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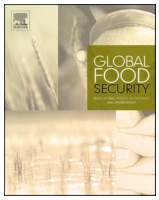

Trade-offs for healthy and sustainable diets in Europe: Social-ecological dynamics in an intensive agricultural system

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A B S T R A C T

Food production and trade are key drivers of environmental change worldwide. Global initiatives emphasize the need to shift towards healthier and more sustainable diets, with increased consumption of fruits and vegetables (F&V). However, F&V cultivation relies on diverse high-value crop species that often require intensive fertilization and irrigation for optimum yield and quality, as well as a large labor force. This generates trade-offs across scales between the impacts in the production regions and the global need to increase F&V production. Through multi-actor dialogues, we analysed the social-ecological dynamics of the F&V agriculture system in Southeast Spain, which crucially supplies F&V to Northern Europe. Using a new approach combining the 3Horizons method and system thinking tools, our results reveal the agricultural system's context-specific structures as a foundation for exploring transformative opportunities. We found that the agricultural system a) is sustained in a governance model that lacks cooperation and fosters polarized views, 2) surpasses the biophysical limits, and 3) relies on immigrant low-wage labor. Additionally, our results underscore the need to share the responsibilities and costs of the food-system transformation across the supply chain actors, focusing on the potential of retailers, governance institutions at multiple scales, collective structures of farmer producers, and auxiliary industries to support sustainable and just transformative changes.

1. Introduction

Food production and trade are a major driver of global environmental change, exerting significant impacts such as climate change, land-use changes, biodiversity loss, freshwater resource depletion, and alterations in nitrogen and phosphorus cycles of aquatic and terrestrial ecosystems (Springmann et al., 2018; Willett et al., 2019). These pressures are pushing Earth systems beyond safe boundaries for humanity (Campbell et al., 2017), necessitating a transformative shift in the global food system (Sellberg et al., 2020).

The EAT-Lancet Commission represents a global scientific effort aimed at guiding the transformation of the global food system toward healthier and more sustainable production and consumption patterns (Willett et al., 2019). In line with other international dietary guidelines (e.g., WHO/FAO, 2003), the EAT-Lancet diet emphasizes fruit and vegetable (F&V) consumption, with suggested intakes of approximately 5 servings per day. However, global F&V availability falls short of these recommended levels, particularly in lower-income groups and countries (Siegel et al., 2014; Miller et al., 2016; Mason-D'Croz et al., 2019). Furthermore, projected population growth by 2050 necessitates an estimated 50%–150% increase in global F&V production (Willett et al., 2019; Stratton et al., 2021), potentially amplifying by 2–28% the environmental impacts of F&V production (Springmann et al., 2018).

Large-scale F&V systems rely on cultivating diverse high-value crop species and varieties, often requiring intensive fertilization and irrigation to achieve high yields. In less than 20 years, global trade of F&V has

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more than doubled (approximately 130 billion USD in global exports in 2018; FAO, 2020), with the major exporting regions being located in Southern European countries (i.e., Spain or Italy) and the Global South regions (i.e., Latin America and the Caribbean and Asia) (FAOSTAT, 2021; FAO, 2020). The abundance of sunny hours and the lack of a genuine thermal winter make these regions perfect to produce many varieties at large scale and all year round. However, the F&V systems' high dependence on irrigation and sensitivity to temperature extremes can also make them particularly susceptible to climate change impacts, such as the increasing recurrent droughts, floods and wildfires (Peet and Wolfe, 2000; Scheelbeek et al., 2018; Lloyd, 2023), especially those crops where the application of environmental control systems is more limited. Likewise, the effects of F&V system dynamics on vulnerable population groups are amplified due to the prevalence of small-scale farmers, who contribute over 50% of global F&V production (Herrero et al., 2017; FAO, 2020), and the concentration of F&V trade in large national and multinational retailers that -as in many other sectors-take most of the added value of the products (Galdeano-Gómez et al., 2015; Milford et al., 2021). Consequently, if a healthier and more sustainable global diet is to be pursued, place-based research is vital to comprehensively understand the intricate interplay and dynamics between scales within food systems, revealing the trade-offs and uncovering the social-ecological structures that shape context-specific impacts and opportunities for transformations (Balvanera et al. 2017b, 2017a). Cross-scale and multi-dimensional approaches are also important to avoid overly simplistic and binary solutions in which there are winners and losers in absolute terms rather than a complex constellation of trade-offs (Whitfield et al., 2023).

In this study, building on multi-actor dialogues facilitated by the research project XPaths (www.xpathsfutures.org), we investigate the regional environmental, social, economic, and governance dynamics of an intensive F&V agriculture system in the Southeast of Spain. Based on the perspectives of diverse local and regional actors, we explore the underlying causes of systemic challenges. Further, we discuss the social-ecological trade-offs of increasing F&V production and the multi-scale shared responsibilities required to move towards sustainable and just food systems.

2. Methods

2.1. Case study area

Spain accounts for almost 2% of the global F&V production, being the seventh producer globally and the main European Union (EU) producer, with an annual production exceeding 39 million tons (FAOSTAT, 2021) (Fig. 1). Furthermore, Spain is the second country (after China) regarding F&V exportations globally (FAOSTAT, 2021). Notably, around 42% of the Spanish production is exported (FAOSTAT, 2021), with almost 80% being destined for other EU countries (ICEX, 2021). Particularly, the semi-arid Southeast of Spain plays a vital role in supplying F&V to the EU, especially during winter months. The region's exports account for more than 78% of their production (ICEX, 2021; MAPA, 2021), which constitutes almost 40% of Spain's F&V exports to EU (ICEX, 2021)

Until the end of the 1960s, the Southeast semi-arid region of Spain (mainly corresponding with the province of Almeria and the Autonomous Community of Murcia) was categorized as economically "underdeveloped", ranking among the lowest in terms of GDP within Spain (Sánchez-Picón et al., 2011). However, in the 1980s, with the introduction and development of intensive agriculture and the boom of the "sun & sand" tourist sector, the region experienced significant economic and population growth (Sánchez-Picón et al., 2011) (Box 1). The entrance of Spain into the European Common Market was key for this transition, as well as the further expansion of (greenhouse) cultivation in Almeria and Murcia, irrigated with underground water and the Tajo-Segura water transfer respectively. Currently, 24,9% and 11,20% of the active population in Almeria and Murcia respectively work in the agricultural sector (which is highly above the national percentage of 4, 3%; MDSA2030, 2022).

2.2. Data collection

To collect the perspectives of diverse local and regional actors we conducted participatory multi-actor dialogues based on the 3H4SDG approach (Aguiar et al., 2020; Collste et al., 2023). This approach structures the knowledge co-production process in three steps: 1) envisioning desired futures, 2) identifying current challenges, and 3) exploring strategies to reach the desired futures. Throughout these steps, ideas are collected regarding different dimensions of sustainability,

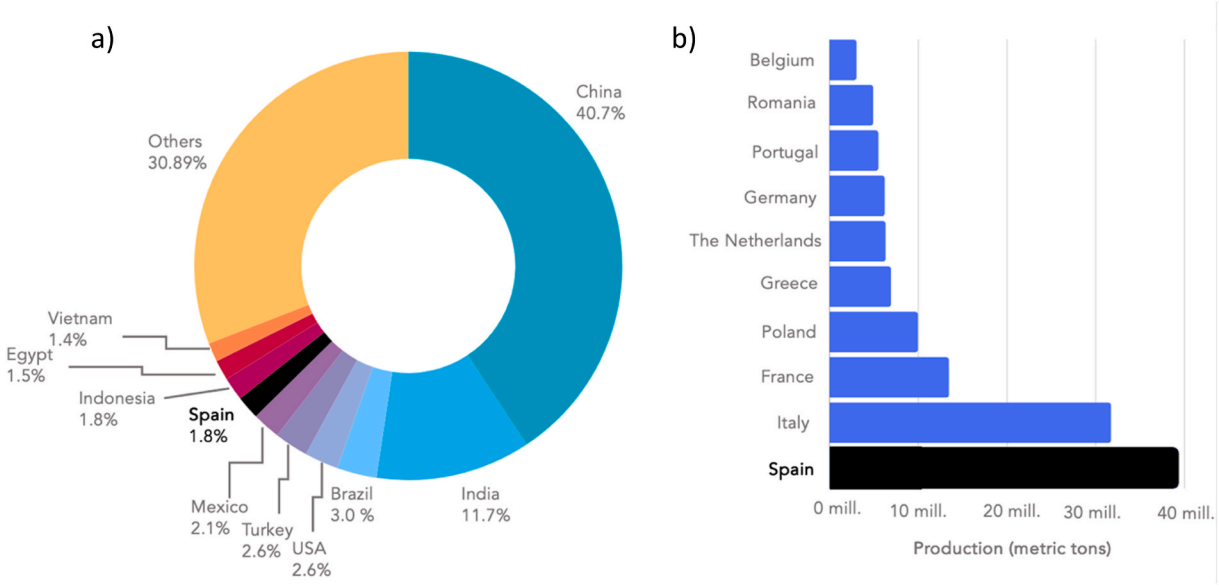

Fig. 1. Fruit and vegetable production: a) Top ten global fruit and vegetable producers (in % of production); b) Top ten European Union fruit and vegetable producers (in metric tons). Sources: FAOSTAT 2021.

BOX 1
Something from Nothing: The cooperative movement in the Almeria agricultural system

The Sea of Greenhouses, Almería, Spain. Image by European Union, Copernicus Sentinel-2 imagery (2020). Source: www.copernicus.eu

The small-holding rapid development of intensive agriculture in Almeria was driven by the cooperative credit movement, which gave marginalized farmers access to credit so that they could buy or improve small farms, set up rudimentary greenhouses, and successfully earn a living (Giagnocavo et al., 2012, 2014). With the end of the dictatorship in 1975, the credit cooperative set up an experimental farm based on intensive greenhouse vegetable production (cultivating a diverse range of crops, such as tomatoes, peppers, cucumbers, and melons), effectively "de-risking" innovation for the small farmers. Marketing cooperatives (producer organizations) were also promoted to aggregate production and access markets and an association of cooperatives was formed to lobby for market share, organize the sector, and share knowledge. Cooperatives also helped to create a functioning civil society out of a fearful and distrustful population fragmented by the politics and social structures of the dictatorship. With finance, knowledge, and market needs addressed by collective action, the introduction and development of intensive agriculture began in earnest (Giagnocavo 2018; 2020). This was coupled with other economic and political events, such as the liberalization of trade, which allowed Almería to export to other European countries during their off-seasons. The cooperative system has created a much greater equitable distribution of wealth from agricultural activities in the region. However, certain inequalities remain, as with the growth of the agroecological system came the necessity of paid farm labor -not included as cooperative members. This lack of inclusion has a special impact on migrant workers from Africa, Eastern Europe, and Latin America.

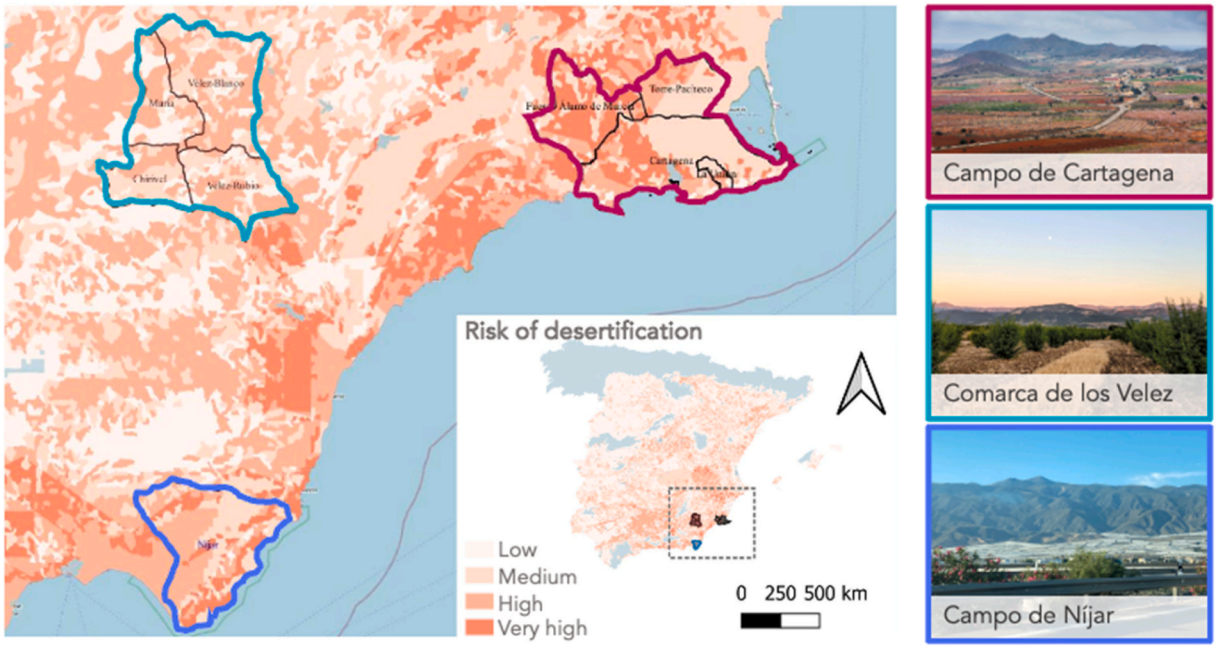

Fig. 2. Map overview of the semi-arid case study areas in southeast Spain: Comarca de Los Vélez and Campo de Níjar (Almería province), and Campo de Cartagena (Autonomous Community of Murcia). The 3H-CLD process consisted of four in-person workshops and one online workshop. Three of the in-person workshops were conducted in the local case studies (i.e., Campo de Cartagena, Comarca de Los Vélez, and Campo de Níjar), and one at the regional scale (with actors from both the Province of Almeria and the Autonomous Community of Murcia). The online workshop was organized with participants from all the case studies and scales, to share the results of the CLDs and bridge the gap between local and regional levels of analysis.

namely environmental, social, economic, and governance. To incorporate a systems thinking vision that considers the underlying system structures that might promote or hinder transformative change, we incorporated the co-creation of Causal Loop Diagrams (CLDs) in identifying current challenges in the second step of the process. We named this new approach 3H-CLD (see Appendix 1; Aguiar et al., 2025), which was conducted from June 2022 to March 2023 in Spain with 90 participants (Fig. 2) For detailed information on participants and case study selection see López-Rodriguez et al. (2024).

