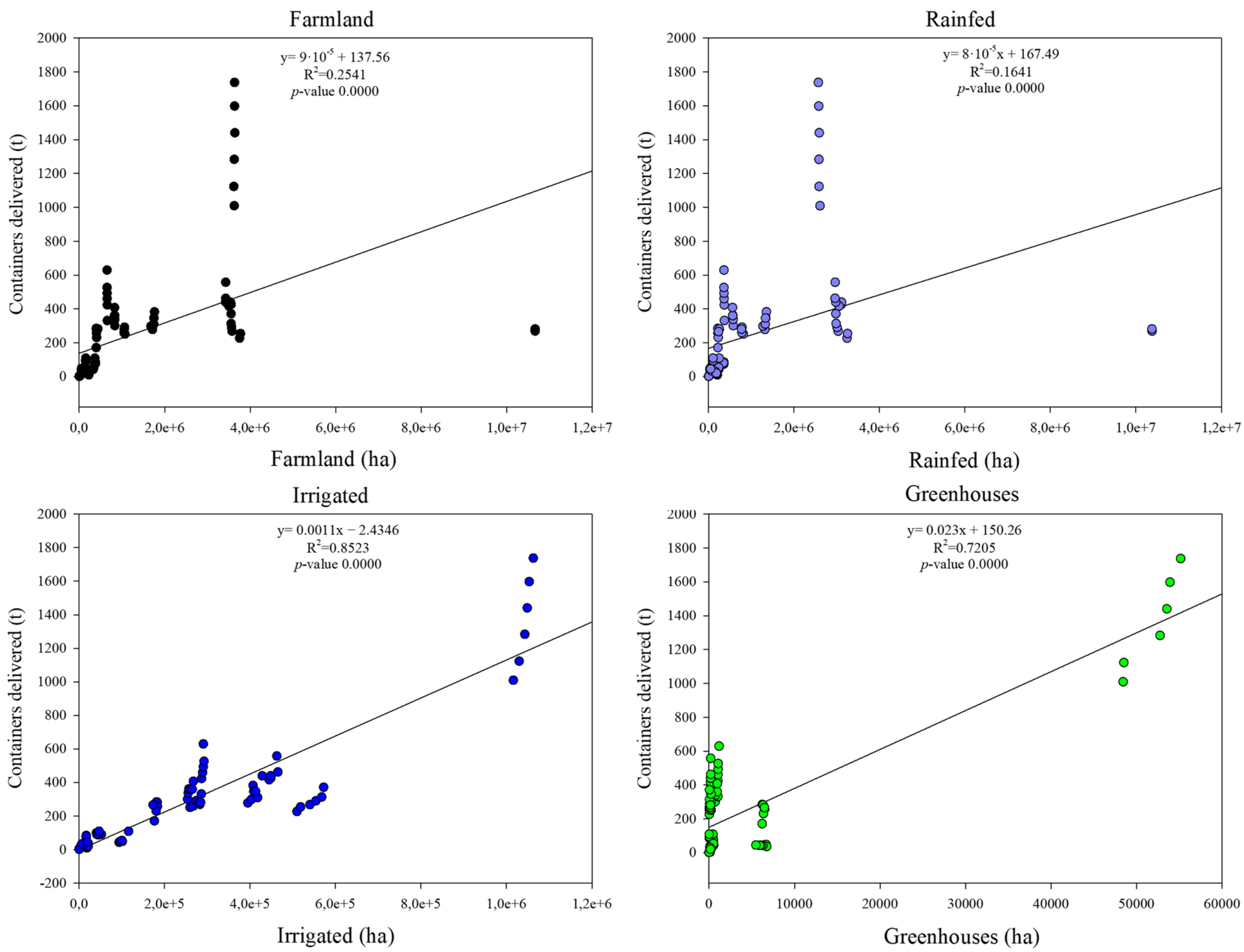

Fig. 3 Relationship between the amount of agricultural packaging delivered by the Autonomous Communities, the total cultivated area, and the different farming systems (rainfed, irrigated, and greenhouse) ($n=85$). Source: own elaboration based on MAPA [67] and SIGFITO [65]

delivered. These crops are usually located in autonomous communities such as Andalusia, which also has a high rate of irrigated crops [23, 24]. In 2021, some autonomous communities, such as Catalonia and the Valencian Community, delivered more containers than Castile-La Mancha. These communities show a higher irrigation rate than Castile-La Mancha (44.4% and 32.2% versus 16.1%) [24], and that is why the crops grown in these territories demand larger amounts of agrochemicals [23]. In addition, it seems that the concentration in relationship between the number of containers managed by the Autonomous Communities, the total cultivated area has a greater influence than the degree of intensification for the generation of agricultural packaging. The "olive grove" subsector reported a higher ratio than those in the "vegetables and flowers" one. The former exceeds the cultivated area of the la er by more than six times, while the la er includes cultivation systems with a high degree of intensification, such as greenhouse agriculture [23].

Relationship 2: price of a barrel of Brent oil, collection rate of agricultural packaging, recycling of agricultural plastic packaging

Results suggest the existence of a directly proportional relationship between the Brent oil price, the container collection rate of agricultural packaging, and the amount of agricultural plastic packaging recycled per container (Fig. 5). The direct influence of the price of a barrel of oil on the plastic management system is similar to that reported by other authors [16].

In our case, different behavior is observed between the two correlations. Regarding the collection rate, the high oil price during the months prior to the end of the annual collection period for agricultural packaging increased the collection rate. On the other hand, a strong relationship exists between the current price of oil and the number of containers recycled per collection point. The high value of the raw material could

