Bioeconomy as a transforming driver of intensive greenhouse horticulture in SE Spain

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\section*{A R T I C L E   I N F O}

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\section*{A B S T R A C T}

Bioeconomy is becoming the main driver transforming European agri-food value chains towards global sustainability in the food supply chain. Intensive horticultural production systems based on medium and low-tech greenhouses are suitable scenarios implementing bioeconomy strategies to achieve sustainability targets. Since the publication of the European Strategy of Bioeconomy in 2012, policy measures intended to boost bioeconomy are responsible for changing what are now considered outdated production systems to more high-tech models capable of responding to climate-change challenges. This article describes the potential for the agri-food supply chain to drive the transition of medium and low-tech intensive greenhouse systems to biobased, circular economy value-chains. Key areas of impact relate to waste valorisation and management, new inputs based on biotechnological innovations, building clusters of innovative delivery partners within the sector, and the increase in public awareness of the impact of the bioeconomy through socio-economic analysis.

\section*{Introduction}

Since the European Strategy of Bioeconomy was launched in 2012 [1], several countries and regions have developed their own specific strategies by adapting the European initiative to local food production systems, such as the case of the Andalusia region (Spain) [2]. Patermann and Aguilar [3] described how the concept of bioeconomy has evolved keeping the original, namely: ensuring food security; managing natural resources sustainably; reducing dependence on non-renewable resources; mitigating and adapting to climate change; creating jobs and maintaining European competitiveness, while reducing dependence on fossil fuel reserves by replacement with existing or new biobased products and new bioprocesses.

The EU Strategy of Bioeconomy was revised and updated in 2018 [4], drawing attention to the role of bioeconomy in, linking this concept to the Sustainable Development Goals and addressing policy priorities such as the Circular Economy Action Plan [5]. The revision proposes the following action plan

1. Strengthen and scale up the biobased sectors, unlock investments and markets.
2. Deploy local bioeconomies rapidly across the whole of Europe.
3. Understand the ecological boundaries of the bioeconomy.

This is consistent with the original strategy and introduces new aspects: it assumes that much of the innovation is available on a laboratory...
scale, but needs investment, market promotion and policy measures to overcome the “innovation valley of death”; and the local and environmental dimensions of the bioeconomy are emphasized, paying attention to the ecological boundaries concept.

The connection between science, policy and society is necessary to catalyze the inclusion of bioeconomy in society. It is impossible to develop new markets for new biobased products if consumers neither trust in bioprocesses nor perceive biomass as a safe raw material. To make progress in this respect, transdisciplinary work schemes are required to develop (i) social learning processes that contribute to build understanding and confidence in this new economic paradigm, and (ii) multi-actor approaches that facilitate the creation of collective solutions to deploy bioeconomy measures. It is necessary to convey that the benefits of the bioeconomy need to be highlighted, showing that it generates wealth, growth, development and jobs through conservation, management and investment in nature.

The south-east region of Spain concentrates a significant part of European greenhouse-based on medium/low technology. It has previously been described as an ideal scenario for the deployment of bioeconomy [6]. This intensive horticulture value-chain the main economic activity. As an example, in the region of Almeria, during the 2018-2019 season, vegetables were grown on a total of 35,839 ha of greenhouses, with a yield of 3,251,167 tons, worth €2684 M. The system generates more than 75,000 direct jobs and is supported by an auxiliary industry of 152 relevant companies, with a combined turnover of €1367 M and 6244 employees, including companies supplying seeds, substrates, plastics, packaging, irrigation technologies and support industries such as residue control laboratories. However, these production systems have major drawbacks [6], notably dependency on mineral fertilizers and scarce natural resources, lack of adequate waste management strategies, and the vulnerability of its high dependency on a unique business model based on a linear value-chain, which is basically the production and market placing of commodities, threatened by climate change challenges.