2.2.1. Participatory causal loop diagrams

The co-creation of CLDs enabled the identification of the most pressing challenges and their root causes as perceived by actors with different experiences and expertise at multiple scales. Within the broader 3H-CLD process, the participatory CLDs were co-created in step 2 through several phases (Fig. 3). First, the participants identified the main problems that hold the current system in place and collectively prioritized two to three core problems. The selected problems acted as the initial variables to start building the CLDs. The exercise progressed by encouraging participants to reflect on the causes and effects of the variables in the diagram (e.g., what is generating this problem/variable? or what is being generated by this problem/variable?). In this way, participants could iteratively examine deeper factors and add new variables to the CLDs. To establish causal relationships between variables in the CLDs, arrows and polarity signs (+ or -) were added between variable pairs to denote the type of cause-effect relationship. A '+' sign indicates variables moving in the same direction (that is, an increase in variable "A" causes an increase in variable "B" compared to what would otherwise have been the case), while a '–' sign denoted opposite directions (that is, an increase in variable "A" causes a decrease in variable "B" comparing to what would otherwise have been the case). Further, as systems thinking emphasizes interconnectedness through circular causal relationships, feedback loops were identified with the participants when possible. Eight CLDs resulted from the workshops. The discussions held between the participants around the creation of the CLDs were recorded and transcribed to support the following phases.

2.2.2. Integrated causal loop diagrams

During the 3H-CLD workshops, priority was given to nurturing the dialogue between the participants, rather than obtaining exhaustive and finalized CLDs outputs. Thus, the paper's co-authors and two other regional economic experts reviewed the eight CLDs in consecutive internal meetings, integrating and refining them to produce 3 integrative CLDs (iCLDs). Reviewers included an interdisciplinary team of researchers with broad experience working in Almeria and Murcia, as well as systems thinking experts. The iCLDs were built by first identifying recurrent and relevant variables and cause-effect patterns across the 8 CLDs. The creation of the iCLDs was then an iterative process of synthesis of the results from the workshop and expert consultation, with a special emphasis placed on identifying feedback loops. They were categorized as either reinforcing loops, which typically drive the system to continue in the same direction - amplifying an ongoing process; or balancing loops, which often steer the system towards stability and buffer system dynamics. The snowballing effect of reinforcing loops propels the system in the same direction (either growth or decline), while balancing loops typically keep the system in stability or control (Maani and Cavana, 2007). The iCLD creation process allowed us to identify some of the pivotal components holding the system in place and offer a succinct yet comprehensive foundation for understanding the causes of problematic system dynamics. When cause-effect links were

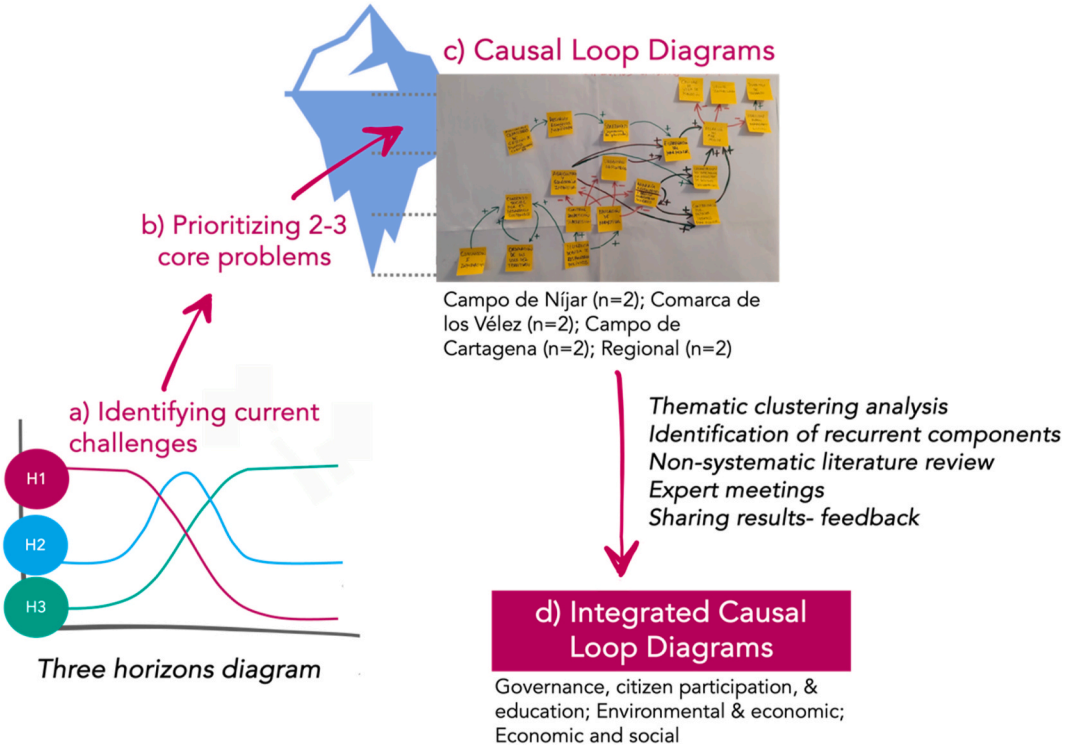

Fig. 3. The 3H-CLD method for building the integrative causal loop diagrams (iCLDs). a) identification of current challenges using the 3H-CLD approach; b) prioritization of 2–3 core problems; c) generation of 8 participatory CLDs; and d) creation of 3 iCLDs. Phases a, b, and c were part of the multistakeholder dialogues, while Phase d involved an interdisciplinary team of researchers analyzing, processing, and synthesizing the results. Building on the 8 participatory CLDs (6 focused on the local case studies and 2 on the regional scale), the last Phase included: 1) Thematic clustering analysis of the main concerns, which guided the construction of three interconnected iCLDs related to "Governance and education dynamics", "Environmental dynamics", and "Economic and social dynamics"; 2) Revision of the eight CLDs and identification of recurrent similar components; 3) Building new diagrams based on the recurrent and relevant components, the transcripts from the discussions, the initial causal relations from the eight CLDs, a non-systematic literature review, expert meetings to discuss the results and stakeholders' feedback.

difficult to distill from stakeholder perceptions but identified as relevant by the expert group, a literature review was conducted. The Vensim software was used to digitalize the iCLDs. Preliminary results were presented in March 2023 in an online workshop with multiple stakeholders from the case study areas. Afterward, results were shared with the participants to allow providing feedback individually. See Fig. 3 for a detailed explanation of the construction of the 3 iCLDs-which are explained in the result section.

3. Results

3.1. Governance and education dynamics

This iCLD covers some of the major problems identified by the participants during the workshops, namely, the need for governance mechanisms that enhance public participation and sustainability education to promote well-informed citizenship and their involvement in decision-making to progress toward sustainability. The iCLD highlights how participants perceived the functioning of the current governance system and its relation with the conditions for citizen participation and the promotion of education for sustainability programs. This iCLD shows four reinforcing loops (Fig. 4). See Table 1 in Appendix 1 for participant quotes and literature supporting the causal links.

The *Collaborative governance reinforcing loop (R1)* refers to the deliberative dialogue and active citizen participation that brings multiple voices and different perspectives to the fore to push a collective decision-making process. By enabling multiple stakeholders to directly influence decision-making processes, short-term votes-gaining-oriented decisions can be mitigated. Participants refer to two of the cornerstones for collaborative governance, namely transparency and social trust in the process. Transparency involves the availability and provision of truthful information to the citizens as well as the clarity about government rules, regulations, and decisions. By ensuring a certain degree of transparency between the citizens and government, a stronger degree of social trust, and increasing mobilization and participation of citizens might be expected over time. Building social trust fosters people to work together, understand different perspectives, embrace dissensus and engage in strong collaborative processes for decision-making despite potential disagreements. Furthermore, collective efforts in moving towards greater participation in decision-making are linked to the ability to build a sense of agency and hope that fosters a participation culture (*Empowerment reinforcing loop (R2)*). Mobilization and citizen participation are influenced by and influence the creation of conditions for such participation, and such conditions are key to ensuring collaborative governance.

The *Legitimacy reinforcing loop (R3)* shows how transparency on the information provided to the citizens fosters the availability of reliable information that supports better-informed citizens. Such well-informed citizens will bring credibility and legitimacy to the decision-making processes, which has a positive impact on the conditions for citizen participation and collaborative governance. In connection with this, the *Information reinforcing loop (R4)* refers to the potential role of communication media in generating reliable information that keeps people properly informed. Furthermore, well-informed people will demand higher standards of information in communication media. However, the participants' perceptions revealed a high level of skepticism regarding this, attributing it to the disinformation caused by an overload of information and the lack of trust in the communication media. Additionally, the participants highlight that Education for Sustainability has the potential to positively affect the *Information reinforcing loop (R4)* and the *Empowerment reinforcing loop (R2),* through increased environmental awareness and critical thinking.

An outcome of adequate collaborative governance is the creation of policies and laws that are adapted to the context, coherent and socially inclusive. Such policies will influence governance decisions on funds distributions, that affect social-economic dynamics (see section 4.1.3) and the policies and laws oriented to balance human well-being and ecosystems' integrity (see section 4.1.2).

3.2. Environmental dynamics

This iCLD summarizes the main environmental challenges concerning the irrigated intensive agricultural production system (see also section 4.1.3) and the tourist sector, namely, the loss of biodiversity, habitats, and ecosystem services, the pollution by agrochemicals, the erosion and degradation of the soil, and the land conversion and aquifers

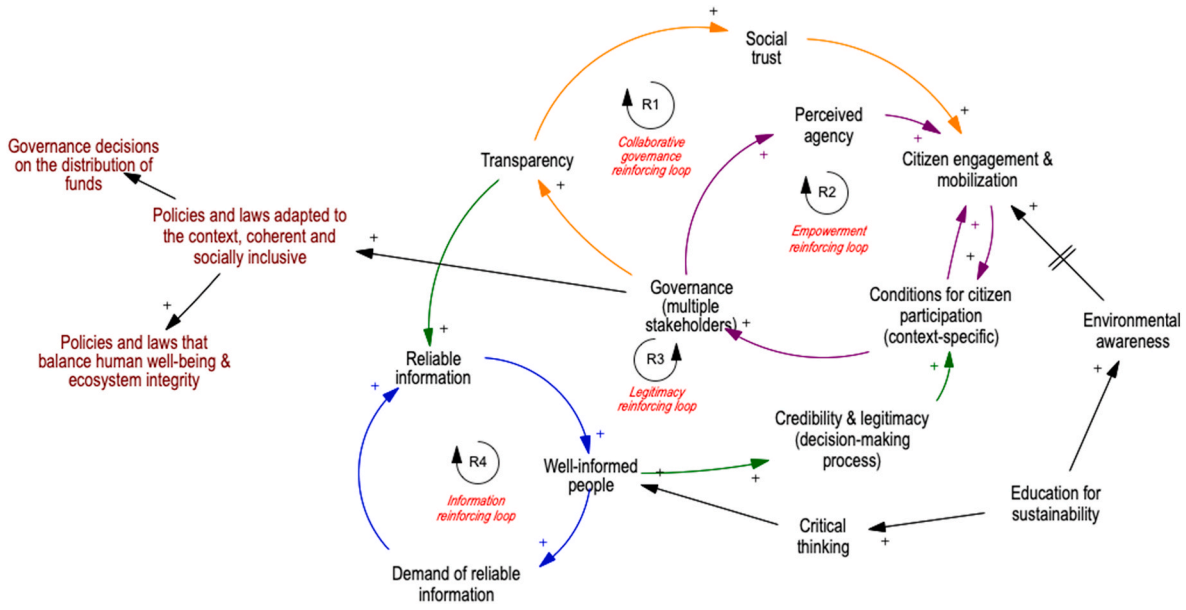

Fig. 4. Integrated causal loop diagram (iCLD) of the governance and education dynamics. (+) arrows represent an increasing effect on the variable, and (−) arrows represent a decreasing effect. Colors aim to support readability by highlighting (a) the main reinforcing and balancing loops (colored arrows) and (b) the variables that are more external to the system (dark red). Black arrows represent the causal relations outside the loops, and arrows crossed with two lines represent a delay in the causal relation.

overexploitation. This iCLD shows three reinforcing loops and three balancing loops (Fig. 5). See Table 2 in Appendix 1.