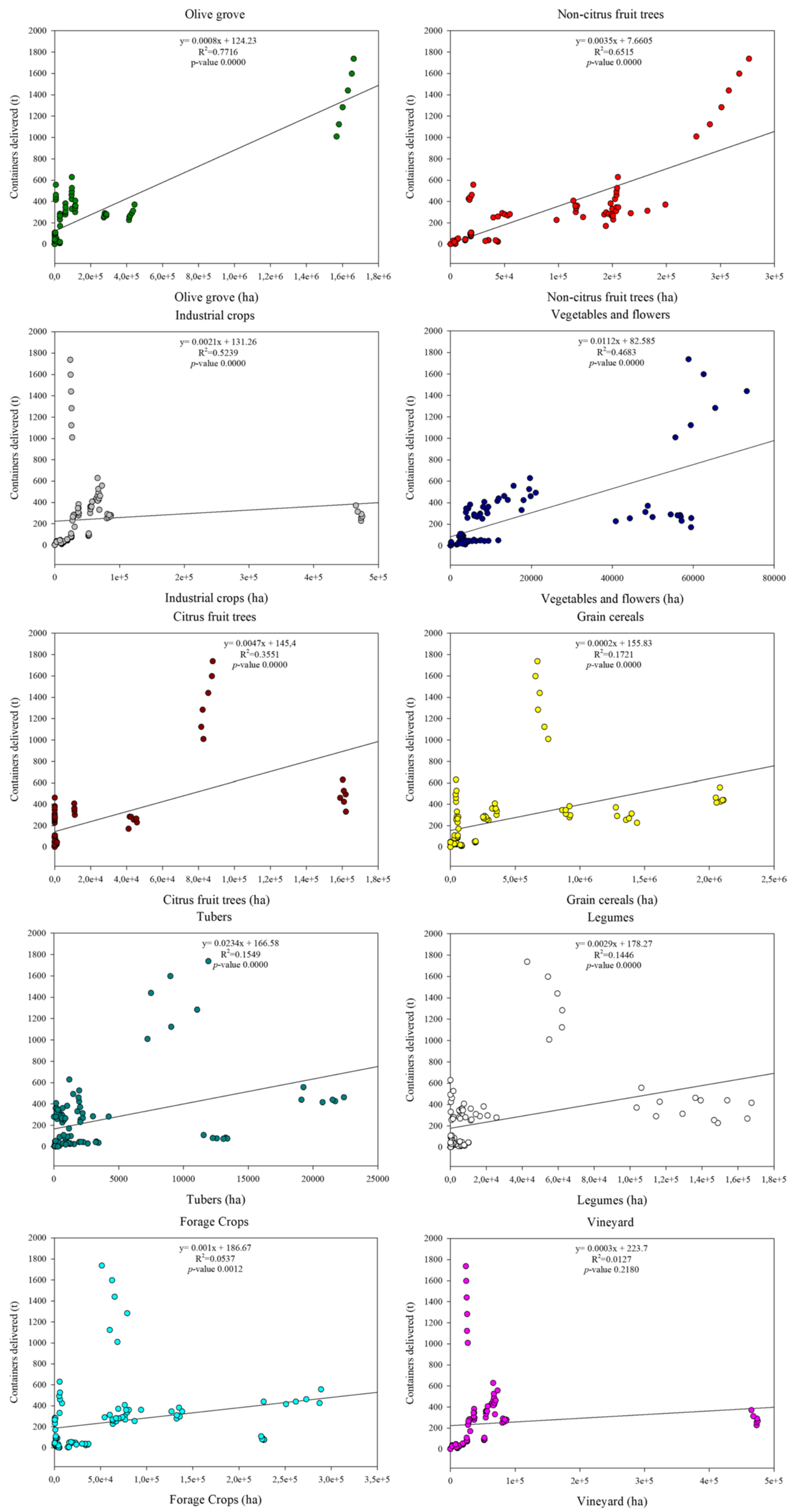

Fig. 4 Relationship between the amount of agricultural packaging delivered by the Autonomous Communities and the cultivated area of different subsectors. Source: own elaboration based on MAPA [67] and SIGFITO [65]