The main objective of this article is to carry out a prospective analysis of the value-chain, from a circular bioeconomy approach, prioritizing a local deployment of the bioeconomy through proposals for biobased products and business diversification that allow sustainable production according to local boundaries. From the methodological point of view, a series of circular bioeconomy measures are proposed that would help to solve the above-mentioned drawbacks using an inter- and trans-disciplinary approach. It addresses a circular bioeconomy roadmap dealing with different relevant weaknesses of the current value chain. Circular bioeconomy alternatives are proposed, seeking as the main goal a reduction in vulnerability through business diversification (and job creation), biobased products, mineral fertilizer reduction and efficient value-chain organisation. Table 1 summarize the approaches addressed in this paper:

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<td>Area of concern</td>
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1. Related to biomass waste management: a route to obtain high value-added products such as bioblocks or biomolecules is proposed as an alternative to current valorisation strategies.
2. In relation to agro inputs: the substitution of fossil fuel reliant fertilizers by microalgae-based biofertilizers, biostimulants, and the development of bioindustries.
3. In relation to management of the value chain: there is a shift from the linear model to a circular one, with the deployment of vertical and horizontal clusters being critical as a means of reorganizing the value chain according to circular bioeconomy principles.
4. The trans-disciplinary and multi-actor approach: a key for building trust and raising societal awareness about the environmental, social and economic trade-offs and synergies of the intensive greenhouse horticulture model.

Plant biomass valuation

Intensive horticulture in SE Spain generates a huge amount of different classes of waste, e.g., biomass, plastics, substrates and containers [7]. An extensive research on non-biomass waste from greenhouses has been published [8]. Here, we focus on biomass residues classified in Table 2 as biomass from plants and non-commercial fruits and vegetables. The amounts and types of biomass were obtained from a survey carried out by the authors in 2018, on 900 farmers and approximately 1400 ha of greenhouses.

The estimated total biomass production in the area of study is close to 2 million tons per year, which is consistent with data published in previous years [6]; most plant biomass is mixed with plastic string (raffia) used to keep plants upright during their growth. Fig. 1 depicts a monthly distribution of biomass production, with estimation over the total cropped 35,850 ha in the area. Biomass production is not uniform over time, decreasing in September and October. The increase in biomass from January onwards is due to farmers shifting crops at the end of winter to another short-cycle spring crop. The highest amount of biomass is produced between May and August with the end of the annual-cycle crops and the short spring cycle crops.

Currently small companies in the Almeria province, such as SACH Ltd (www.gruposach.es/es/), Ecotech Ltd (www.ecotechalvoria.co.uk), and Frutilados del Poniente Ltd (https://joseantoniocardos.es/tag/frutilados-del-poniente/) collect the biomass from greenhouses and process it independently to obtain compost, earthworm humus and animal feed respectively. This model of biomass management fits into a linear bioindustry model of services, where each company has to afford the whole process, from biomass transport and primary processing to the final product.

The major constituents of biomass from intensive horticulture include polysaccharides (cellulose and hemicellulose 75-85 wt %), polyphenolic lignins (10-20 wt %) and about 5% of other natural components [9,10]. The hydrolysis of these main constituents (depicted in Fig. 2) leads to C6/C5 sugars with great potential as a source of bioblocks [11]; natural compounds widely used in pharmaceuticals and cosmetics are obtained from plants and a wide range of essential molecular targets is obtained by the catalytic conversion of carbohydrates.

The current situation requires shifts to a biorefinery cluster,
interconnecting activities such as: (i) logistics, biomass suppliers; (ii) primary processing, biomass conditioning, fractionation of its components to obtain the maximum potential valorisation in cascade and isolation of intermediate pure compounds of high value; (iii) secondary processing, where intermediate products are obtained as bioproducts, building-blocks, biomaterials, food/feed ingredients, fibres or bioenergy, which after conversion are marketable. Among these alternatives, the production of furanic bioblocks, which serve as feedstock for the bioplastic industry among others, is addressed below, as a clear example of circular bioeconomy with great potential for innovation and new markets.