The *Agrochemicals reinforcing loop* (R1) involves the loss of biodiversity resulting from the use of agrochemicals in agriculture and other pollution sources. Polluted irrigation returns containing agrochemicals such as fertilizers, soil fumigants, and pesticides constitute a major cause of groundwater contamination in the region. Particularly, nitrogen and phosphorus (N&P) from these sources infiltrate the soil, degrading the quality of the aquifers. Furthermore, seasonal heavy rain events lead to nutrient-rich runoff, carrying N&P, heavy metals from past mining activities, untreated reclaimed water, and plastics. This negatively impacts biodiversity in aquatic and terrestrial habitats and the services that they provide, subsequently creating a need for increased agrochemicals (e.g., to combat pests in an ecosystem that has lost the auxiliary predators) to maintain production. On the other hand, the decline in biodiversity contributes to a gradual reduction in crop yields over the medium to long term, initiating the *Biodiversity loss balancing loop* (B1).

The *Tourism reinforcing loop* (R2) signifies the seasonal concentration of tourists in the coastal areas of the region, driven by large-scale urban developments supported by revenue generated from tourism. This further enhances the region's attractiveness as a "sun & sand" tourist destination. However, the loss of biodiversity and degradation of natural habitats (e.g., the extreme case of the Mar Menor, Box 2), adversely affect the tourism sector (especially the rural and outdoors-related tourism). As these areas lose their natural value, they become less attractive to tourists. Consequently, if there is a reduction in tourist activities and an associated reduction in water and land use, waste generation, etc., this alleviates pressure on ecosystems (*Tourist balancing loop* (B2)).

The *Land conversion & aquifers overexploitation reinforcing loop* (R3) illustrates the mutual reinforcement between land conversion dynamics and the overexploitation of aquifers, coupled with the utilization of diverse water sources. The expansion of irrigated agriculture has intensified the strain on water resources, particularly underground water, leading to the overexploitation of some aquifers. Additionally, the degradation of groundwater quality due to salinization and N&P pollution in combination with the aquifers' overexploitation have compelled the adoption of alternative water sources, including reclaimed water, desalinated water, and transferred water. However, these alternative sources have brought associated challenges such as conflicts with other regions in the case of transferred water in Murcia, and the necessity for subsidies to reduce desalinated water prices. While the diversification of water sources, along with advancements in irrigation technologies, has alleviated pressure on the aquifer system, the availability of water for agricultural activities has contributed to the continuous expansion of cultivated lands in recent decades. Uncertain variables, including droughts and high temperatures induced by climate change, conflicts arising from the growing scarcity of water (e.g., limitations on water transferred from the Tajo-Segura transfer imposed by national institutions), and the rising prices of desalinated water due to the global increase in energy prices, might act as limiting factors for the continued progression of land conversion to agriculture.

Finally, the *Erosion balancing loop* (B4) pertains to the erosion occurring in agricultural land as a result of its conversion from rain-fed crops to irrigated crops, and of tillage practices that keep the soil bare almost during the whole year. While the intensification of agricultural production relies on this land transformation, erosion serves as a balancing loop for agricultural production.

3.3. Economic and social dynamics

This iCLD reflects the main economic and social dynamics configuring emigration and immigration patterns in the region and inequalities. This iCLD shows seven reinforcing loops (Fig. 6). See Table 3 in Appendix 1.

The *Growth reinforcing loop* (R1) represents a common economic dynamic in production systems, whereby revenues generated from irrigated agricultural production are reinvested to further increase production. However, it is important to note that there are differences depending on the business model. For example, agriculture cooperatives reinvest or distribute the benefits amongst their members. Simultaneously, the *Economies of scale reinforcing loop* (R2) demonstrates the cost advantages of large-scale intensive systems, resulting in higher revenue generation compared to smaller production systems. In our region, the advantages are mostly connected to the producer organizations in first and second-tier marketing cooperatives as well as

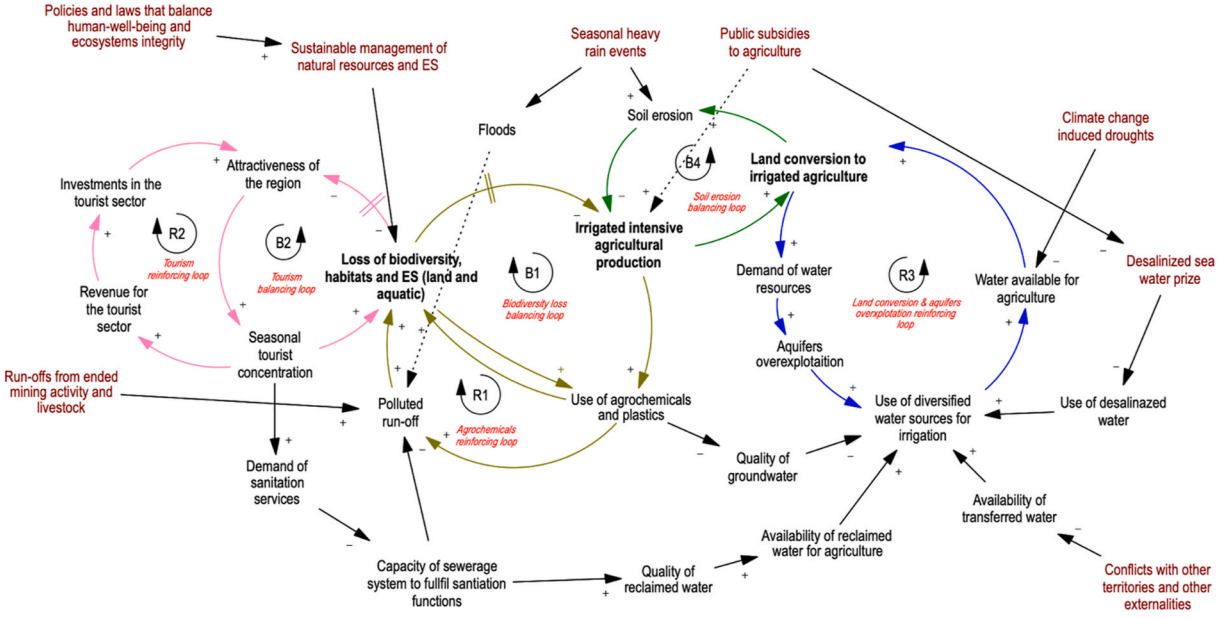

Fig. 5. Integrated causal loop diagram (ICLD) of the environmental dynamics. (+) arrows represent an increasing effect on the variable, and (−) arrows represent a decreasing effect. Colors aim to support readability by highlighting (a) the main reinforcing and balancing loops (colored arrows) and (b) the variables that are more external to the system (dark red). Black arrows represent the causal relations outside the loops, and arrows crossed with two lines represent a delay in the causal relation.

BOX 2
Eutrophication and social-ecological tensions in the Mar Menor, Murcia

Mar Menor, Murcia, Spain. Image by Jose A. Source: Wikimedia Commons

The Mar Menor is the largest European hypersaline lagoon (135 km^2) located in the Region of Murcia, Southeast Spain. The lagoon and the surrounding salt marshes have been recognized as a *Special Protection Area* (SPA) in the EU's Natura 2000 network, as a *Wetland of International Importance* in the RAMSAR list, and a *Specially Protected Area of Mediterranean Importance* (SPAMI). Since 2016, the Mar Menor has been in the spotlight of regional, national, and international media, when the first episode of anoxia due to a phytoplankton bloom caused the massive death of flora and fauna. Different economic activities have caused Mar Menor's water deterioration for decades: nitrate inputs from agricultural intensification, mining activities (now ended), and the pressures generated by the "sun and beach" tourism (Velasco et al., 2018; Álvarez-Rogel et al., 2020). Current attempts to solve the lagoon's dramatic situation range from technological measures to recover the ecological features of the lagoon (e.g., beach cleaning, and water quality monitoring), participatory research processes to inform decision-making, and contestation from environmental movements and researchers to put a limit to the polluting activities (and comply with the environmental laws in place). In 2021 the Ministry for an Ecological Transition defined a holistic plan of measures to recover the Mar Menor, including the inspection and closure of illegal wells and desalination plants in the farms and a new multi-actor participatory processes.

companies, which coordinate the exportation of products to international markets. Thus, these revenues are influenced by the market power of external (European) supermarkets, which can impact agricultural product prices. Additionally, the irrigated intensive agriculture production system generates externalities, as described in section 4.1.2.

This production system forms an agro-industrial cluster with R&D&I centers, input companies (e.g., seeds, plastics, fertilizers), and other auxiliary companies, fostering the emergence of medium to high-income professionals (e.g., farmers, engineers, lawyers, etc.), driving great economic growth in the region over the past 60 years. However, it also generates numerous low-income or low-wage jobs, e.g., greenhouse workers, packaging, etc. This duality of high and low-income jobs generates the coexistence of two contrasting realities in the region. On the one hand, the *Emigration reinforcing loop* (R3) illustrates how low-income and temporary contracts reduce the attractiveness of the regional labor market, especially for young people who may choose to migrate elsewhere. As a result, many jobs are filled by immigrant workers, mainly from Africa, but also from Eastern Europe and Latin America (*Immigration reinforcing loop* (R4)), and the supply of immigrant labor exerts downward pressure on wages (when considering the increase in the percentage of foreign-born population over the total population).

On the other hand, the *Inequality reinforcing loop* (R5) signifies the disparities generated by the agricultural production system. The numerous low-wage jobs required for agriculture in the region lead to an unequal distribution of benefits and incomes derived from production activities. These social inequalities can contribute to exacerbating negative intergroup relations, which hinder social integration -especially between immigrants and locals (e.g., the segregation of some immigrant populations in ghettos due to housing prices and mistrust) - and fuel conflicts. Participants perceive that these (latent) conflicts may also contribute to diminishing the region's social and cultural attractiveness, further encouraging the emigration of young people (e.g., from municipalities with a large immigrant population) that might reinforce the dynamics described in R3 and R4. The region's attractiveness is further hampered by the lack of public investment in social, economic, and cultural services (especially for young people and in rural areas), which also impacts social integration processes in the medium to long term -public education that fosters diversity and an improved cultural offer are seen as key factors to foster societal integration.

The *Alternative models reinforcing loop* (R6) introduces possibilities for economic generation beyond the mainstreamed irrigated agricultural production system. Alternative business models such as small and medium-sized social enterprises, multi-stakeholder cooperatives, and circular economy businesses, offer opportunities for new and sustainable models that can diversify the region's economic activity in the long term while maintaining traditions and people's roots in the territories. A diversified economy (focusing on increasing the added value of the products, processes, and services), is argued to enhance the social and cultural attractiveness of the region, potentially encouraging young people to remain and thereby improving the prospects for creating these new business models. These businesses follow a similar revenue-investment dynamic as more traditional enterprises (*Small businesses reinforcing loop* (R7)). However, challenges in accessing subsidies or attracting investments, which are often more easily secured by larger businesses due to European and Spanish regulations and/or financial criteria, pose challenges.