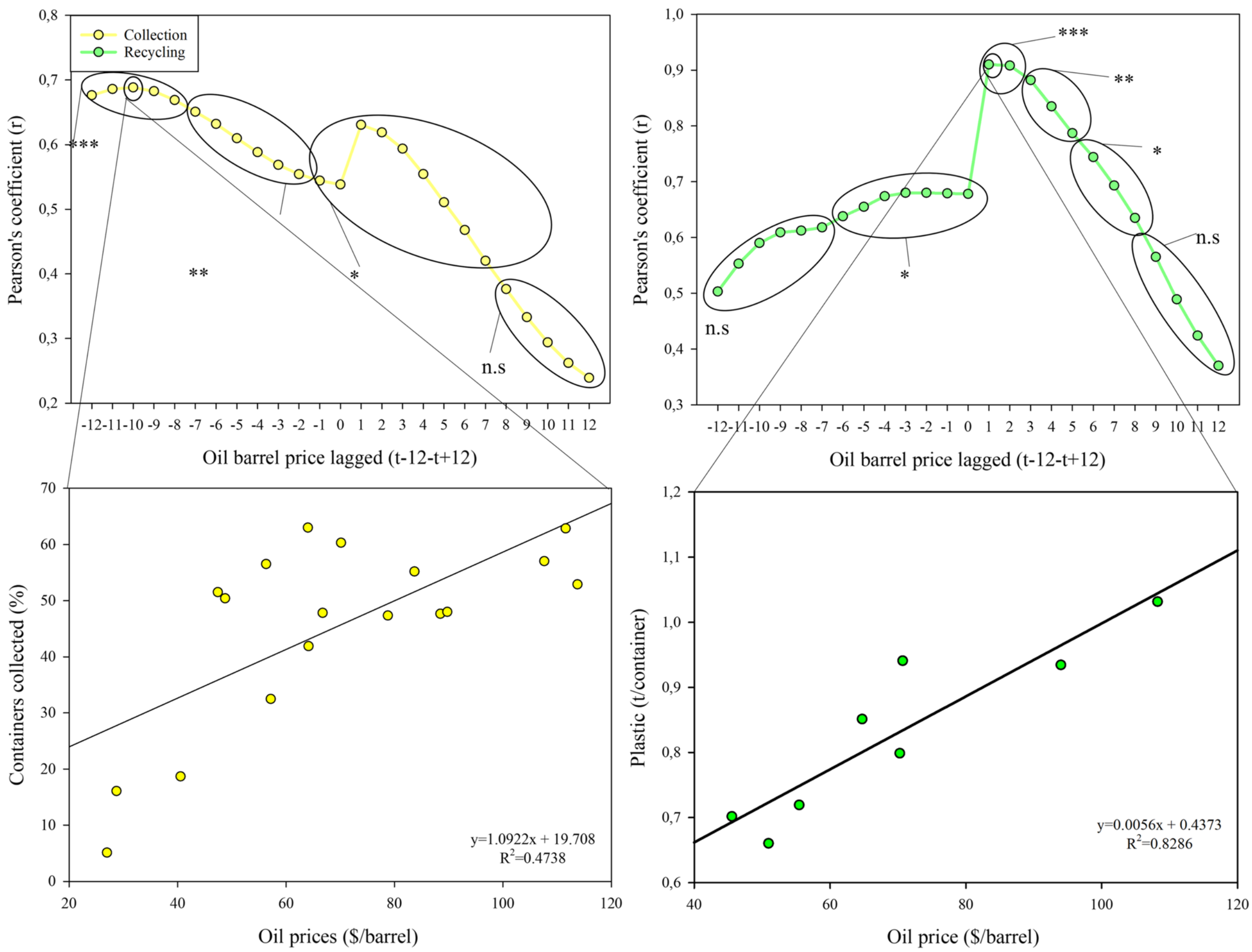

Fig. 5 Relationship between the price of a barrel of Brent crude oil, the collection rate of agricultural packaging ($n=18$), and agricultural plastic packaging recycled per container ($n=8$). *, **, *** significance at 95%, 99% and 99.9% confidence level; n.s: no significant differences. Source: own elaboration based on SIGFITO [65] and EIA [68]

lead to an expansion of the demand for by-products from the plastic manufacturing industry [81].

The results of our research suggest that the price of a barrel of oil can act as a barrier for recycled by-products in months when the price of oil is low (Fig. 5). The recycled feedstock has a lower market price than virgin material [82]. However, the high volatility in the price of oil can lead to substantial decreases in the price of raw material [84–85] resulting in reduced demand for recycled plastic by-products due to the higher profitability of virgin material [16, 81]. Lower demand for additives to obtain quality similar to the traditional product [86, 87] also affects the achievement of the environmental objectives proposed in the 2030 Agenda.

Effect of sustainability policies on Spanish farmers' expense account

Table 5 shows the variable, fixed, and total production costs of the species grown under greenhouse in Almeria. The conventional production model (A1) shows total production costs of 53,734.3 €/ha. Variable costs, specifically labor and inputs sub-item, make up the highest operating costs.

Alternatives 2 and 3 were impacted by the measures proposed by the administrations. The initiatives affect variable production costs (Table 5). Actions related to agricultural packaging of fertilizer and phytosanitary products (non-reusable plastic tax, bonus for the consumption of by-products, and packaging composed of by-products) have a 0.03% influence on expense accounts. It would cost farmers 0.02% more if manufacturers did not pass on the bonus and the lower production costs of

Table 5 Variation in greenhouse crop expenses due to CE policies

	A1 (€/ha·year)	A2 (€/ha·year)	ΔA2 (%)	A3 (€/ha·year)	ΔA2 (%)
Total variable cost (€)	42,485.4 ± 14,369.9	42,471.8 ± 14,369.9	− 0,04 ± 0.01	44,511.1 ± 14,369.9	5.35 ± 2.04
1. Technical assessment (€)	176.9 ± 0.0	176.9 ± 0.0	0.00 ± 0.00	176.9 ± 0.0	0.00 ± 0.00
2. Soil preparation (€)	5080.2 ± 0.0	5080.2 ± 0.0	0.00 ± 0.00	5080.2 ± 0.0	0.00 ± 0.00
3. Plant waste removal	1150.5 ± 0.0	1.1505 ± 0.0	0.00 ± 0.00	1,150.5 ± 0.0	0.00 ± 0.00
4. Cover, structure and cultivation inputs	2716.7 ± 0.0	2716.7 ± 0.0	0.00 ± 0.00	4088.1 ± 0.0	50.48 ± 0.00
4.1. Plastic *mulching*	950.1 ± 0.0	950.1 ± 0.0	0.00 ± 0.00	4643.1 ± 0.0	388.70 ± 0.00
4.2. Subsidy for biodegradable plastic *mulching*	0.0 ± 0.0	0.0 ± 0.0	–	2,321.5 ± 0.0	–
4.3. Remaining cover, structure and cultivation inputs	1766.6 ± 0.0	1766.6 ± 0.0	0.00 ± 0.00	1766.6 ± 0.0	0.00 ± 0.00
5. Seeds and seedling production	3645.5 ± 2482.8	3645.5 ± 2482.8	0.00 ± 0.00	3645.5 ± 2482.8	0.00 ± 0.00
6. Labor and production inputs	29,715.7 ± 12,430.6	29,702.0 ± 12,430.6	− 0.06 ± 0.03	30,369.9 ± 12,430.6	2.74 ± 1.59
6.1. Phytosanitary products packaging	83.5 ± 0.0	78.1 ± 0.0	− 6.46 ± 0.00	78.1 ± 0.0	− 6.46 ± 0.00
6.2. Bonus for reusable plastic in phytosanitary containers	0.0 ± 0.0	9.7 ± 0.0	–	9.7 ± 0.0	–
6.3. Tax on non-reusable plastic in phytosanitary containers	0.0 ± 0.0	6.7 ± 0.0	–	6.7 ± 0.0	–
6.4. Fertilizers packaging	30.4 ± 0.0	24.9 ± 0.0	− 18.05 ± 0.00	24.9 ± 0.0	− 18.05 ± 0.00
6.5. Bonus for reusable plastics in fertilizer containers	0.0 ± 0.0	2.3 ± 0.0	–	2.3 ± 0.0	–
6.6. Tax on non- reusable plastics in fertilizer containers	0.0 ± 0.0	2.4 ± 0.0	–	2.4 ± 0.0	–
6.7. Trellising raffia	121.8 ± 0.0	121.8 ± 0.0	0.00 ± 0.00	546.2 ± 0.0	348.48 ± 0.00
6.8. Subsidy for biodegradable plastic in raffia	0.0 ± 0.0	0.0 ± 0.0	–	360.5 ± 0.0	–
6.9. Trellising clips	145.9 ± 0.0	145.9 ± 0.0	0.00 ± 0.00	643.8 ± 0.0	341.18 ± 0.00
6.10. Subsidy for biodegradable plastic in rings	0.0 ± 0.0	0.0 ± 0.0	–	321.9 ± 0.0	–
6.11. TS for plastic spills	0.0 ± 0.0	0.0 ± 0.0	–	428.0 ± 0.0	–
6.11. Remaining labor and supplies	29,334.1 ± 12,430.6	29,334.1 ± 12,430.6	0.00 ± 0.00	29,334.1 ± 12,430.6	0.00 ± 0.00
Total fixed costs	11,248.8 ± 0.6	11,248.8 ± 0.6	0.00 ± 0.00	11,248.8 ± 0.6	0.00 ± 0.00
7. Soil maintenance	1178.8 ± 0.1	1178.8 ± 0.1	0.00 ± 0.00	1178.8 ± 0.1	0.00 ± 0.00
8. Covering and structure	2359.1 ± 0.1	2359.1 ± 0.1	0.00 ± 0.00	2359.1 ± 0.1	0.00 ± 0.00
9. Energy and fixed supplies	931.7 ± 0.0	931.7 ± 0.0	0.00 ± 0.00	931.7 ± 0.0	0.00 ± 0.00
10. Insurance, management and financial services	2051.6 ± 0.1	2051.6 ± 0.1	0.00 ± 0.00	2051.6 ± 0.1	0.00 ± 0.00
11. Equipment and irrigation system	4727.6 ± 0.3	4727.6 ± 0.3	0.00 ± 0.00	4727.6 ± 0.3	0.00 ± 0.00
Total expenses	53,734.3 ± 14,369.8	53,720.6 ± 14,369.8	− 0.03 ± 0.01	55,759.9 ± 14,369.8	4.03 ± 1.16[a]