There are many platform chemicals, defined by the International Energy Agency (IEA) Bioenergy Task 42 [12] as “intermediate products from biomass feedstock towards products or linkages between different biorefinery concepts or final products”. They include alcohols, sugars, acids, furanics and biohydrocarbons (ethanol, glycerol, sorbitol, xylitol, lactic, succinic, 3-hydroxypropanoic, levulinic acid, furfural, 5-hydroxymethylfurfural (HMF), 2,5-furandicarboxylic acid (FDCA) and isoprene) [13]. Furanics are promising biobuilding blocks in terms of potential for synthesis. HMF is regarded as a pivotal element in the transition from a fossil-based economy to a sustainable one [14,15]. As proof of its relevance, current research into the fields of HMF synthesis and chemistry shows more than 10,000 articles and patents over the past 10 years [16], being a major topic in green chemistry for both its synthesis and its reactivity.

The synthesis of HMF from carbohydrates involves two stages, where isomerization and dehydration are essential to achieve it successfully (Fig. 3). Since HMF molecules have no chiral centres, all hexoses can be selectively transformed into HMF. The best starting materials based on conversion and selectivity are ketohexoses, fructose main isomers, by removal of three water molecules. Aldohexose, glucose main isomer, is less efficient and selective than ketohexoses, but it can be easily isomerized to them (Fig. 3). However, for wide industrial applications, major methods of HMF synthesis are still unsuitable due to several factors, notably solvents, catalyst regeneration, low selectivity of conversion, HMF isolation and purification, together with HMF tendency to polymerization or hydrolysis.

The high reactivity of HMF and its enormous potential for synthesis lies in the fact that it combines three functional centers: aldehyde, hydroxymethyl, and furan ring, with only six carbons. However it shows low stability and in the presence of acids it polymerizes into insoluble products. Therefore, the generated HMF is quickly transformed into a more stable and useful compound, such as FDCA (Fig. 4). It could be a suitable possibility based on atom economy and is a highly important furanic monomer and a renewable alternative to fossil-based terephthalic acid (TPA) [17–19].

From a commercial point of view, the most attractive derivative of FDCA is 100 % biobased polyethylene furanoate (PEF), employing biobased ethylene glycol in the polycondensation reaction. This represents
The ideal example of an innovative biorefinery product that improves traditional analogue, polyethylene terephthalate (PET) obtained from fossil TPA, in many aspects. PEF combines upgraded technical characteristics such as enhanced barrier properties, a more appropriate glass transition temperature, and a lower melting point compared with PET. In addition, PEF implies ecologically responsible manufacturing related to lower non-renewable energy use and greenhouse gas emissions [20].

Annual world production of TPA is estimated to be more than 60 million tons [21, 22]. Thus, PEF has a major market with the potential to adsorb a large part of biomass valorisation. A total annual production of FDCA of 170,000 tons over the next few years has been announced [23–25]. Therefore, in order to substitute TPA (fossil fuel) by FDCA (biobased), development of new manufacturing facilities is required to achieve 60 million tons per year of FDCA, meaning a 400-fold increase in production. Moreover, the current market price of FDCA is approximately 500 times higher than that of TPA [26]. This difference is partly associated with the relatively low scale of industrial production of FDCA. Current approaches should be improved to reduce its production costs, and the development of suitable, robust, selective and efficient catalysts based on abundant and inexpensive metals will be required to make this technology more feasible. Plant biomass from the greenhouse area, mainly based on cellulose, lignin and hemicellulose, is a good raw material for the production of biopolymers with a potential for producing more than 2.5 million tons per year in the study area. Moreover, this promises the creation of new job opportunities, diversifying the production system with additional industries beyond agriculture.

**Biomass valorisation (Biofertilizers) and Biostimulants**

The use of nitrate-based fertilizers (3.5–5 tons per ha) has led to environmental concerns, with the greenhouse areas of SE Spain being considered a Nitrate Vulnerable Zone (NVZ) [27]. The regional administration has legislated to reduce both nitrogen fertilizer inputs to crops and associated environmental pollution. The replacement of mineral fertilizers or plant protection products with “bioinputs” meaning biopesticides, biostimulants and biofertilizers is key for the future of horticulture. The production of biobased products is dependent on biotechnology industries that provide microorganisms (bacteria, fungi, microalgae) and their products, not only for agricultural purposes but also to supply different sectors, constituting a way of diversifying the economy in agricultural areas.