4. Discussion

While there is a consensus within the scientific community that a fundamental transformation of global food systems is indispensable to maintain Earth's equilibrium within planetary boundaries, there are myriad ideas of what an appropriate food system transformation looks like. Our findings underscore that transitioning to plant-based diets may

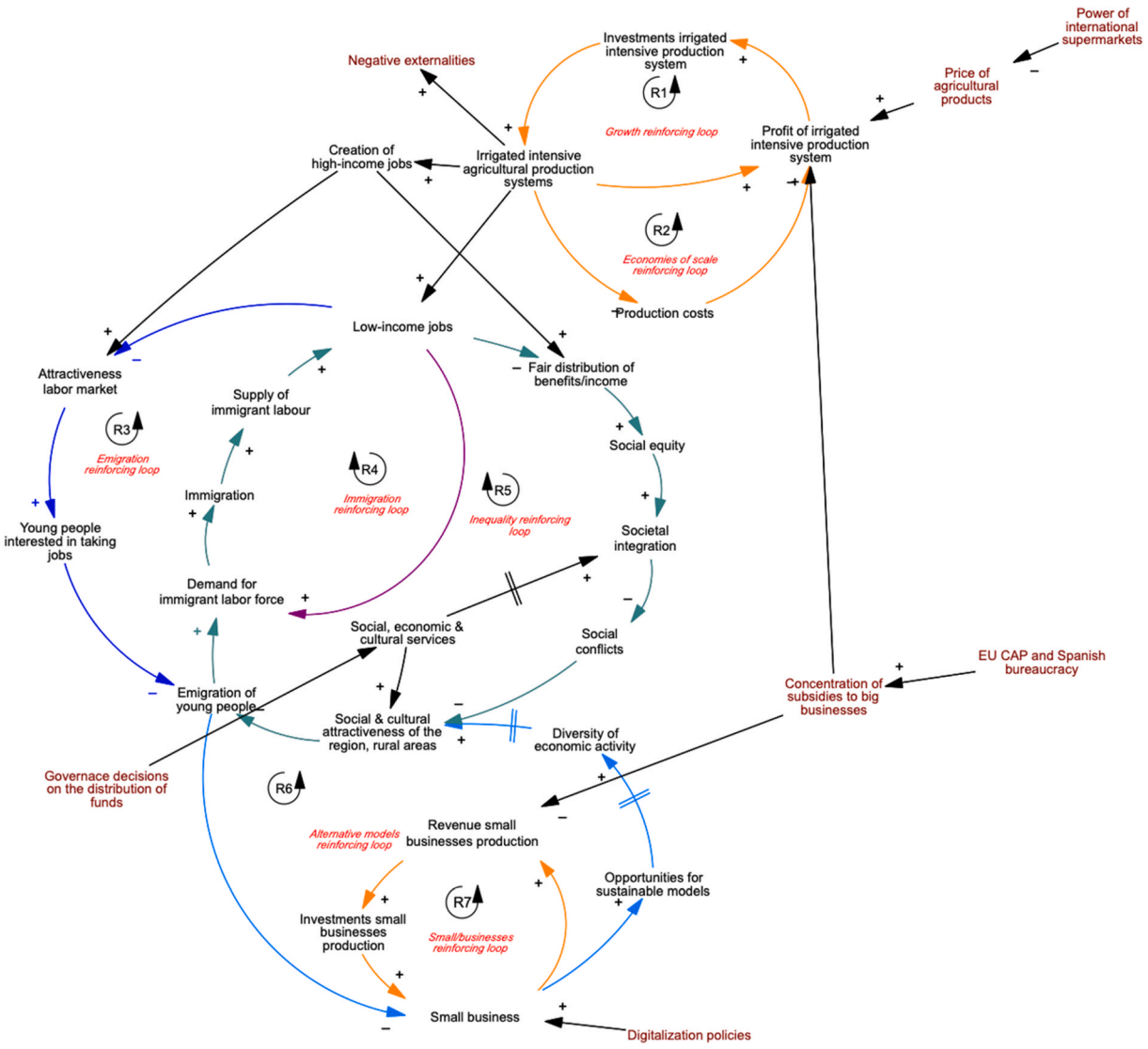

Fig. 6. Integrated causal loop diagram (ICLD) of the economic and social dynamics. (+) arrows represent an increasing effect on the variable, and (−) arrows represent a decreasing effect. Colors aim to support readability by highlighting (a) the main reinforcing and balancing loops (colored arrows) and (b) the variables that are more external to the system (dark red). Black arrows represent the causal relations outside the loops, and arrows crossed with two lines represent a delay in the causal relation.

exacerbate current unsustainable dynamics in F&V production at sub-national scales if there is not a reconfiguration of the system at multiple scales and dimensions. Thus, it is crucial to unravel such unsustainable dynamics and the cross-scale trade-offs for advancing towards a more sustainable global food production, not only on the environment but also on associated social, economic, and governance subsystems. By using a region in Southeast Spain, we illustrate the potential trade-offs across scales in meeting (future) global F&V demands.

4.1. A governance model lacking cooperation and fostering polarized views

Our findings emphasized the erosion of trust and legitimacy of sustainability-related governmental processes due to several reasons, such as the lack of mechanisms in Spanish public administrations to foster collaborative governance and the absent participatory culture among the citizens to share responsibilities and work towards sustainability (see, e.g., López-Rodríguez et al., 2020) Furthermore, our results reflect the inadequacy of the existing educational system in nurturing sustainability competencies (Wiek et al., 2011) as well as the widespread dissemination of mis- and disinformation concerning sustainability issues -especially related to the F&V production model-that contributes to generating social confusion and polarized views (Galaz et al., 2023). Hence, the increasing challenges of the Spanish drylands are enhanced by the obstacles to progress toward more plural governance systems (Castro et al., 2019) along with polarized perspectives concerning the future trajectory of the current F&V production model. For example, perspectives diverge on the strategies to tackle the social-ecological challenges stemming from this model and the attribution of responsibilities for the problems. In this respect, Cabello and Brugnach (2023) identified two contrasting narratives around the eutrophication of the Mar Menor (see Box 2). These narratives exhibit polarized views regarding the causal factors, responsible entities, and potential solutions for the lagoon's eutrophication, including the role of the F&V agriculture model. Each perspective is championed by advocacy groups with their own supporters and opponents, who seek to sway public opinion (e.g., through social media or prominent regional newspapers), thereby fostering a dynamic of escalating polarization. These tensions are coupled with the complex Spanish water and ecosystems management systems, which involve multi-level governmental entities with

intersecting competencies and different consultative bodies often representing multiple and contrasting interests. These multi-layered organizational systems create multiple disagreements on how water and ecosystems should be managed.

In summary, our results confirm that improving trust, transparency, sense of agency, democratic decision-making, legitimacy, and sustainability competencies is perceived as key to fostering the involvement of well–informed actors in the pursuit of successful collaborative governance and the establishment of institutions, as well as policies and laws, aligned with sustainability and justice (see, e.g. Gash, 2016). To advance in this direction, recent literature suggests the need to build upon multi-actor approaches -such as XPaths-that include public, private, academic, and civil society actors to co-produce knowledge and promote social learning processes to find pathways for the transition to a sustainable F&V model, creating a culture of shared responsibility (Castro et al., 2019; Giagnocavo, 2020; MITECO, 2021).

4.2. An agricultural model surpassing biophysical limits in drylands

The increasing F&V production since the 1980s has directly affected the environmental system in the Southeast of Spain (Castro et al., 2018b). The loss of biodiversity, destruction of valuable ecosystems, water scarcity and pollution, and erosion processes constitute key constraints for increasing (or even sustaining) the F&V production levels in the region (Castro et al., 2018a; Quintas-Soriano et al., 2018). Uncertain variables such as droughts intensification, floods, and increasing temperatures induced by climate change, along with conflicts arising from the increasing scarcity of water, and escalating prices of desalinated water due to the global surge in energy prices, may also serve as limiting factors for the continued progression of land conversion to agriculture in the region (Quintas-Soriano et al., 2014). Some of these challenges were identified by A.J. Castro et al. (2019) in a transdisciplinary process with the Almeria greenhouse horticulture sector. Among other issues, they identified the trade-offs between conserving biodiversity and habitats and expanding agricultural land, as well as the difficulties in the implementation of measures for the sustainable and efficient use of water. Addressing these challenges might require levering alternative water sources subsidized through tax relief or price reductions and better control of illegal wells (Castro et al., 2015).

Multiple technical solutions have been implemented and proposed by farmers, agricultural organizations (such as irrigation communities and cooperatives), and researchers to increase irrigation efficiency, reduce fertilizers, or minimize waste production (see, e.g., Fundación Ingenio, 2020; Aznar-Sanchez et al., 2020; Egea et al., 2021). These locally implemented measures are aligned with some of the technical solutions proposed to make food production more sustainable globally (the so-called sustainable intensification; Ibarrola-Rivas et al., 2018). For example, increasing nitrogen-use efficiency, phosphorus recycling, improvements in storage capacity and utilization of rainwater (Springmann et al., 2018; Ruiz-Nieto et al., 2022) or the mechanization and monitoring of cropping systems, soil erosion control measures, integrated pest management or precision agricultural techniques (Willett et al., 2019; Stratton et al., 2021). I fact, the drylands of Southeast Spain are internationally recognized as a frontier in agricultural technological advancements and efficient irrigation systems (Colino-Sueiras and Martínez-Paz, 2002; Castro et al., 2019). However, these technical solutions have also been contested, arguing that effective solutions demand a deep transformation of agricultural practices, addressing the root causes of the problems through process-integrated approaches that tackle the social, ecological, and economic dimensions of the system (Ruiz-Nieto et al., 2022). Other authors have highlighted the lack of knowledge on the precise utilization of water and fertilizers, the uncertainty regarding the portion of ferti-irrigation absorbed by crops and the amount that is reintroduced into the system, and the unknown extension of illegal irrigation and number of crop yields (Cabello and Brugnach, 2023). Further, despite the regulations to limit the expansion of agricultural land, in Almeria, for example, the greenhouse area increases every year, with an average accumulated increase of 1,8% in the last ten years (Cajamar 2022).

4.3. An agricultural model sustained on immigrant low-wage labor

The expansion of the F&V production model has radically changed the socio-economic dynamics in the region. Our analysis shows an immigration-emigration reinforcing loop in which the labor conditions are unattractive to local youth, prompting their migration to other regions and incentivizing immigration from other countries (notably Northern Africa, Eastern Europe, and Latin America) to fill the vast labor required to feed Europe. Long-term international migration has contributed to the development of multicultural and diverse societies in municipalities with high F&V production. For instance, in 2022, 40.4% of Campo de Nijar's population was foreign-born, and the municipality's population has doubled over the past 20 years (INE, 2024), resulting in a pressing lack of affordable and adequate housing. Adequate housing is one of the major challenges faced by the immigrant population. Multiple scholars and international media have raised concerns regarding the substandard living and working conditions experienced by certain migrant workers in greenhouses and crop areas, especially undocumented migrants (Corrado et al., 2016). It is estimated that more than 3000 people are living in extreme conditions across more than 70 shantytowns and other settlements in Almeria (with an average of 63% being undocumented) and almost 300 people in 20 larger shantytowns in Murcia (Cepaim, 2018; MDSA2030, 2022). Similar scenarios for other production regions (or enclaves) have been documented across Europe, for example in France, Greece, or Italy (Corrado et al., 2016; Olmos et al., 2018; Rye and O'Reilly, 2021; Reid et al., 2021). The normalisation of living and working conditions for undocumented migrants is often dependent on public administrations recognising that this population resides in the territory permanently. Furthermore, the mechanisms for the personal integration of migrant families (both documented and undocumented) become essential, and public policies in these territories must be proactive and decisive in achieving the full integration of the immigrant population, not only from a cultural or educational perspective but also from a socio-economic and gender equality standpoint (Kofman, 2023).

Additionally, Medland (2017) cautions against the EU Seasonal Workers' Directive's misconceiving understanding of seasons (Directive 2014/36/EU), which fails to align with the year-round F&V cultivation in this region (including production, clean-up, reconditioning, or packaging). Consequently, the Spanish Law 4/2000, which transposed this Directive, hinders the opportunities for immigrant workers to secure a permanent contract (setting their contracts to a maximum of 9 months). By necessitating the renewal of contracts for each campaign, this law exacerbates the vulnerability of immigrant workers to abusive labor practices, such as being required to work more hours than stipulated in their contracts or experiencing difficulties in obtaining time off for medical appointments (Andalucía Acoge, 2022). Additionally, the expiration of the Collective Bargaining Agreement for Agricultural Workers in Almeria and Murcia in 2015 and 2016, respectively, is hampering the working conditions of all agricultural workers-regardless of their nationality (update: after the submission of this paper, the Collective Bargaining Agreement for Agricultural Workers in Almeria was updated on November 25, 2024).

4.4. Beyond the local: sharing responsibilities and costs across scales to transform the agrifood system

To address the escalating demand for F&V production in alignment with diets promoting planetary health and amid population growth, the intricate dynamics mentioned above pose a pivotal question: who should shoulder the responsibilities and the accompanying costs of transforming the agrifood system? While responsibilities in a food value

chain are shared, there are stronger and weaker links. In this sense, our results bring some insights into some key actors that operate beyond the local agrifood system but have a great potential to influence it and share the responsibility for its transformation. The actors identified can be grouped into four main types: retailers, public administrations, F&V cooperatives/companies, and agriculture-related auxiliary companies.

First, regarding the retailers, one main factor impacting agrifood systems is "the growth of supermarket chains as "food authorities" […], not only control[ing] distribution, but also shap[ing] decisively the production, processing and consumption of food […] as a result of their enormous buyer power" (Corrado et al., 2016, p.7-8). Transnational retailers generate their own private standards and certification systems to regulate, among other issues, environmental criteria, food safety and quality, or labor rights in the agrifood supply chains (Van Der Grijp et al., 2005; Corrado et al., 2016; Halabi and Ching-Fu, 2017). Such a privileged situation allows these retailers to set low F&V prices in an asymmetric power relation with suppliers, which are dispersed despite their aggregation in farmers' cooperatives and companies (European Parliament, 2011; Corrado et al., 2016). As shown in our result, one response of small-medium farmers to the pressure of these retailer-driven food chains has been the growing use of immigrant labor force, which is driving inequalities in enclaves of fresh F&V production (Corrado et al., 2016). We argue that beyond developing better private standards for labor rights, sharing responsibilities regarding workers' rights while securing affordable F&V access requires measures that avoid putting pressure on cost reduction down in the food chain toward farmers (Moraes et al., 2012; Corrado et al., 2016).

Second, our findings highlighted national and European policies' need to foster agrifood transformations through environmental and social regulations that are contextually adapted, coherent, and socially inclusive. Our results suggest that European laws and other regulations impacting F&V production (e.g., the Common Agricultural Policy or the Seasonal Workers Directive 2014/36/EU) are ill-suited to the specific contexts of F&V production enclaves. While the EU operational programs specifically designed for producer organizations in the F&V sector are considered a model approach, it has many shortcomings in offering support for the weaker links in the F&V supply chain.