Source: own elaboration based on Honore et al. [53], Sayadi-Gmada et al. [69], Castillo-Díaz et al. [52], Castillo-Díaz et al. [16], Ufarte [70], Ufarte [48], García [71] and García [72]

A1: conventional system; A2: Alternative 1 + tax − bonus − decrease in the cost of packaging production; A3: Alternative 2 + biodegradable plastics in raffia, rings and mulching − subsidy for biodegradable plastic. ΔA expresses the percentage increase with respect to alternative 1

[a] An increase in production costs of 0.02% arises if items 6.2 and 6.5 are deducted during the economic analysis performed in A2

[b] An increase in production costs of 9.80 arises if items 4.2, 6.8 and 6.10 are deducted during the economic analysis performed in A3

by-product reuse within the framework of the CE along the supply chain.

The use of biodegradable plastic negatively affects producer profits and losses (Table 5). These materials can increase production costs by up to 4.03%. Costs will increase up to 9.80% for producers who do not benefit from the subsidies granted by the Spanish Government through the FVPOs operational programs [76, 77]. The current measures proposed by the administrations do not cover the higher price of alternative inputs and do not encourage their consumption.

The price of inputs made with biodegradable polymers increases the expenditure on conventional material by 341.18%, 348.48%, and 388.70% for trellising clips, trellising raffia, and mulching, respectively (Table 5). The TS increases production costs by 428.0 €/ha, which may negatively influence the willingness to incorporate new materials and technologies. In addition, the economic losses that farmers suffer on a yearly basis are an entry barrier. The economic margin has decreased in recent decades due to stability in the prices at origin and a rise in production costs, a situation aggravated by the inflation rate [88].

The results of this study show that the initiatives to comply with the 2030 Agenda and the CE framework regarding agricultural plastic influence the upward trend in production costs. However, the use of biodegradable plastic in techniques such as mulching or trellising of plants allows for the expansion of environmental sustainability by reducing the amount of petrochemical plastics used in agriculture, a measure within the framework of the EC. In addition, inputs such as mulch, raffia or plastic rings hinder the management of agricultural biomass in greenhouse systems as they are mixed with the plant by-product [16, 89, 90]. Protected agriculture offers high productivity per unit area and increases the wealth and employment of the territories where this type of agricultural activity is developed. Covered agriculture in the province of Almeria (Spain) exports 80% of the goods obtained to Central and Northern Europe in the winter months and obtains an income of 2300 million euros, which helps to maintain the food security of the European Union and the socioeconomic development of the Almeria territory [73]. Although both the European territory and its inhabitants demand the implementation of sustainable food production, the implementation of biodegradable materials and other initiatives to reduce the negative externalities of petrochemical plastic is urgent [41]. Therefore, the proliferation of measures that help to mitigate the economic impact of the evaluated alternatives on producer cost accounts should be favored.

Initiatives and suggestions to improve the management of agricultural packaging and plastics in Spain

The influence of the cultivated area, the type of farming system, the irrigation regime, and the agricultural subsector on container collection highlights the need for these to be counted as variables when defining new waste management plans for agriculture (Figs. 3 and 4). For the first time, the Spanish government included a specific chapter on agricultural waste in the State Framework Plan for Waste Management to offer a global view of the problem [46]. Future revisions should identify measures adjusted according to the cultivated area and degree of intensification of agricultural systems to reduce technical and legislative barriers. The seasonal production of agricultural waste suggests treating a high amount of waste in a short time [17, 46]. Regulations should grant special permits to transport waste between nearby areas and extend the opening hours of waste treatment centers. Also, they should increase the number of management plants or collection centers, identify the pretreatment needs of treatment centers, which may vary between managers depending on the regulatory framework, and increase the training of farmers who must apply regulations possibly unknown to them [16, 17, 69].

The system of bonuses proposed by Spain for the use of plastic packaging by-products does not consider the volatility of the price of its raw material (i.e., the price of a barrel of crude oil) as a variable to adjust the amount of the bonus. On the contrary, it establishes a fixed rate system. The relationship observed in Fig. 5 highlights the need to establish a variable rate bonus system, which could avoid possibly severe changes in the demand for recycled plastic by-products. This way, adherence with the ecological transformation proposed by the European Union in its economic model to comply with the 2030 Agenda could be ensured, reducing the consumption of a non-renewable input whose use leads to various environmental impacts on marine and terrestrial ecosystems and the fauna and flora that inhabit them [91].

There are some loopholes in the new regulations proposed to manage packaging that may lead to incorrect or non-application of the incentive system [57]. The bonus system depends on the type and quantity of polymer used in each container. However, it is optional to indicate the polymer composition of the containers, and this action is rewarded with an extra bonus of 10% [57]. The feasibility of the bonus system depends solely and exclusively on knowing the precise polymer composition of each input. Identification of the quantity and type of polymer used on the packaging should be mandatory.