Composting biomass waste produces most biofertilizers. A recent study [28] reported that 77% of farmers in SE Spain contract the management of biomass to authorized companies, while close to 23% choose self-management. In the first place most of the waste is used as raw material to produce compost, while a small percentage is also dedicated to the production of energy and livestock feed; in the second place the biomass is usually chopped and incorporated into the soil as green fertilizer.

Biostimulants are increasingly valuable inputs, which may originate from the biomass or from other biological sources, such as microalgae. The ideal scenario is to connect innovative companies to waste-management streams in order to obtain the maximum value for the raw material. There are many different definitions of biostimulants, reviewed in [29], where biostimulant is defined as a “formulated product of biological origin that improves plant productivity as a consequence of properties of the complex constituent, not as a sole consequence of the presence of known active ingredients, plant nutrients, growth regulators or plant protective compounds”. The European Biostimulants Industry Council (EBIC) defines biostimulants as “substances and or micro-organisms whose function when applied to plants or the rhizosphere is to stimulate natural processes to enhance/benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and crop quality” [30]. Both definitions go beyond a biomass valorisation strategy, including microorganisms, substances from microorganisms, micro and macroalgae. Biostimulants have been categorized into seven groups: beneficial fungi, beneficial bacteria, humic and fulvic acids, seaweed extract, chitosan, inorganic compounds and protein hydrolysates [31]. A recent review [32] of examples of biostimulants derived from agricultural by-products, demonstrates the potential of agricultural biomass in this field and establishes the suitability of raw material for the development of biostimulants. Given that the market for biostimulants has been growing at over 10% per year since 2005 [30], the development of a major biostimulant industry, associated with the cluster of horticultural production in Mediterranean areas is of particular interest.

Microalgae constituents are mainly carbon 45%, Nitrogen 7% and phosphorus 1%, but from them it is possible to obtain biostimulants for high value horticultural production, especially amino acids from protein hydrolysates. Uses of microalgae are related to the production of energy (mainly biofuels), bioplastics, biostimulants and biopesticides, nutraceuticals and nutrients for aquaculture, animal feed, or human food [33]. A limiting factor in this industry is the cost of production. Microalgae production is carried out mainly in two types of photobioreactors [34], open and closed systems (Fig. 5). Open systems produce 90% of

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**Fig. 4.** Reaction of 5-hydroxymethylfurfural (HMF) to produce 2,5-furandicarboxylic acid (FDCA) and levulinic acid, used as bioblocks to obtain 100% biobased polyethylene furanoate (PEF) for biopolymers.

**Fig. 5.** Closed Tubular (A) and Open Raceway (B) Photobioreactors at SABANA Demo 1 industrial facilities of Biorizon Biotech, which produce microalgae as a source of biostimulants.
biomass with raceway photobioreactors being the most efficient. They consist of a large, shallow pond to facilitate light penetration, in which microalgae are circulated by means of paddlewheel drives. These photobioreactors are low cost, easy to scale-up and have low energy demand. In Mediterranean areas it is possible to set up this kind of photobioreactor inside greenhouses, reducing contamination risks and keeping environmental conditions quite constant. Closed photobioreactors, such as the tubular type, are used to culture microalgae that need to be isolated from the environment. In tubular photobioreactors, the microalgae are continuously recirculated along a solar receiver, designed to maximize solar radiation (Fig. 5). These reactors allow better control of the culture parameters and the production of microalgae, including sensitive strains such as Haematococcus or Porphyridium, with high productivity of 1 g/L·day. However costs rise to ten times that of the open photobioreactors.