Third, farmer producers are a fundamental part of supply chains and networks that provide F&V to consumers, yet they are the weakest link. In an attempt to balance market power, small-scale growers often rely on horizontal integration through the formation of marketing and supply companies, cooperatives, and other social economy enterprises (e.g. S.A.T.) (Pérez-Mesa et al., 2021). They produce the F&V, and in doing so they exert a direct activity on natural resources and ecosystems, as well as on the working conditions of the workers involved. While they derive some benefits from the agricultural system, they also bear the risks and costs of production and those derived from compliance with the requirements of public and private actors and attempts to improve sustainable practices. Thus, although technological innovations for water and fertilizer efficiency, as well as collective structures for democratic governance (i.e., agricultural cooperatives), may contribute towards more sustainable and just agriculture, further considerations are needed. For example, concerning inclusiveness, there are still effective limitations on who might join the cooperatives (e.g., owning or managing a farm), and workers and women in packaging, for example, are traditionally excluded from being cooperative members and hold the status of non-member workers. Regarding water consumption, several authors have raised concerns about the "paradox of irrigation efficiency" (Grafton et al., 2018; Pérez-Blanco et al., 2021), referring to the myth that investments in modern irrigation systems will automatically safe water – not considering that water might be redirected to higher water-intensive crops or to increase the hectares under cultivation (La Roca and Martínez, 2023).

Finally, and although outside the scope of this paper due to its huge diversity, the agriculture-related auxiliary companies, and especially the big input companies (e.g., seeds, plastics, fertilizers) -together with the big retailers-have the policy advocacy, innovation, and buyer/supplier power to steer the system into new directions. Perspectives on the role of keystone actors (such as transnational corporations) in moving towards sustainability are gaining relevance (see, e.g., Österblom et al., 2015, 2022; Folke et al., 2019). However, whether their role sits in the realm of responsibility (to fix the problems caused in the first place) or levelers of transformative change is discussed, as system change would require a major structural transformation of these actors and alternative forms of organizing the economic system (Etzion, 2020; Schneider et al., 2020).

5. Conclusions

The imperative to enhance F&V production is pivotal for establishing more sustainable and just food systems. However, this pursuit is not without challenges, as F&V enclaves worldwide grapple with social-ecological dynamics that may perpetuate unsustainable pathways. Our research sheds light on these intricate dynamics and points at the cross-scale trade-offs of increasing F&V production globally, while providing guidelines to start a discussion on where the leverage points to change the system may reside. Our findings highlight the importance of applying a system perspective to share the responsibilities and costs required for food system transformations among multiple stakeholders at different scales. Retailers, governance institutions at multiple scales, collective structures of farmer producers, auxiliary industries, and other actors across the supply chain have the potential -and also the responsibility-to steer the system toward sustainability focusing on fostering collaborations between institutions, considering the biophysical limits of the territories and promoting a labor model that is inclusive and just.

CRediT authorship contribution statement

Jiménez-Aceituno A: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **López-Rodríguez M.D:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **Castro A.J:** Writing – review & editing, Validation, Data curation. **Cortés-Calderón S:** Writing – review & editing, Formal analysis. **Collste D:** Writing – review & editing, Formal analysis. **Aparicio G:** Writing – review & editing, Visualization, Validation. **Rölfer L:** Writing – review & editing. **Bote M.A:** Writing – review & editing, Validation. **Marín L:** Writing – review & editing, Validation. **Gómez-Tenorio M.A:** Writing – review & editing, Validation. **González-Martín B:** Writing – review & editing, Validation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Amanda Jiménez-Aceituno, Maria D. López-Rodriguez, Antonio J. Castro, Sofía Cortés-Calderón and David Collste report financial support was provided by Swedish Research Council Formas (ref:2020-00474). If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. The 3H-CLD approach

The 3H4SDG approach has been used to guide socially inclusive and plural discussions to develop bottom-up pathways toward the SDGs in the global research initiative The World in 2050 (www.unsdsn.org/the-world-in-2050), specifically aiming to include perspectives from the Global South in the design of global-scale sustainability pathways. Based on the Three Horizons Framework (Sharpe et al., 2016) and adapted to specifically discussing pathways towards the Sustainable Development Goals (SDGs), the 3H4SDG approach guides a knowledge co-production process structured in three steps: 1) envisioning the desired future, 2) identifying current challenges and its root causes, and 3) exploring strategies to reach the desired futures from the present. Throughout these three steps, ideas are collected regarding different dimensions of sustainability, namely environmental, social, economic, and governance. While this approach has been very useful in understanding local and regional aspirations (Aguiar et al., 2020; Collste et al., 2023), it lacked a systems thinking vision that considers how transformative change may occur and the underlying system structures that might promote or hinder such transformative change. Thus, an improved version of the 3H4SDG was implemented in the XPaths project (www.xpathsfutures.org), which incorporated the co-creation of Causal Loop Diagrams (CLD) in the identification of current concerns in the second step of the process. This new approach is named the 3H-CLD. All four workshops followed the 3H4SDG's 3-step structure (with participants divided into small groups of 6–8) and included plenary discussions and art-based activities to share and discuss group outcomes.

Appendix 1. Tables. Explanation of the causal links for the iCLD using participant quotations from the local workshops in Campo de Cartagena (CC), Comarca de Los Velez (LV) and Campo de Níjar (CN) and the regional workshop (R). G1-G2 refers to the groups in which the 8 CLD were elaborated. When quotations were not found, the rationale and/or references from the literature supporting the causal links were provided. Each pair of variables is identified with the "R" (reinforcing) or "B" (balancing) loop they belong to, according to Figs. 4–6. "EV" refers to external variables.

Table 1
iCLD on Governance and Education ynamics

Loop	Source	Polarity	Sink	Rationale, quotes and references
R1 R3	Collaborative governance (multiple stakeholders)	+	Transparency	"Believers in and proponents of collaborative governance tout its flexibility, creativity and demand-driven orientation towards policy and program development, as well as its adherence to the values of deliberation and transparency" (Gash, 2016, p. 454) "Promoting transparency and legitimacy, then, is the bread and butter of collaborative governance, if the goal is to foster synergies that inspire, create and innovate." (Gash, 2016, p. 456–457)
R1	Transparency	+	Social trust	"The population mistrusts and doubts everything, the question, the answer, the information … not only the media itself is doubted, but also everything that is communicated to through the media. One participant comments that "before you could trust more, now you can't trust anyone"." (CC-G2)
R1	Social trust	+	Citizen engagement mobilization	"Invite people to get involved, but that has to do with regaining trust as well, making sure people get involved in things that are worthwhile, that are real. We have to build trust to generate that behavior" (CC-G2) "People don't participate because they don't trust/don't know what to trust, and so they don't get involved because they aren't confident that they will take to the streets for a truly just cause." (CC-G2) "There is a widespread idea that all politicians are the same, that everything is the fault of the politicians. But the fault of the politicians is also our fault. This distrust in politicians generates a lack of citizen participation, people are either not going to vote or they are going to vote without hope, and participation in social movements, demonstrations, etc., decreases a lot" (CC-G2)
R1	Citizen engagement mobilization	+	Conditions for citizen participation (context specific)	"The democratic and participatory culture has completely disappeared in the last 20 years. It is important to reopen channels and create social fabric. We do not have a culture of participation and commitment, of responsibility" (R-G2) "There is a democratic deficit in institutional functioning. This problem is bidirectional: passivity both on the part of the managers and on the part of the population. Lack of culture of participation and organization of groups." (CN-G2)
R1 R2 R3	Conditions for citizen participation (context specific)	+	Collaborative governance (multiple stakeholders)	"Lack of civil society and the form of culture, the culture is one of consumerism. There is a lack of initiatives, training associations, a lack of social fabric, […] civil society organization." (R-G2) "Apathy, people do not react until the problem is not inside their house. Lack of awareness, culture and collective involvement and associationism. Not even the people who are part of associations are involved. Personal interests are prioritized over collective interests." (LV-G2)
R2	Collaborative governance (multiple stakeholders)	+	Perceived agency	"Low participation in society, the people […] are very apathetic and inactive on a social level. […] Society in general does not see any hope, we need some governance that serve as a reference" (CC-G1)
R2	Perceived agency	+	Citizen engagement & mobilization	"Policy makers are the ones we have chosen, but we have chosen them because of the lack of training, because of the apathy of society. For example, in workers' demonstrations against unemployment, most of the people who go are not unemployed, they are the usual ones, many people who are unemployed do not go to the demonstrations because they have no hope that things will change" (CC-G1)
R2	Conditions for citizen participation (context specific)	+	Citizen engagement & mobilization	"There is a democratic deficit in institutional functioning. This problem is bidirectional: passivity both on the part of the managers and on the part of the population. Lack of culture of participation and organization of groups." (CN-G2)

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Table 1 (*continued*)

Loop	Source	Polarity	Sink	Rationale, quotes and references
				"From the social point of view, what creates a challenge is to develop a society that is much more aware of the environment. There is no real integration of the immigrant, and every time people are more and more disconnected from the heritage here. More cultural activities should be promoted. There are no spaces for young people to meet, no youth centers to meet, watch movies, etc. Generate cultural spaces where culture and activities can be produced and consumed." (CN-G2)
R3	Transparency	+	Reliable information	"Currently it is a society with more freedom: of culture, functional disability … but there is a lack of tools to deal with that freedom. Disinformation due to an excess of information that really is always partial and poor quality information." (CC-G1)
R3 R4	Reliable information	+	Well-informed people	"Neither the information nor the channel through which the information has to pass works. There is a very uninformed population and very easy to deceive. When a society is uninformed, it is weak, vulnerable. It's a paradox, we have more media than ever and the channel is precisely so saturated that people don't know how to distinguish the truth. All information is treated equally, and that causes people to believe information that is not true." (CC-G2)
R3	Well-informed people	+	Credibility & legitimacy (decision-making process)	"In order for citizens to express their preferences effectively—and hold their representatives accountable for realizing those preferences—they require access to the widest possible range of information and arguments" (Kosack and Fung, 2014, p.67) "Lack of technical knowledge in governance, who decides and who commands and makes policies has no knowledge of socio-ecological systems, nor do they consider it important." (LV-G2)
R3	Credibility & legitimacy (decision-making process)	+	Conditions for participation (context specific)	"Individuals will only sacrifice their self-interests if they perceive the collaborative as having procedural and substantive legitimacy. To that end the entity must develop decision-making mechanisms that are believed to be credible and "free from behind-the-scenes manipulation" […] The collaborative must also enlist the help of "facilitative leaders"—individuals who manage the relationships within the collaborative and establish a context for "deliberative dialogue" […], mutual understanding and joint decision-making" (Gash, 2016, p. 456) "These joint endeavors— problem definition, analysis, brainstorming and implementation—require mutual respect and interdependence among participants. And this, of course, rests on the perceived credibility, legitimacy and potential of the collaborative by its members." (Gash, 2016, p. 458) "Legitimacy is a necessary binding agent to sustain member commitment" (Gash, 2016, p. 459)
R4	Well-informed people	+	Demand of reliable information	
R4	Demand of reliable information	+	Reliable information	"We have an example here in the Mar Menor, which got to what it got due to the lack of involvement of many people, not only those who did it wrong but also those who looked the other way. When different facts such as the mortality of fish began to emerge, then public opinion began to turn, to become aware, and began to demand that the decision-makers do things that had not been done before. Thus this vicious circle was broken. What happened up to that moment is that the media had diffused environmental concerns and had sold them as being good for everything, such as that with this water we could have economic development and meanwhile nothing was wrong with the Mar Menor. At some point there has to be a rupture on the part of the base groups for this vicious circle to break. It has to grow one way or another for it to break the natural trend and minimize decision lag." (CC-G2)
EV	Education for sustainability	+	Environmental awareness	"Young people do not have a mentality focused on sustainability, it is something that should be crushed from schools and institutes." (R-G2) "The arid territory today is not valued, we must promote environmental education towards this type of landscape." (CN-G2) "Everything that has to do with sustainability and natural resources has a lot of spiritual value, but no recognized economic value. Should we start putting value on natural resources, on nature? The resources that are converted to the market do not have a problem, but those that do not end up being destroyed. With natural capital and ES, economic value is beginning to be placed on it." (R-G2)
EV	Environmental awareness	+ (time dealy)	Citizen engagement & mobilization	"Judges and prosecutors are now beginning to be aware that Murcian society has a higher level of education and awareness than before. Critical thinking, education, play a very important role in social participation." (CC-G2) "Right now, we live in a culture of regression, the advances that have been made both in social rights and in environmental awareness by certain groups are called into question. There is a very negative general response to environmental activism. Many people think that it is more important that a bottle of tomato sauce not fall on a painting and they put it in the same balance as the environmental and global problem we currently have. That is a clear setback." (CC-G2) "Ignorance of the population and lack of local culture of the population. In the case of almonds, this is a dryland area where there are many almond trees, but you go to a supermarket and you don't find any almonds from here, you don't have the possibility of buying local products. There is also no awareness, because if people started asking when they went shopping (where it came from, how it was collected, etc.), then things would change. Local businesses are not being promoted." (LV-G2)

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Table 1 (*continued*)