The transfer of competences regarding the declaration of by-products to autonomous communities can lead to a heterogeneous authorization of certain by-products in the national territory, despite the fact that a coordination commission was proposed for its control [50]. This can lead certain autonomous territories to use by-products with high polluting potential, which will affect the environment as long as the coordination commission does not prohibit their use. In previous decades, the transfer of environmental competences to the autonomous communities has resulted in heterogeneous environmental regulations, which provided competitive advantages for certain polluting industries in some autonomous communities [92, 93]. Therefore, the national administration should be the one to authorize the declaration of by-products.

The economic analysis performed in this research suggests that using biodegradable polymers and a single TS increases production costs. This trend continues even after applying the subsidies proposed by the Spanish government through the FVPOs operational programs [16, 76, 77]. The administration should increase the aid structure by an amount that promotes similar costs than those of the conventional alternative (Table 5). Table 6 shows the amount of aid, which should be expressed as a percentage of the purchase invoice (alternative 2) to avoid

Table 6 Amount of aid for biodegradable plastic

Element	Alternative 1	Alternative 2
	Amount of aid (€/ha·year)	**Minimum amount of aid (percentage of the purchase invoice)[a]**
Trellising raffia	424.4	78.0
Trellising rings	497.9	77.0
Mulching	3693.0	80.0

Source: own elaboration based on Castillo-Díaz et al. [16]

[a] The value was calculated via the difference between the market price of conventional material and the market price of biodegradable material. Finally, it has been expressed as a percentage by taking the price increase as the numerator and the market price of the biodegradable material as the denominator

the possible effects of inflation [88]. It should be granted to all producers. The minimum amount of aid should be accompanied by a 10% bonus to encourage the use of biodegradable plastics to entice producers to make multiyear commitments, considering the recent emergence of the these plastic products [70, 71] and the possible lack of awareness about them.

In turn, the administration should regulate that producers who engage in bad practices (dumping, burning, or burying plastic) must cover the cost of the single TS. The sanctioning regime of the regulations should be designed for this purpose. This would prevent the economic impact of the cost of the TS on farmers who behave in an exemplary manner. In addition, this system should be modulated according to the specific needs of each agricultural subsector since the TS evaluated in this work is customized to the requirements of greenhouse agriculture, whose needs increase the administrative cost of the system [48] and may make it unfeasible for other subsectors such as grain cereals or forage crops with low incomes [94].

Conclusions

In Spain, the cultivated area, the type of agricultural system, the irrigation regime, and the agricultural subsector influence the management of agricultural packaging. However, these variables are not taken into account when elaborating regulatory proposals and action plans, which are currently based on the EC. Spanish administrations should modulate regulations according to the specific needs of the existing agricultural systems in Spain to favor the reduction of the negative externalities of plastic in the framework of the EC and make agriculture an environmentally neutral activity. The importance of the agriculture sector in the Spanish territory makes it necessary to create a specific regulatory framework in this area for primary production to meet the objectives proposed in the 2030 Agenda with the green transition proposed by the European Union based on the EC.

New regulatory reformulations try to promote relevant measures, although the design of some of them does not seem to be the optimal solution. The influence of the oil price on the by-product utilization system calls for establishing a system of bonuses at a variable rate instead of a fixed rate, using the price of the raw material as the adjustment parameter due to the volatile and unpredictable nature of oil price variations. Mandating the identification of the polymer composition of packaging should also be considered to ensure the correct functioning of the bonus system. The imperfections offered in the new Spanish regulations may compromise Spain's leading position in the EU's green and circular transition, jeopardizing decades of efforts to reduce the negative externalities caused by plastics from agrochemical packaging and other agricultural plastics.

The transfer of powers to autonomous communities to authorize the use of by-products within their borders could result in heterogeneous approval of materials among the different autonomous territories. The Coordination Commission should have all the competencies for the authorization of by-products to avoid adverse effects on the environment. The EC's change in regulations should not relax the mechanisms for preventing environmental impacts, but rather increase them.

The economic analysis conducted in this work reveals that the initiatives that the administrations are promoting to expand the sustainability of agricultural systems, such as the use biodegradable plastic or the TS, increase farmer production costs, continuing with the upward trend observed in their expense account in recent years. The application of the measures identified in this work is urgent in order to match the environmental sustainability of agricultural systems with their high economic and social viability, as they allow a reduction in the negative externalities of petrochemical plastic in crop models that demand a large amount of plastic, such as greenhouse agriculture, but at the same time help to sustain the food security of international territories. This will increase the long-term sustainability of agricultural models with measures based on the EC framework. The current support system is unable to match the high production costs of the conventional alternative. Therefore, aid coefficients should be increased to 80% of the purchase invoice to promote the introduction of biodegradable plastic and reduce petrochemical plastic within the framework of the EC. In addition, to soften the economic impact of the TS, its economic costs should be obtained from the sanctioning regime of the waste regulations and through the producers who carry out bad practices (burning, burying, or dumping of waste).

Abbreviations
AEVAE: Spanish Association for the Recovery of Packaging; CDRRS: Collective deposit, return and refund systems; CE: Circular economy; DRRIS: Deposit, return and individual return systems; ECOICOP: European Classification of Individual Consumption by Purpose; EIA: Energy Information Administration; EPR: Extended producer responsibility regime; FVPOs: Fruit and Vegetable Producers Organizations; GVA: Gross value added; MAPA: Ministry of Agriculture, Fisheries and Food; MITECO: Ministry for the Ecological Transition and the Demographic challenge; TS: Traceability system; UAA: Useful agricultural area.

Author contributions
Conceptualization, FJC-D, AB-F, LJB-U and FC-F; data collection, FJC-D; formal analysis, FJC-D, AB-F, LJB-U and FC-F; methodology, FJC-D, AB-F, LJB-U and FC-F; Software, FJC-D; validation, FJC-D, AB-F, LJB-U and FC-F; investigation, FJC-D, AB-F, LJB-U and FC-F; resources, FC-F; writing—original draft preparation, FJC-D; writing—review and editing, FJC-D, AB-F, LJB-U and FC-F; visualization, FJC-D; supervision, FJC-D, AB-F, LJB-U and FC-F. All authors have read and approved the final manuscript.

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The authors declare no competing interests.