Production capacity is a limiting factor due to the associated costs necessary to achieve production rates at industrial scales. SABANA [34] is an EU Horizon 2020 funded project coordinated by the University of Almeria. The project addresses two important regional objectives: the production of microalgae using different culture media (including urban waste-water) and development of a facility that allows testing of scalability of developments from laboratory to pilot, demonstration and industrial size. This is a new type of bioindustry linked to the horticulture value-chain, but also able to access new markets with products related to food, feed, pharmaceuticals and cosmetics. Microalgae production is a business model which is being integrated into the Mediterranean horticulture area. Over the last ten years, SE Spain has established two leading companies, Alga Energy (https://www.algen energy.com/) and Biorizon (www.biorizon.es/), which are, in this particular area, the main actors in the market of amino acid biostimulants for fruit and vegetable production.

The biostimulant market has a large potential growth: the project BIO4SAFE [35] forecasts the area to grow from a total value of €1449 M in 2016, double that in 2022. Currently, 80 % of fertilizers are synthetic or mineral and just 2.25 % of the market is shared by biostimulants. Almeria greenhouse horticulture is in a good position to develop this kind of industry, which is in demand by the agri-food sector.

Consumers concern might be aroused by the difficult categorization and unclear definition of biostimulants within the legal framework of the registration process in Europe [39]. The nature of biostimulants complicates the description of their mechanisms of action; sometimes they are microorganisms acting on the soil to increase nutrient absorption but not interacting with plants directly. In consequence, it is necessary to provide safety statements for products, the environment and consumers, as well as their positive effect on yields. Biostimulants also have a complex multicomponent composition, such as amino acids, amino-polysaccharides, plant hormones or hormone-like substances, etc. The complexity of the matrix demands high-throughput analytical methods, based on techniques, such as nuclear magnetic resonance, but where metabolomics plays an essential role combining mass spectrometry with powerful data analysis. A reliable quality control and coordinated European and national legislations within this framework, will benefit the development of a strong biostimulants industry associated with greenhouse horticulture.

Shifting the horticulture value-chain to a circular bioeconomy cluster

The EU Clusters Portal defines clusters as regional or local ecosystems of companies, industries, economic actors, institutions or other supporting actors that cooperate to provide a broad array of services, suppliers, expertise, knowledge and technology [36]. This definition is consistent with that of Porter [37] in 1990. The European Observatory for Clusters and Industrial Change [38], elaborate the “clusters mapping tool”, where cross-sectoral regional indicators of clusters specialisation can be visualized.

As part of a Focus Group of the Agricultural European Innovation Partnership (EIP-AGRI), a document was drafted dealing with clusters related with circular bioeconomy in intensive horticulture [39]. Clusters are necessary to shift the current linear value-chain model towards a more circular one, where synergies between different companies are taken advantage of, reducing risks and costs and optimizing the flow of material, energy, knowledge and technology, strengthening the resilience of the whole value-chains and their sustainability. The relationships between cluster partners can be: (i) an exchange of tangible goods such as raw material and energy; or (ii) an exchange of intangibles, such as knowledge transfer. The first corresponds to a “vertical” cluster definition, which has a local dimension and focuses on a specific value-chain with the main objective of increasing its sustainability. The second relationship refers to a “horizontal” clusters definition, which covers wider geographical areas, at regional or even cross-border scale and focuses on specific infrastructure, knowledge, skills or activities, for example digitalisation of the production system.