Loop	Source	Polarity	Sink	Rationale, quotes and references
EV	Education for sustainability	+	Critical thinking	"Key competencies can be selected and defined which can be considered as important teaching and learning objectives of higher education in the North as well as the South. The most important key competencies are those for systemic thinking and handling of complexity, anticipatory thinking and critical thinking" (Rieckmann, 2012, p.134) "Education for Sustainable Development consequently promotes competencies like critical thinking, imagining future scenarios and making decisions in a collaborative way" (Rieckmann, 2018, p.35)
EV	Critical thinking	+	Well-informed people	"Critical thinking competency: the ability to question norms, practices and opinions; reflect on own one's values, perceptions and actions; and take a position in the sustainability discourse" (Rieckmann, 2018, p.44)
EV	Collaborative governance (multiple stakeholders)	+	Policies and laws adapted to the context, coherent and socially inclusive	"The term [collaborative governance] is used to capture a range of collaborative decision-making activities in which policy approaches are developed through conversations with multiple partners representing diverse interests […] any "method of collective decision-making where public agencies and non-state stakeholders engage each other in a consensus-oriented deliberative process"[…] This model of interest aggregation "combine[s] the perspectives, resources, and skills of a group of people and organizations" […] in order to "resolve shared dilemmas". […] collaborative governance suggests that all aspects of policy design must stem from joint decision-making efforts or "shared power"" (Gash, 2016, p. 455)
EV	Policies and laws adapted to the context, coherent and socially inclusive	+	Policies and laws that balance human well-being & ecosystem integrity	"There is no balance between what can be produced and the people to be supplied, considering the limitations of the territory. But in this case there is no limit to production, so it overflows: more water is consumed than we have, the surface area of greenhouses is increased, … We only operate based on regulatory limits and not on the basis of awareness. The limit is set by profitability, not by any other factor." (CN-G2) "The short-term vision of governance has environmental consequences, making it difficult to fit, for example, the sustainable development goals with the current capital system." (LV-G2) "Lack of technical knowledge in governance, who decides and who commands and makes policies has no knowledge of socio-ecological systems, nor do they consider it important. In addition, it is trying to make a framework that is too large, policies should work locally and grow little by little." (LV-G2)
EV	Policies and laws adapted to the context, coherent and socially inclusive	+	Governance decisions on the distribution of funds	"Not all areas are governed in the same way; there are many more resources where there is more population […] There is almost a direct correlation between how areas are governed and how resources are distributed." (CC-G1)

Table 2
iCLD on Environmental dynamics

Loop	Source	Polarity	Sink	Rationale, quotes and references
R1	Use of agrochemicals and plastics	+	Polluted runoff	"There are no permanent watercourses (runoff mostly infiltrates in the streambeds of the drainage network), although the recent groundwater level rise indicates that several courses may behave partially and temporally as a watercourse (p. 2). Nutrient inputs occur superficially, mainly at the mouth of the Albujón rambla where the flow became permanent since the 1980s." (p.10). (Jiménez-Martínez et al., 2016) "Examples of these impacts are, for example, the disturbing image of ephemeral streams (i.e., ramblas in Spanish) overflowing with the tide of garbage due to a deficient plan of rural hygiene" (Castro et al., 2019) "Authors in the Mar Menor acknowledge that the lagoon receives both nitrogen and phosphorus and they alternate on the limiting role depending on a number of conditions […] In addition, many studies emphasize the insufficient capacity for wastewater treatment in specific locations, seasons and storm events. […]. A stronger consensus is observed around the large area of intensive vegetable crop farming as the main source of nitrogen in the form of nitrates from fertilizers" (Cabello and Brugnach, 2023, p. 1118). "The oldest anthropogenic pressure on the Mar Menor lagoon is linked to the above-described mining in the Sierra de Cartagena- La Unión" (Jiménez-Martínez et al., 2016, p.10)
R1	Polluted runoff	+	Loss of biodiversity, habitats and ES (land and aquatic)	"There are many pollutants present in the water, resulting from anthropic activity. The excess of nutrients in the Mar Menor has given rise to a total eutrophication of the Mar Menor. Not only is the water contaminated, but also the air, the soil, due to agricultural, livestock, industrial and mining activities, although it is not talked about as much." (CC-G1)
R1	Loss of biodiversity, habitats and ES (land and aquatic)	+	Use of agrochemicals and plastics	"The fourth and last fund element considered is the technical means of production. […]it includes instruments or substances that aim at replacing certain ecosystem functions and services such as pest control, fertility replacement, etc., which are manufactured outside the agricultural sector and

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Table 2 (*continued*)

Loop	Source	Polarity	Sink	Rationale, quotes and references
				through the use of fossil fuels or mineral sources." (González de Molina et al., 2020, p.13)
B1	Irrigated intensive agricultural production	+	Use of agrochemicals and plastics	"The production cycles have been entirely separated from natural cycles, and the environmental, social, and economic functions of the traditionally irrigated lands of the Mediterranean have disappeared (e.g., biodiversity, landscape variety, and the conservation of fertile soil). The new production model has forced a spiral of instability; in the case of newly irrigated lands, this is in the form of pollution via the use of pesticides and fertilizers, and the exploitation of aquifers". (Sánchez-Picón et al., 2011, p. 1366)
B1	Use of agrochemicals and plastics	+	Loss of biodiversity, habitats and ES (land and aquatic)	"The loss of biodiversity has been conditioned by the gradual disappearance of dry farming, extensive agriculture has become intensive." (CN-G1) "There are many pollutants present in the water, resulting from anthropic activity. The excess of nutrients in the Mar Menor has given rise to a total eutrophication of the Mar Menor. Not only is the water contaminated, but also the air, the soil, due to agricultural, livestock, industrial and mining activities, although it is not talked about as much." (CC-G1)
B1	Loss of biodiversity, habitats and ES (land and aquatic)	- (time delay)	Irrigated intensive agricultural production	"Depletion of the aquifers, they are leaving the soil completely inert, salinization of the soil, the pH is changing. This is in the hands of very few people, it is monopolized by 4–5 groups, […]. When the big companies release the land, that land is unusable for production." (LV-G1)
R2	Seasonal tourist concentration	+	Revenue for the tourist sector	"Seasonality and imbalance in tourism. The problem is dual: shortage of services out of season, and lack of supplies in high season" (CN-G1)
R2	Revenue for the tourist sector	+	Investments in the tourist sector	
R2	Investments in the tourist sector	+	Attractiveness of the region	"Respondents identified similar positive arguments for urban intensification linked to economic factors, such as its contribution to the promotion of employment (42.79%), creation of housing (17.57%), increasing tourism (6.31%) and increasing population (5.41%). (p. 539). Urban expansion has fostered an explosion of sun and beach tourism at the southwest of the study area (a sort of tourism that takes place on coastlines, where tourists usually sun bathe during the day) (Quintas-Soriano et al., 2016, p. 541)"
R2 **B2**	Attractiveness of the region	+	Seasonal tourist concentration	"This highlights the controversy existing in this area between two opposite models of territorial development; whereas there is massive sun and beach tourism b ased on urban intensification, nature conservation represents the dominant land use in the southeastern portion of the study area (Fig. 1). One of the protected areas, the Cabo de Gata Natural Park, represents the major tourism attraction in the region." (Quintas-Soriano et al., 2016, p. 542)
B2	Seasonal tourist concentration	+	Loss of biodiversity, habitats and ES (land and aquatic)	"A lot of pressure from tourism, there is more or less widespread fear that the park will collapse at some point. There is a massification that is not being limited. Every year it gets worse, more people on the beaches, more rubbish, more queues … People who live here all year round can no longer enjoy the natural park." (CN-G2)
B2	Loss of biodiversity, habitats and ES (land and aquatic)	- (time delay)	Attractiveness of the region	"Concretely, we have found that the Industry and Building, Financial and Real Estate, Major and Minor trade, and Accommodation sectors are impacted by ecological degradation in the Mar Menor" (Maté-Sánchez-Val and Aparicio-Serrano, 2023, p. 7) " Positive arguments supporting protected areas demonstrate that respondents identify these areas in terms of enjoying healthy environments and nature conservation, leading to increasing tourism" (Quintas-Soriano et al., 2016, p. 542)
R3	Land conversion to irrigated agriculture	+	Demand of water resources	"The majority of rainfed land is being converted to irrigated land without taking into account the specific characteristics of the context and the terrain. Crops that perform very well in rainfed areas, such as almond trees, are being replaced by intensive agriculture." (LV-G1) " The loss of biodiversity has been conditioned by the gradual disappearance of rain-fed agriculture, extensive agriculture has become intensive. It is necessary to mark a limit to the surface of the greenhouses based on the available resources, currently there is no limitation to the surface of greenhouses." (CN-G1)
R3	Demand of water resources	+	Aquifers overexplotaition	"There is also a problem with water. In the illegal wells, much more water is being extracted than is possible. Large companies have access to wells, but it is very difficult to get wells legalized on a personal level." (LV-G1) "Depletion of the aquifers, they are leaving the soil completely inert, salinization of the soil, the pH is changing." (LV-G1) "Excessive consumption of resources, overexploitation of natural resources, specifically aquifers and mainly soil. Many of today's ecosystems are at risk of collapse." (R-G1)
R3	Aquifers overexplotaition		Use of diversified water sources for irrigation	"The new intensive agriculture model is characterized as being dependent on underground water. […]Measures have been taken to increase the water
R3	Use of diversified water sources for irrigation	+	Water available for agriculture	supply (river diversions, desalination plants, small dams, and reuse methods) and to connect the entire system via a "water highway". In terms of demand, measures have been undertaken to improve the collection and use of rainwater" (Sánchez-Picón et al., 2011, p. 1365)
R3	Water available for agriculture	+	Land conversion to irrigated agriculture	"The majority of rainfed land is being converted to irrigated land without taking into account the specific characteristics of the context and the terrain. Crops that perform very well in rainfed areas, such as almond trees, are being replaced by intensive agriculture." (LV-G1)

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Table 2 (*continued*)

Loop	Source	Polarity	Sink	Rationale, quotes and references
				"Balance between what can be produced and the people that need to be supplied, taking into account the limitations of the territory, but in this case there is no limit to production, and then it overflows: more water is consumed than is available, the area of greenhouses is increased." (CN-G2)
B4	Irrigated intensive agricultural production	+	Land conversion to irrigated agriculture	"The majority of rainfed land is being converted to irrigated land without taking into account the specific characteristics of the context and the terrain. Crops that perform very well in rainfed areas, such as almond trees, are being replaced by intensive agriculture." (LV-G1) "The loss of biodiversity has been conditioned by the gradual disappearance of rain-fed agriculture, extensive agriculture has become intensive. It is necessary to mark a limit to the surface of the greenhouses based on the available resources, currently there is no limitation to the surface of greenhouses." (CN-G1)
B4	Land conversion to irrigated agriculture	+	Soil erosion	"The expansion of agricultural land has occupied dredging canals thereby boosting runoff and erosion during intense rain episodes." (Cabello and Brugnach, 2023, p. 1119). "Moreover, respondents perceived negative impacts on cultural services and on erosion control associated with the abandonment of agricultural traditional practices that are used for soil conservation, such as terracing" (Quintas-soriano et al., 2016, p. 540)
B4	Soil erosion	–	Irrigated intensive agricultural production	"Anthropic actions can cause changes in soils and have accelerated erosion rates and diverted nutrient flows. When the use of the soil changes, especially in conditions of great fragility, the region in question will often display a significant tendency toward erosion. Inadequate agricultural practices, such as intensive tillage, the removal of vegetation, the excessive use of chemical fertilizers and pesticides or excessive grazing all cause increased rates of soil erosion, the rapid mineralization of organic matter, lower soil fertility, soil, higher CO2 emissions and the loss of biodiversity." (Mostazo et al., 2023, p.1)
B4	Irrigated intensive agricultural production	+	Land conversion to irrigated agriculture	"The majority of rainfed land is being converted to irrigated land without taking into account the specific characteristics of the context and the terrain. Crops that perform very well in rainfed areas, such as almond trees, are being replaced by intensive agriculture." (LV-G1) " The loss of biodiversity has been conditioned by the gradual disappearance of rainfed farming, extensive agriculture has become intensive. It is necessary to set a limit to the surface area of greenhouses according to the available resources; there is currently no limit to the greenhouse surface area" (CN-G1)
	Climate change induced droughts	–	Water available for agriculture	"Anthropogenically-caused climate change has brought additional stress on surface water and groundwater, thus making water recycling an important component of the water supply portofolio in Spanish arid regions. Recycled water increases the resources of semi-arid regions (up to 10% of total resources), like in the Southeast of Spain." (Gil-Meseguer et al., 2018, p. 725)
	Policies and laws that balance human well-being & ecosystem integrity	+	Sustainable management of natural resources and ecosystems services	"Current policies are not adapted to climate change, the system is too slow to deal with the causes and consequences. There is an official discourse, above all, about sustainability, some fantastic plans are made towards sustainability and then the opposite is done." (R-G1)
	Sustainable management of natural resources and ecosystems services	–	Loss of biodiversity, habitats and ecosystem services (land and aquatic)	"There is no balance between what can be produced and the people to be supplied, considering the limitations of the territory. But in this case there is no limit to production, so it overflows: more water is consumed than we have, the surface area of greenhouses is increased, … We only operate based on regulatory limits and not on the basis of awareness. The limit is set by profitability, not by any other factor." (CN-G2) "The short-term vision of governance has environmental consequences, making it difficult to fit, for example, the sustainable development goals with the current capital system." (LV-G2)
	Run-offs from ended mining activity and livestock	+	Polluted run-off	"What is happening in the Mar Menor, what is urgent, is eutrophication. The Mar Menor has a very complex problem, which dates back years. There are many polluting factors (nitrates from agriculture, mining and heavy metals)." (CC-G2)
	Seasonal heavy rain events	+	Floods	"Flood events are indeed a major trigger for eutrophic crises in the lagoon. The
	Seasonal heavy rain events	+	Soil erosion	expansion of agricultural land has occupied dredging canals thereby boosting runoff and erosion during intense rain episodes." (Cabello and Brugnach, 2023, p. 1119)
	Floods	+	Polluted run-off	"There is also agreement on the increasing flood problem dragging massive amounts of sediments and fertilizers into the lagoon" (Cabello and Brugnach, 2023, p. 1117).
	Public subsidies to agriculture	+	Irrigated intensive agricultural production	"Economic incentives are not focused on real, contextual problems and needs, and policies do not support small businesses" (LV-G1)
	Public subsidies to agriculture	–	Desalinized sea water prize	"Desalinated water can be more expensive than water from other origins but this depends on many factors […]. Many agricultural products can support the price of desalinated water without a great impact in the overall price. All the possible technical issues (environmental, effects over soils, boron, etc.) for this application can be solved with investments which mean that the key factor for the feasibility will be always water price." (Zarzo et al., 2013, p.14) "The government is also going to bring forward some very significant works that were included in the Segura, Júcar and Tajo hydrological plans. Direct management is entrusted to the Sociedad Estatal de Aguas de las Cuencas