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References
1. FAO, IFAD (2019) United Nations Decade of Family Farming 2019–2028. Global Action Plan. Food and Agriculture Organization of the United Nations and IFAD, Rome
2. Maudos J, Salamanca J (2022) Observatorio sobre el sector agroalimentario español en el contexto europeo. Informe 2021. Cajamar, Almería
3. Maudos J, Salamanca J, Ballesteros M, Miravalles B (2019) Observatorio sobre el sector agroalimentario de las regiones españolas. Informe 2019. Cajamar, Almería
4. MITECO (2021) La España Vacía. https://datos.gob.es/es/aplicaciones/la-espana-vacia. Accessed 13 Feb 2022
5. WHO, UN (2019) An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. World Health Organization and United Nations, Rome
6. FAO (2019) Background notes on sustainable productive and resilient agro-food systems. Food and Agriculture Organization of the United Nations and IFAD, Rome
7. Herrera-franco G, Carrion-Mero P, Montalvan-Burbano N et al (2022) Bibliometric analysis of groundwater's life cycle assessment research. Water 14:1082. https://doi.org/10.3390/w14071082
8. Hecht SB (1999) Agroecología: bases científicas para una agricultura sustentable. In: Altieri M (ed) Agroecología: bases científicas para una agricultura sustentable. Nordan-Com, Montevideo, pp 15–30
9. Gómez-Tenorio MÁ, Magdaleno-González J, Tello-Marquina JC (2021) Evaluación e implementación de técnicas regenerativas para la mejora de la fertilidad en el cultivo del almendro en las provincias de Almería y Granada. Editorial Teniagrícola, Madrid
10. Jacobs AA, Evans RS, Allison JK et al (2022) Soil & tillage research cover crops and no-tillage reduce crop production costs and soil loss, compensating for lack of short-term soil quality improvement in a maize and soybean production system. Soil Tillage Res 218:105310. https://doi.org/10.1016/j.still.2021.105310
11. European Union (2019) Audit preview. Biodiversity in farming. Publications Office of the European Union, Brussels
12. Dhaoui O, Antunes I, Agoubi B, Kharroubi A (2022) Integration of water contamination indicators and vulnerability indices on groundwater management in Menzel Habib area, south-eastern Tunisia. Environ Res 205:112491. https://doi.org/10.1016/j.envres.2021.112491
13. Junta de Andalucía (2018) Seis millones para retirar plásticos de invernaderos abandonados. http://www.juntadeandalucia.es/presidencia/portavoz/tierraymar/136538/JuntadeAndalucia/ConsejeriadeAgricultura/Invernaderos. Accessed 1 May 2021
14. Duque-Acevedo M, Belmonte-Ureña LJ, Plaza-Úbeda JA, Camacho-Ferre F (2020) The management of agricultural waste biomass in the framework of circular economy and bioeconomy: an opportunity for greenhouse agriculture in Southeast Spain. Agronomy 10:489. https://doi.org/10.3390/agronomy10040489
15. Región de Murcia (2019) Decreto-Ley 2/2019 de 26 de Diciembre, de Protección Integral del Mar Menor. Bol Ofic la Región Murc 298:36008–36089
16. Castillo-Díaz FJ, Belmonte-Ureña LJ, Camacho-Ferre F, Tello-Marquina JC (2021) The management of agriculture plastic waste in the framework of circular economy. Case of the Almeria Greenhouse (Spain). Int J Environ Res Public Health 18(22):12042. https://doi.org/10.3390/ijerph182212042
17. Junta de Andalucía (2016) Líneas de actuación en materia de gestión de restos vegetales en la horticultura de Andalucía. Consejería Agricultura, Ganadería Pesca y Desarrollo Sostenible de la Junta Andalucía, Sevilla
18. Sigfito (2006) Los envases de fitosanitarios: un problema con solución. Horticultura 194:50–51
19. Beriot N, Peek J, Zornoza R et al (2021) Science of the total environment low density-microplastics detected in sheep faeces and soil : a case study from the intensive vegetable farming in Southeast Spain. Sci Total Environ 755:142653. https://doi.org/10.1016/j.scitotenv.2020.142653
20. Camacho-Ferre F (2000) Estudio técnico de plan de higiene rural. término municipal de Níjar. Universidad de Almería, Mónsul Ingeniería y Níjar Natura, Almería
21. Herrmann C, Rhein S, Str KF (2022) Consumers ' sustainability-related perception of and willingness-to-pay for food packaging alternatives. Resour Conserv Recycl. https://doi.org/10.1016/j.resconrec.2022.106219
22. Cicloplast, (2017) Situación Actual de la Gestión de Plásticos Agrícolas en España y en Europa. Cicloplast, Madrid
23. MAPA (2020) Anuario de estadística. 2020. Ministerio de Agricultura, Pesca y Alimentación, Madrid
24. MAPA (2021) Encuesta sobre Superficies y Rendimiento de los Cultivos. Año 2021. Ministerio de Agricultura, Pesca y Alimentación, Madrid
25. Rabobank (2017) World vegetable map. Rabobank
26. Amelia TSM, Khalik WMAWM, Ong MC et al (2021) Marine microplastics as vectors of major ocean pollutants and its hazards to the marine ecosystem and humans. Prog Earth Planet Sci 8:12. https://doi.org/10.1186/s40645-020-00405-4
27. Oehlmann J, Schulte-Oehlmann U, Kloas W et al (2009) A critical analysis of the biological impacts of plasticizers on wildlife. Philos Trans R Soc B Biol Sci 364:2047–2062. https://doi.org/10.1098/rstb.2008.0242
28. Sunday E, Obinwanne C, Okokon E et al (2022) Microplastics in agroecosystems-impacts on ecosystem functions and food chain. Resour Conserv Recycl 177:105961. https://doi.org/10.1016/j.resconrec.2021.105961
29. Bochicchio D, Panizon E, Monticelli L, Rossi G (2017) Interaction of hydrophobic polymers with model lipid bilayers. Sci Rep 7:1–9. https://doi.org/10.1038/s41598-017-06668-0
30. Dahl M, Bergman S, Björk M et al (2021) A temporal record of microplastic pollution in Mediterranean seagrass soils. Environ Pollut 273:116451. https://doi.org/10.1016/j.envpol.2021.116451