The structure of ‘clusters’, ‘platforms’ or ‘hubs’ is becoming a model of organization that facilitates access and the establishment of business and economic activities that make up the entire value chain, with the goals not only of securing incomes but also of increasing its sustainability and resilience to external threats. For example, the digitalization ‘hubs’ will allow information and communication technologies to reach each link in the chain, promoting the training of farmers, the incorporation of Information and Communication Technologies (ICTs) into production, packaging, marketing and quality control and product safety, but also the analysis of final consumer behaviour in relation to those emotional factors that lead us to choose one product over another, which in many cases are related to external factors that surround the mode of production. Examples of these horizontal clusters are the projects funded by the H2020 industrial leadership programme “Internet of Food and Farms” [40] or ICTBIOCHAIN [41] funded by The Bio-Based Industries Joint Undertaking (BBI-JU). Another example where bioeconomy predicts the success of the cluster organization is biomass waste management, where farmers must be involved as suppliers of raw materials. In this case, it is already happening that large biomass management companies establish joint ventures with entrepreneurs who design new processes, diversifying the bioproduct portfolio. Examples of cluster initiatives are Foodregion [42] in Germany, the Wageningen Metropolitan Food Clusters [43] in The Netherlands and Agrimax [44] in Spain and Italy. This allows innovative start-ups and pilot plants to grow under the umbrella of big companies, with consequent economic growth for the region.

Evidence that bioeconomy is reaching the Almeria greenhouse horticulture sector is the initiative of regional administrations to promote a new bioeconomy-based territorial cluster, which connects inland and coastal areas [45]. On the one hand coastal areas where greenhouse horticulture is concentrated host knowledge, technologies, logistics, access to international markets, and a greater population as potential consumers. On the other hand, inland areas, suffering high-unemployment rates and rural abandonment, are of extreme importance for the preservation of important ecosystem services (e.g. aquifer recharge or erosion control) that directly and indirectly support the greenhouse system and auxiliary industry on the coast. The territorial cluster aims to compensate the economic and social imbalance between inland and coastal regions, helping both territories to transition to a sustainable development model.

Societal challenges for implementing bioeconomy

While bioeconomy-based natural resource management is considered to halt the loss of biodiversity and the ecosystem services [46,47], several challenges concerning the connection of bioeconomy goals and outcomes with society remain unknown [48]. Some of the societal challenges identified by the EU [49] are articulated along three main aspects: (i) educational, (ii) social awareness
and communication and (iii) knowledge co-production and stakeholder engagement. There is an urgent need to identify skill gaps in educational curricula in the biobased sector, which requires identifying present and future skills needed across the bioeconomy to connect education and research with industry. From a perspective of social awareness and communication, it is a priority for society to understand what bioeconomy is, to identify its demands and concerns of consumers and other groups in the value chain, as well as to communicate the environmental impacts of biobased products and services to build trust and acceptance. Finally, from the perspective of stakeholder engagement and the co-creation of knowledge, it is necessary to create a multi-stakeholders participation approach to capitalizing creativity from a bottom-up design, as well as to offer solutions to build trust and acceptance and sense of ownership among all stakeholder groups involved in bioeconomy.

The EU is devoting resources to overcome the traditional limited capacity of the scientific community to enable bioeconomy to permeate into policy and societal domains. In this sense, several efforts have been made by the interdisciplinary scientific community of Almeria to find pathways for the transition to a sustainable greenhouse system, creating a culture of shared responsibility between public, private, academic and civil society actors. As a result, a multi-actor, transdisciplinary research has identified the implementation of bioeconomy as one of six fundamental challenges in transitioning to an agricultural model that aims to ameliorate risks and avoid a systemic collapse, whilst balancing concern for profitability with sustainability [50]. As a result of this work, local bioeconomy concerns have been reflected in the policy document of the regional strategy of bioeconomy [2].

The role of transdisciplinary research for bioeconomy implementation in societal domains

Transdisciplinary research offers a means to promote oriented-transformation towards sustainability from the bioeconomy perspective [46]. Transdisciplinarity implies that scientists from many areas (e.g. physical, biological, and social scientists) and non-scientists can work together through co-learning and knowledge co-production processes to formulate problems and provide evidence-based solutions to address the current societal challenges facilitating an effective dialogue across science, policy and society [51-53]. This is crucial to (i) strengthen the understanding of scientific discourse by decision and policymakers and the general public, (ii) facilitate the scientific knowledge that can be incorporated into policy and practice, and (iii) raise awareness regarding sustainability issues in order to co-generate outcomes based on a balance of trade-offs among scientific advances, policy needs and societal concerns [54,55].