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Table 2 (*continued*)

Loop	Source	Polarity	Sink	Rationale, quotes and references
				Mediterráneas (Acuamed), which will have a special agreement to activate investment in photovoltaic parks, and to determine a maximum selling price to users of desalinated water." (Council of Ministers of Spain, 2023)
	Desalinized sea water prize	–	Use of desalinized water	"Another problem to evaluate the cost of water, mainly from desalination, is the energy price. In recent years, it has been increasing very fast, and due to this, the main cost in a desalination production, the water costs are continuously increasing […].However, there are public and private initiatives using desalination for agriculture and it is predictable that this will continue to happen in the future." (Zarzo et al. 2013, p.5-6) "The change of governments in past elections in Spain completely changed the situation making it even more complicated. On the one hand, the new government declared in the past more support to the transfers between basins instead of the desalination, and who should be responsible for the operation of the desalination plants built. On the other hand, the farmers and other sectors claiming that the price of desalinated water is very expensive" (Zarzo et al. 2013, p.9)
	Use of desalinized water	+	Use of diversified water sources for irrigation	"A new paradigm for water policy in Spain has emerged for the hydrological planning period (2016–2021), which calls for a greater contribution of unconventional resources (desalination and reuse of municipal sewage). […] Irrigation is the main consumer of these reuse flows." (Gil-Meseguer et al., 2018, p. 725)
	Availability of transferred water	+	Use of diversified water sources for irrigation	
	Availability of transferred water	+	Conflicts with other territories and other externalities	"The water used for irrigation in the study area [Region of Murcia] comes from several sources. Most of it comes from surface and underground sources (854 Mm3/year) and interbasin water transfers through the Tagus-Segura aqueduct (322 Mm3/year). Other water resources in the area are irrigation returns (124 Mm3/year), reclaimed water (144 Mm3/year) and desalinated seawater (158 Mm3/year)" (Martin-Gorriz et al., 2020, p. 4)
	Seasonal tourist concentration	+	Demand of sanitation services	"There is also a problem with water. In the illegal wells, much more water is being extracted than is possible. Large companies have access to wells, but it is very difficult to get wells legalized on a personal level." (LV-G1)
	Demand of sanitation services	–	Capacity of sewerage system to fulfil sanitation functions	"Furthermore, the development of intensive agriculture created competition with other economic activities, such as tourism, for the use of natural resources. This is the case in El Ejido, Roquetas de Mar, and Aguilas, where a significant concentration of greenhouses and growing tourist activity for the use of territory and natural resources such as water and even sand" (Sánchez-Picón et al., 2011) "The STPs [sewage treatment plants] in the Murcia region have treatment capacities varying from more than 35 hm3/year in Murcia East, to the smallest ones installed in rural areas with less than 0.5 hm3/year […]. Most experts indicated that the process depended on the characteristics of sewage, where seasonality of tourism plays an important role." (Gil-Meseguer et al., 2018, p. 730)
	Capacity of sewerage system to fulfil sanitation functions	–	Polluted run-off	"The STPs [sewage treatment plants] in the Murcia region have treatment capacities varying from more than 35 hm3/year in Murcia East, to the smallest ones installed in rural areas with less than 0.5 hm3/year […]. Most experts indicated that the process depended on the characteristics of sewage, where seasonality of tourism plays an important role." (Gil-Meseguer et al., 2018, p. 730)
	Capacity of sewerage system to fulfil sanitation functions	+	Quality of reclaimed water	"There is unanimity on past urban wastewater dumped to the lagoon as a major source of phosphorus. […] In addition, many studies emphasize the insufficient capacity for wastewater treatment in specific locations, seasons and storm events." (Cabello and Brugnach, 2023, p. 1118).
	Quality of reclaimed water	+	Availability of reclaimed water for agriculture	"More than 90 sewage treatment plants (STPs) […] treat more than 100 million m3/year of sewage in the region of Murcia […] in 10 years the treatment capacity has been increased and reused volumes reach a constant percentage higher than 90% of the treated sewage. Sewage treatment has restored water quality in the Segura River -considered a few years ago one of the most polluted rivers in Europe- and is used for aquatic sports and recreation as it runs through the city of Murcia (Gil-Meseguer et al., 2018, p. 730)
	Availability of reclaimed water for agriculture	+	Use of diversified water sources for irrigation	"The investment made in the DHS [Segura Hydrographic Demarcation], in terms of sewage purification and regeneration, produces about 110 hm3/year of purified sewage annually" (Gil-Meseguer et al., 2018, p. 725)
				"A new paradigm for water policy in Spain has emerged for the hydrological planning period (2016–2021), which calls for a greater contribution of unconventional resources (desalination and reuse of municipal sewage). […] Irrigation is the main consumer of these reuse flows. […] Anthropogenically-caused climate change has brought additional stress on surface water and groundwater, thus making water recycling an important component of the water supply portofolio in Spanish arid regions. Recycled water increases the resources of semi-arid regions (up to 10% of total resources), like in the Southeast of Spain." (Gil-Meseguer et al., 2018, p. 725)

Table 3
iCLD on Economic and Social dynamics

Loop	Source	Polarity	Sink	Rationale, quotes and references
R1	Irrigated intensive agricultural production systems	+	Profit of irrigated intensive production system	These links portray the notion that a fraction of the revenues from sales are usually reinvested in the production capacity, and that the investments in production capacity cause an expansion of the production system (see, e.g., Sterman, 2000)
R1 & R2	Revenue irrigated intensive production system	+	Investments irrigated intensive production system	
R1 & R2	Investments irrigated intensive production system	+	Irrigated intensive agricultural production system	"The model of intensive agriculture in Almeria has meant that in half a century the income per capita of the province has rocketed from last position on a national scale to currently trending at intermediate levels (89% of the average income). Protected crops (greenhouses) inject a total of 13% towards the value of the GDP in the province of Almeria (COEXPHAL, 2017), quintupling the average that agriculture contributes to the economic aggregates of Spain as a whole (2.5%) and doubling that of Andalusia (5.2%)." (Salmerón, 2020, p. 19) "But the degradation of the SESMM [social-ecological system of the Mar Menor] is mainly determined by an uncontrolled development of the agricultural sector and the agri-food industry in the entire watershed, especially since the conversion of rainfed agriculture to irrigation with the arrival of water from the Tajo-Segura Transfer in 1979, technological advances in agriculture and socio-economic changes, all driven by the great differential in profitability between rainfed and irrigated crops" (Guaita-García et al., 2022)
R2	Irrigated intensive agricultural production system	–	Production costs	This link represents the notion that in many businesss, "the unit costs fall as the scale of production rises (at least up to a certain point)." (Sterman, 2000, p. 368).
R2	Production costs	–	Profit of irrigated intensive production system	This link represents the notion that lower production costs imply higher profit, as profit constitutes the sales minus the costs.
R3	Low-income jobs	–	Attractiveness of the labor market	This link represents the notion that low-income jobs make the labor market less attractive than high-income jobs. The characteristics of the agricultural labor market entail a high dependency on seasonal and precarious labour (McCollum and Findlay, 2018).
R3	Attractiveness of the labor market	+	Young people interested in taking jobs	"There is an aging of the agricultural sector, especially the family model. There are many young people here who drop out of school early and take over the business, taking advantage of grants for young farmers, both for invention and improvement. Even so, there is no generational change" (CN-G1)
R3	Young people interested in taking jobs	–	Emigration of young people	"[There is a] loss of young population, especially the educated. And a loss of values" (LV-G2)
R3 & R5	Emigration of young people	+	Demand for immigrant labour force	Labor demand in the agricultural sector is met increasingly by non-EU migrants (Taylor and Charlton, 2019; Kalantaryan et al., 2021).
R3, R4 & R5	Demand for immigrant labor force	+	Immigration	"On the one hand, many people come from North Africa and Eastern Europe, and on the other hand, the most active and dynamic people go to study abroad and many do not return, people who have not seen the future in the province." (R-G1)
R3, R4 & R5	Immigration	+	Supply of immigrant labor	"Migrants [non-EU] use Almería, and specifically the Campo de Níjar, as a springboard to Europe. They come from abroad to produce money and send it home, if they leave it is because they cannot get it. Many stay because there is still a lot of work, even if it is sporadic and poorly paid. There is a lot of informal work, migrants can only take this." (CN-G2)
R3, R4 & R5	Supply of immigrant labor	+	Low-income jobs	
R4	Low-income jobs	+	Demand for immigrant labour force	
R5	Low-income jobs	–	Fair distribution of benefits/ income	"[In Spain] low skill workers tend to be employed under temporary contracts, with low and certain severance pays. By contrast, skilled workers tend to be hired under permanent contracts. During the early months of a recession, due to wage rigidities, firms make internal adjustments by firing these temporary (lowly skilled) workers. Such a dual structure might have its origins in the labor market reform of 1984, which allowed firms to hire workers under a temporary contract characterized by lower and clearly defined firing costs, relative to tenure contract workers. The temporary rate increased beginning in the mid-1980s onward, and mostly in Agriculture and the Construction sector." (Hidalgo Pérez et al., 2016, p. 460) Non-EU migrants occupied in the agricultural sector in southeastern Spain have the highest rate of unemployment and the highest risk of poverty (Kalantaryan et al., 2021).
R5	Fair distribution of benefits/ income	+	Social equity	"Poverty and inequality, poor distribution of income." (R-G1) "The middle class is getting more and more stretched out, the rich are getting richer and the lower class is getting poorer, especially now with inflation." (LV-G2) "There is more and more social inequality, there is a growing gap between rich and poor. The real challenge is to achieve a change in the economic model focused on the balance between the environment and equity, a fair system, socially and environmentally." (R-G2)
R5	Social equity	+	Societal integration	"Legal immigrants and their children have access to all services (health, education), but illegal immigrants only to health services, not all immigrants have the same relationship with the system or integrate in the same way." (CN-G1)
R5	Societal integration	–	Social conflicts	"El Ejido and surrounding areas (*Poniente almeriense*) appeared in media headlines in early 2000 due to a social conflict involving Moroccan immigrant workers and other local residents. These areas are characterised by a very productive and lucrative intensive agriculture that is partially based on the intensive working conditions and low salaries of foreigners labouring under greenhouses made of plastic" (Morén-Alegret and Solana, 2004, p. 22) "Inter-ethnic relations are thus strained due to economic tensions, prejudices and cultural differences […] These combined factors have resulted in a deterioration of interethnic relations (Pumares and Jolivet, 2014) and fostered ethnic conflicts such as the racist riots of El Ejido in 2000 (Martínez Veiga, 2014)
R5	Social conflicts	–	Social & cultural attractiveness of the region, rural areas	

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Table 3 (*continued*)