31. Wilson ST, Karl DM, Royer S, Ferro S (2018) Production of methane and ethylene from plastic in the environment. PLoS ONE 13:1–13. https://doi.org/10.1371/journal.pone.0200574
32. De-la-Torre GE, Dioses-Salinas DC, Pizarro-Ortega CI, Santillán L (2021) New plastic formations in the Anthropocene. Sci Total Environ 754:142216. https://doi.org/10.1016/j.scitotenv.2020.142216
33. Gobierno de España (2001) Real Decreto 1416/2001, de 14 de diciembre, sobre envases de productos fito- sanitarios. Boletín Of del Estado 311:50002–50004
34. Nature FG, SIGFITO (2016) Guia para la gestión de los residuos agrarios. Nature y SIGFITO, Madrid
35. Andrades R, Trindade PAA, Giarrizzo T (2021) A novel facet of the impact of plastic pollution on fish: silver croaker (*Plagioscion squamosissimus*) suffocated by a plastic bag in the Amazon estuary. Brazil Mar Pollut Bull 166:112197. https://doi.org/10.1016/j.marpolbul.2021.112197
36. Pop CE, Draga S, Măciucă R et al (2021) Bisphenol a effects in aqueous environment on lemna minor. Processes 9:1512. https://doi.org/10.3390/pr9091512
37. UN (2015) Draft outcome document of the United Nations summit for the adoption of the post-2015 development agenda, New York
38. European Commission (2015) Closing the loop: an EU action plan for the circular economy. COM(2015) 614 final. 2122015, Bruselas, Bélgica 1–5
39. Commission E (2020) A new circular economy action plan. Publications Office of the European Union, Brussels
40. Comission E (2019) The European Green Deal. Publications Office of the European Union, Brussels
41. Commission E (2018) A European strategy for plastics in a circular economy. Publications Office of the European Union, Strasbourg
42. Commission E (2020) EU Biodiversity strategy for 2030. Bringing nature back into our lives. Publications Office of the European Union, Brussels
43. Commission E (2020) A farm to fork strategy for a fair, healthy and environmentally-friendly food system. Publications Office of the European Union, Brussels
44. Duque-Acevedo M, Belmonte-Ureña LJ, Yakovleva N, Camacho-ferre F (2020) Analysis of the circular economic production models and their approach in agriculture and agricultural waste biomass management. Int J Environ Res Public Health 12:9549. https://doi.org/10.3390/ijerph17249549
45. Commission E (2018) Annexes of the European strategy for plastics in a circular economy. Publications Office of the European Union, Strasbourg
46. MAGRAMA (2015) Plan Estatal Marco de Gestión de Residuos PEMAR (2016–2022). Ministerio de Agricultura, Pesca y Alimentación, Madrid
47. MAPA (2012) Producción y Consumos Sostenibles y Residuos Agrarios, Ministerio de Agricultura, Pesca y Alimentación, Madrid
48. Ufarte A (2020) Waste traceability management systems PILOT ACTION FACTSHEET : technical & business feasibility. Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible la Junta Andalucía y Ecogestiona, Sevilla
49. Junta de Andalucía (2018) La Junta pone en marcha una campaña de retirada de plásticos agrícolas en las principales zonas de cultivo y cauces fluviales. http://www.juntadeandalucia.es/medioambiente/site/portalweb/menuitem.30d4b35a97db5c61716f2b105510e1ca/?vgnextoid=cbdd3be747fe4610VgnVCM100000341de50aRCRD&vgnextchannel=2229b8f8606b8210VgnVCM10000055011eacRCRD. Accessed 1 May 2021
50. Gobierno de España (2022) Ley 7/2022, de 8 de abril, de residuos y suelos contaminados para una economía circular. Boletín Of del Estado 85:1–137
51. MAPA (2021) Encuesta de Comercialización de Productos Fitosanitarios 2020. Ministerio de Agricultura, Pesca y Alimentación, Madrid
52. Castillo-Díaz FJ, Belmonte-Ureña LJ, Camacho-Ferre F, Tello-marquina JC (2022) Biodisinfection as a profitable fertilization method for horticultural crops in the framework of the circular economy. Agronomy 12:521. https://doi.org/10.3390/agronomy12020521
53. Honoré MN, Belmonte-Ureña LJ, Navarro-Velasco A, Camacho-Ferre F (2019) Profit analysis of papaya crops under greenhouses as an alternative to traditional intensive horticulture in Southeast Spain. Int J Environ Res Public Health 16:2908. https://doi.org/10.3390/ijerph16162908
54. Gobierno de España (1997) Ley 11/1997, de 24 de abril, de Envases y Residuos de Envases. Boletín Of la Junta Andalucía 99:13270–13277
55. Gobierno de España (1998) Real Decreto 782/1998, de 30 de abril, por el que se aprueba el Reglamento para el desarrollo y ejecución de la Ley 11/1997, de 24 de abril, de Envases y Residuos de Envases. Boletín Of del Estado 104:1–26
56. Gobierno de España (2001) Ley 14/2000, de 29 de diciembre, de Medidas fiscales, administrativas y delordensocial. Boletín Of del Estado 313:46631–46723
57. MITECO (2021) Proyecto de Real Decreto de Envases y Residuos de Envases. https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/participacion-publica/210927proyectorddeenvases_tcm30-531124.pdf. Accessed 1 Mar 2022
58. European Parliament and of the Council of Europea Union (2018) DIRECTIVE (EU) 2018/852 Of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste. Of Jou Eur Uni Ser L. pp 141–154
59. SIGFITO (2004) Memoria Anual 2004. SIGFITO, Madrid
60. Mazur-Wierzbicka E (2021) Circular economy: advancement of European Union countries. Environ Sci Eur 33:111. https://doi.org/10.1186/s12302-021-00549-0
61. SIGFITO (2005) Memoria Anual. 2005. SIGFITO, Madrid
62. SIGFITO (2013) Memoria Anual. 2013. SIGFITO, Madrid
63. AEVAE (2022) Empresas asociadas a AEVAE. https://www.aevae.net/empresas-asociadas-en-aevae/. Accessed 11 Jun 2022
64. SIGFITO (2022) Empresas Adheridas. https://sigfito.es/empresas-adheridas/. Accessed 11 Jun 2022
65. Sigfito, (2020) Memoria Anual 2020. SIGFITO, Madrid
66. SIGFITO (2022) SIGFITO. Publicaciones. https://sigfito.es/actualidad/publicaciones/
67. INE (2022) Censo Agrario. 2020. https://www.ine.es/dyngs/INEbase/es/operacion.htm?c=Estadistica_C&cid=1254736176851&menu=ultiDatos&idp=1254735727106. Accessed 15 May 2022
68. MAPA (2022) Encuesta sobre Superficies y Rendimientos Cultivos (ESYRCE). Encuesta de Marco de Áreas de España. https://www.mapa.gob.es/es/estadistica/temas/estadisticas-agrarias/agricultura/esyrce/. Accessed 02 Feb 2022
69. EIA (2022) Precio del Barril de Petróleo. https://www.eia.gov/ Accessed 02 Feb 2022
70. Sayadi-Gmada S, Roc C, Rojas-Serrano F et al (2019) Inorganic waste management in greenhouse agriculture in Almeria (SE Spain): towards a circular system in intensive horticultural production. Sustainability 11(14):3782. https://doi.org/10.3390/su11143782
71. Ufarte A (2020) Use of alternative materials for plastic staking elements PILOT ACTION FACTSHEET : technical & business feasibility. Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible de la Junta Andalucía y Ecogestiona, Sevilla
72. García R (2020) Use of alternative materials for plastic mulching films technical & business feasibility. Cons Agric Ganad Pesca y Desarro Sosten la Junta Andalucía y COEXPHAL. pp 1–18
73. García R (2020) Comparison of different associative waste management levels PILOT ACTION FACTSHEET : technical & business feasibility. Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible de la Junta Andalucía y COEXPHAL Sevilla
74. Cajamar (2021) Análisis de la campaña hortofrutícola de Almería. Campaña 2020/2021. Cajamar, Almería
75. Valera-Martínez DL, Belmonte-Ureña LJ, Molinaiz FD, Camacho-Ferre F (2017) The greenhouses of Almería, Spain: technological analysis and profitability. Acta Hortic 1170:2019–2226. https://doi.org/10.17660/ActaHortic.2017.1170.25
76. MAPAMA (2017) Estrategia nacional de los programas operativos sostenibles a desarrollar por las Organizaciones de Productores, Frutas y Hortalizas. Ministerio de Agricultura, Pesca, Alimentación y Medioambiente, Madrid
77. MAPA (2019) Desarrollo de la normativa relativa a la acción 7.28 incluida en las directrices medioambientales que forman parte de la Estrategia Nacional de Programas Operativos Sostenibles. Ministerio de Agricultura, Pesca y Alimentación, Madrid
78. MAPA (2018) Desarrollo de la normativa relativa a la acción 7.29 incluida en las directrices medioambientales que forman parte de la Estrategia Nacional de Programas Operativos Sostenibles. Ministerio de Agricultura, Pesca y Alimentación, Madrid
79. Junta de Andalucía (2019) Anuario de estadísticas agrarias y pesqueras de Andalucía. https://www.juntadeandalucia.es/organismos/agricultur