Transdisciplinary approaches represent an adequate scientific response to help society transition towards sustainability [52] in multiple areas of sustainable governance such as agriculture, biodiversity and water, from national to local scale [50,56,57]. Although the Global Bioeconomy Summit in Berlin [58] periodically brings together high-level participants in bioeconomy from around the world, there are as yet no consolidated platforms in the bioeconomy field to transdisciplinarity perspectives supporting the transition to bioeconomy. To address this gap, new transdisciplinary experiences have flourished at a regional level. An example is the public participatory process aimed to develop the Andalusian Bioeconomy Strategy [2]. The consolidation of these transdisciplinary work schemes within institutional settings, through iterative and ongoing processes, is pivotal to strengthening collaboration and building trust and common understanding among science, policy and society domains.

The current value-chain of Almeria greenhouse horticulture in SE Spain is a unique scenario for promotion of transdisciplinary approaches [6,50]. Although Almeria greenhouse horticulture is a family-farming model, with an average size of 2 ha per holding, farmers have grouped themselves into different collaborative farming associations, of which cooperatives are the most important. The relatively large size of these organisations facilitates farmer access to knowledge, technology and international markets. A transdisciplinary approach in the horticultural sector is absolutely essential to promote sustainable environmental and social policy measures. The changes often encounter resistance, e.g. the rejection by a part of society and consumers to the use of biotechnology in agriculture. The transdisciplinary approach has the advantage that the design of policies, their implementation and communication involve participation by all the final actors, including society in general, which facilitates the understanding and acceptance of the circular bioeconomy in the production system.

Lessons learned and conclusions

Circular bioeconomy is currently the principal driver of the transition of intensive horticulture value-chains in SE Spain, towards a sustainable production system. The main areas of influence of bioeconomy on the current value chain are the valorisation of biomass, the shift to bioinputs, the transition of the linear value chain to circular bioeconomy clusters and the impact on society.

Since 2005, European policies together with funding programmes have made the circular bioeconomy a reality at the political and scientific levels; in the latter, important developments have been achieved at conceptual and laboratory levels such as the production of furanic bio-molecules (FDCA). Public-private partnerships are critical to scale-up of innovations into the markets. Horizon 2020 and the BBI-JU have made very commendable achievements in this regard, such as the SABANA and AGRIMAX projects dealing with pilot biorefineries.

Concerning biomass waste valorisation we consider the conversion of lignocellulose into Ce-Cs, due to its potential for diversifying new markets, sustainable business models and job creation. Bioenergy valorisation can also be considered, although the area of study has great potential renewable energy sources such as sun and wind.

The microalgae industry is a new biobased business model that focussed on the production of biostimulants is triggering a shifting in crop fertilisation. Dependence on mineral fertilizers is being reduced, along with their negative environmental impacts. Biostimulants also increase the quantity and quality of harvests, resilience against abiotic influences and reduce the use of water and plant protection products.

Cluster organisation, establishing alliances between the different links in the value-chain, is necessary to achieve the environmental, economic and social objectives of the bioeconomy. Clusters increase the size and capacity of value chains (as a whole) to access and invest in innovation, knowledge and technology. They provide environmental benefits, resilience, new business models, employment and investments.

H2020 and BBJU have done huge efforts funding up to 65 projects dealing with societal, consumer and general population awareness of how circular bioeconomy can impact on nature and economy. It is necessary for society to perceive the importance of investing in green infrastructures, which are necessary for resilient production systems.

Transdisciplinary science is crucial to support multi-actor work schemes to progress in providing realistic and context-specific pathways to shift the horticulture value-chain to a circular bioeconomy cluster. Despite the wide recognition of the impact of such to advance the implementation of bioeconomy, empirical research to better understand the successful conditions that enable such schemes under specific contexts is limited. Hence, we suggest new empirical transdisciplinary research is needed for operationalizing and making bioeconomy relevant to policy and society globally.

Declaration of Competing Interest

The authors declare no conflict of interest