aganaderiapescaydesarrollosostenible/servicios/estadistica-cartografia/anuarios.html. Accessed 1 June 2022
80. Camacho-Ferre F (2004) Técnicas de Producción en Cultivos Protegidos. Cajamar, Almería
81. Martín-Gil A, Campelo-Rodríguez MP, Recio-Rincón C (2021) Guía de gestión integrada de plagas, Ministerio de Agriculutra, Pesca y Alimentación, Madrid
82. Arandes JM, Bilbao J, López-Valerio D (2004) Reciclado de residuos plásticos. Rev Iberoam Polímeros 5:28–45
83. ANARPLA (2016) Boletín de precios y tendencias. Junio 2016 (1/2016). ANARPLA. Valencia
84. Banco de España (2020) Factores de demanda y oferta en la determinación del precio del petróleo en el contexto de la crisis del Covid-19. Recuadro 2. Informe trimestral de la economía española. Boletín Económico 2/2020. Boletín Económico del Banco España, Madrid
85. Nuño G (2015) El mercado del petróleo: cambios en la oferta y determinantes de la caída de los precios en 2014. Boletín Económico del Banco España, Madrid
86. González C, Teresa M, Pérez G (2020) Factores de microestructura del mercado en la determinación del precio del petróleo. Artículos Analíticos. Boletín Económico 3/2020. Boletín Económico del Banco España, Madrid
87. Espí E (2012) Materiales de cubierta para invernaderos. In: Cuadernos de Estudios Agroalimentarios. Cajamar, Almería. pp 71–88
88. MA Business Ltd (2021) BASF launches IrgaCycle additive solutions for mechanical recycling of plastics. Angew Chemie Int Ed 6(11):951–952. https://doi.org/10.1016/S0306-3747(21)00158-5
89. INE (2022) Índices nacionales: general y de grupos ECOICOP. https://www.ine.es/jaxiT3/Tabla.htm?t=22344. Accessed 11 June 2022
90. Duque-Acevedo M, Belmonte-Ureña LJ, Toresano-Sánchez F, Camacho-Ferre F (2020) Biodegradable raffia as a sustainable and cost-effective alternative to improve the management of agricultural waste biomass. Agronomy 10:1261. https://doi.org/10.3390/agronomy10091261
91. Marín-guirao JI, Martín-Expósito E, García-García C, de Cara-García M (2022) Alternative mulches for sustainable greenhouse tomato production. Agronomy 12:1333. https://doi.org/10.3390/agronomy12061333
92. Herrera-Franco G, Montalván-Urbano DS, Mora-Frank C, Moreno-Alcivar L (2021) Research in petroleum and environment : a bibliometric analysis in South America. Int J Sustain Dev Plan 16:1109–1116
93. Román-Sánchez IM, Belmonte-Ureña LJ (2013) Appraisal of environmental regulations on sustainable consumption of water in the wine-producing Spanish industry. Environ Eng Manag J 10:199–197. https://doi.org/10.30638/eemj.2013.247
94. Román-sánchez IM, Aznar-sánchez JA, Belmonte-ureña LJ (2015) Heterogeneity of the environmental regulation of industrial wastewater: European wineries. Wat Sci Tech 72(9):1667–1673. https://doi.org/10.2166/wst.2015.387
95. MAPA (2016) Resultados técnico-económicos. Cultivos herbáceos. Ministerio de Agricultura, Pesca y Alimentación, Madrid

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