Loop	Source	Polarity	Sink	Rationale, quotes and references
R5 & R6	Social & cultural attractiveness of the region, rural areas	–	Emigration of young people	"Very bad legislation around education. People who study leave. Most do not return, in the villages not enough is offered. There is a lack of attractive things in the towns, promoting more access to culture, art, circus, etc. in rural areas. It worries that the only activity/alternative is to go to a bar." (LV-G1) "In general there is a very evident problem of lack of housing. One thing is the need to live, and the other is the demand. […] It is a paradox that there is a totally empty housing stock on the coast. If a calculation of ceiling per inhabitant is made, there is a surplus, there is no lack of housing, what happens is that there is inequality in access, not only for immigrants, but also for many young people. Many people who have a house sometimes do not want to rent it, they want to rent it to tourists at most, it is not simply that the one who is in demand cannot afford it. It also happens with immigrants in the towns, who do not want to rent houses that are perhaps available." (CN-G1)
R6	Emigration of young people	–	Small/family businesses	"There is an aging of the agricultural sector, especially the family model. There are many young people here who drop out of school early and take over the business, taking advantage of grants for young farmers, both for invention and improvement. Even so, there is no generational change" (CN-G1)
R6	Small/family businesses	+	Opportunities for sustainable models	"Production based on the short term, on consumerism. In the rural environment there are no small companies, only multinational companies that produce massively and without worrying, for example, about the state and health of the soil. Faced with the need for resources and lack of awareness, the owners leave the field without worrying about who is coming after them." (LV-G2)
R6	Opportunities for sustainable models	+ (time delay)	Diversity of economic activity	"Appearance of new market niches that actually cover the current model, such as photovoltaics, are very necessary, but to a certain extent." (CC-G1) "Diversify economic activity, generate new economies from waste, applying a real circular economy model. Companies that can manage waste in a leading way." (CN-G2)
R6	Diversity of economic activity	+ (time delay)	Social & cultural attractiveness of the region, rural areas	"[Need to] develop a heritage protection initiative. Society must be placed at the center, and link the economy with quality as a way of competing, giving importance to rural values, trying to develop a rural economy. [Generating] a diversify economic activity, generate new economies from waste, applying a real circular economy model" (CN-G2) "[Need of] diversification of the secondary sector, the local product of the area is not valued enough. The capitalist model does not favor the rural model" (LV-G2)
R7	Small/family businesses	+	Revenue small businesses production	"[There is a] gradual disappearance of the small entrepreneur. The price of land has risen a lot, having 5 ha is equivalent to 1 million euros, small farmers end up selling their land, basically to international companies that have 15, 20 ha. They do not value the land, they use it and when it is completely dead they move their fields elsewhere. There are many small farmers, but there are 5 who control the roost and have influence." (R-G1)
R7	Revenue small businesses production	+	Investments small businesses production	This link portrays the notion that a fraction of the revenues from sales is reinvested in the production capacity (see, e.g., Sterman, 2000, p. 369).
R7	Investments small businesses production	+	Small/family businesses	This link represents the notion that the investments in production capacity cause an expansion of the production system (see, e.g., Sterman, 2000).
	EU CAP and Spanish bureaucracy	+	Concentration of subsidies to big businesses	"Economic incentives are not focused on real, contextual problems and needs, and policies are not committed to small business." (LV-G1) "There is more bureaucracy of public services and a disappearance of help lines. If there are few people who apply for aid (because most are not capable of processing it), then they remove it, as happened with the aid for waste management from intensive agriculture. It was unattractive and the processing was very complicated and slow, therefore, it ended up being removed. By making them so difficult at the bureaucratic level, many small companies do not arrive and are left out of these aids." (LV-G1)
	Concentration of subsidies to big businesses	–	Revenue small businesses production	"One of the problems that generates the most debate is that not enough is being done to make the energy transition fair. People who have a certain purchasing power have and receive much more aid to adjust and reduce energy costs, eg, the EU subsidizes 60% of solar panels, but who has access to that?" (R-G1)
	Concentration of subsidies to big businesses	+	Revenue irrigated intensive production system	
	Power of international supermarkets	–	Price of agricultural products	"Currently, multinationals have very low wages, and they are the ones that can afford to set very low product prices, giving rise to unfair competition." (LV-G1)
	Price of agricultural products	+	Revenue irrigated intensive production system	
	Irrigated intensive agricultural production system	+	Negative externalities	"Everything is regulated based on the market, made possible by technology. Larger greenhouses are made because the technology now exists to make it possible. All participants seem to agree that the problem is competition. If environmental costs were included in the price of the products, everything that is not being included, the price would no longer be competitive." (CN-G2) "[…] multinational companies that produce massively and without worrying, for example, about the state and health of the soil." (LV-G2) "They [international companies] do not value the land, they use it and when it is completely dead they move their fields elsewhere." (R-G1)
	Irrigated intensive agricultural production system	+	Creation of high-income jobs	This link represents the notion that the bigger the production, the bigger the labour force needed. This is the case for both high-income and low-income jobs.
	Creation of high-income jobs	+	Attractiveness of the labor market	This link represents the notion that high-income jobs make the market more attractive than low-income jobs.

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Table 3 (*continued*)

Loop	Source	Polarity	Sink	Rationale, quotes and references
	Creation of high-income jobs	+	Fair distribution of benefits/ income	This link represents the notion that there is a divide between business owners and low-income workers and that the creation of high-income jobs makes the distribution fairer.
	EU seasonal work policies in agriculture	+	Low-income jobs	The Seasonal Workers Directive (2014/36/EU) is transposed into the Spanish legal system in the Ley Orgánica 4/2000, on the rights and freedoms of foreigners in Spain and their social integration. "Seasonal residence and work visa, which entitles the holder to work as an employee for up to nine months in a period of twelve consecutive months. (Art 25bis. Types of visa, Law 4/2000) "The Autonomous Communities, the City Councils and the social agents will promote the circuits that allow the linking of seasonal workers, in collaboration with the General Administration of the State" (Art 42 Law 4/2000) "Migrants use Almería, and specifically the Campo de Níjar, as a springboard to Europe. They come from outside to produce money and send it home, if they leave it is because they do not get it. There are many people who stay because there is still a lot of work, even if it is sporadic and poorly paid" (CN-G2) "A majority of the people who are working, and who are regularized, do so with a contract (80%), the vast majority have a contract for the campaign. […] in the meetings and interviews it was very common for people to say that they had to work very hard and could not afford to slow down or miss a doctor's appointment because they risked being fired." (Andalucía Acoge, 2022, p. 43–44)
	Governance decisions on the distribution of funds	+	Social, economic & cultural services	"The city council allocates very few investments in the neighborhoods. The vast majority of aid and subsidies go to "the shop windows", in the center of the city, and in the neighborhoods there are fewer and fewer services and aids." (CC-G1)
	Social, economic & cultural services	+ (time delay)	Societal integration	"Vulnerability and volatility of prices, dependence on external factors (as in the current case of energy). The administration and the new legislation must begin to ensure a fair distribution of wealth, begin to take into account factors such as social inequality." (R-G1) "There is also a lack of development and cultural offer. It is necessary to promote a cultural development that is accessible to all, transversal." (CN-G1) "More cultural activities should be promoted. There are no spaces for young people to meet, no youth centers to meet, watch movies, etc." (CN-G2) "The public school acts as one of the few elements of integration. The larger the public school, the greater the integration and the less inequality." (CN-G1)
	Digitalization policies	+	Small/family businesses	"We have to bring the typical rural environments closer to the people of the city, as for example with teleworking, people from the city who begin to value much more the rural environments and the quality of life there. That would also lower prices, housing would be more affordable. It is necessary to reinforce the housing, the Internet line, to adapt the region to attract population. To also promote local consumption. Positioning of the territory as a teleworking area" (CN-G2)

Data availability

Data will be made available on request.

References

Aguiar, AP, Collste, D, Cortés-Calderón, S, Sonetti-González, T, Alves-Martins, M, Castro, AJ, Diallo, A, Eriksson, M, Goffnner, D, Harmackova, Z, Jiménez-Aceituno, A, López-Rodríguez, MD, Mancilla-García, M, Olofsson, V, Perez-Marin, A, Silva-Bezerra, FG, Sinare, H, Stragier, C, 2025. Unraveling deep roots in drylands: a systems thinking participatory approach to the SDGs. Global Sustainability.

Aguiar, A.P.D., Collste, D., Harmáčková, Z.V., et al., 2020. Co-designing global target-seeking scenarios: a cross-scale participatory process for capturing multiple perspectives on pathways to sustainability. Global Environmental Change 65. https://doi.org/10.1016/j.gloenvcha.2020.102198.

Álvarez-Rogel, J., Barberá, G.G., Maxwell, B., et al., 2020. The case of Mar Menor eutrophication: state of the art and description of tested Nature-Based Solutions. Ecol Eng 158, 106086. https://doi.org/10.1016/j.ecoleng.2020.106086.

Andalucía Acoge, 2022. Informe Asentamientos 2022: Consecuencias de la discriminación en los asentamientos en la Comarca de Níjar (Almería).

Aznar-Sanchez, J.A., Velasco-Munoz, J.F., Garcia-Arca, D., Lopez-Felices, B., 2020. Identification of opportunities for applying the circular economy to intensive agriculture in almeria (South-East Spain). AGRONOMY-BASEL 10. https://doi.org/10.3390/agronomy10101499.

Balvanera, P., Calderón-Contreras, R., Castro, A.J., et al., 2017a. Interconnected place-based social-ecological research can inform global sustainability. Curr Opin Environ Sustain 29, 1–7.

Balvanera, P., Daw, T.M., Gardner, T.A., et al., 2017b. Key features for more successful place-based sustainability research on social-ecological systems: a programme on ecosystem change and society (PECS) perspective. Ecology and Society 22. https://doi.org/10.5751/ES-08826-220114.

Cabello, V., Brugnach, M., 2023a. Whose waters, whose nutrients? Knowledge, uncertainty, and controversy over eutrophication in the Mar Menor. Ambio 52, 1112–1124. https://doi.org/10.1007/s13280-023-01846-z.

Cabello, V., Brugnach, M., 2023b. 'Whose waters, whose nutrients? Knowledge, uncertainty, and controversy over eutrophication in the Mar Menor,'. Ambio 52 (6), 1112–1124. https://doi.org/10.1007/s13280-023-01846-z.

Cajamar, 2022. Análisis de la campaña hortofrutícola. Campaña 2021/2022.

Campbell, B.M., Beare, D.J., Bennett, E.M., et al., 2017. Agriculture production as a major driver of the earth system exceeding planetary boundaries. Ecology and Society 22. https://doi.org/10.5751/ES-09595-220408.

Castro, A.J., Martín-López, B., López, E., et al., 2015. Do protected areas networks ensure the supply of ecosystem services? Spatial patterns of two nature reserve systems in semi-arid Spain. Applied Geography 60, 1–9. https://doi.org/10.1016/j.apgeog.2015.02.012.

Castro, A.J., Quintas-Soriano, C., Brandt, J., et al., 2018a. Applying place-based social-ecological research to address water scarcity: insights for future research. Sustainability (Switzerland) 10. https://doi.org/10.3390/su10051516.

Castro, A.J., Quintas-Soriano, C., Egoh, B.N., 2018b. Ecosystem services in dryland systems of the world. J Arid Environ 159, 1–3. https://doi.org/10.1016/j.jaridenv.2018.09.006.

Castro, A.J., López-Rodríguez, M.D., Giagnocavo, C., et al., 2019. Six collective challenges for sustainability of almería greenhouse horticulture. Int J Environ Res Public Health 16. https://doi.org/10.3390/ijerph16214097.

Castro, A.J., et al., 2019. Six collective challenges for sustainability of almería greenhouse horticulture. International Journal of Environmental Research and Public Health/International Journal of Environmental Research and Public Health 16 (21), 4097. https://doi.org/10.3390/ijerph16214097.

Cepaim, 2018. Aproximación a la magnitud del fenómeno de los asentamientos inmigrantes en España.

Colino-Sueiras, J., Martínez-Paz, J.M., 2002. El agua en la agricultura del sureste español: Productividad, precio y demanda. In: García Álvarez-Coque, J.M. (Ed.), La agricultura mediterránea en el siglo XXI. Caja Rural Intermediterránea, Cajamar, pp. 199–221.

Collste, D., Aguiar, A.P.D., Harmáčková, Z.V., et al., 2023. Participatory pathways to the Sustainable Development Goals: inviting divergent perspectives through a cross-

scale systems approach. Environ Res Commun 5, 055014. https://doi.org/10.1088/2515-7620/acce25.
Corrado, A., Castro, C de, Perrotta, D., 2016. Migration and Agriculture: Mobility and Change in the Mediterranean Area. Routledge ISS Studies in Rural Livelihoods, The Hague, the Netherlands.
Council of Ministers of Spain, 2023, 11th May 2023. [online] Available at: https://www.lamoncloa.gob.es/lang/en/gobierno/councilministers/Paginas/2023/20230511_council.aspx. (Accessed 11 May 2023).
Directive 2014/36/EU of the European Parliament and of the Council of 26 February 2014 on the conditions of entry and stay of third-country nationals for the purpose of employment as seasonal workers. Official Journal of the European Union, L 94, pp.375-390.
Egea, F.J., López-Rodríguez, M.D., Oña-Burgos, P., et al., 2021. Bioeconomy as a transforming driver of intensive greenhouse horticulture in SE Spain. N Biotechnol 61, 50–56. https://doi.org/10.1016/j.nbt.2020.11.010.
Etzion, D., 2020. Corporate engagement with the natural environment. Nat Ecol Evol 4. https://doi.org/10.1038/s41559-020-1142-5, 493–493.
European Parliament, 2011. The EU Fruit and Vegetables Sector: Overview and Post 2013 CAP Perspective Study.
FAO, 2020. Año Internacional de las Frutas y Verduras, 2021. Documento de antecedentes. Rome, Italy.
FAOSTAT, 2021. Food and Agriculture Data.
Folke, C., Österblom, H., Jouffray, J.-B., et al., 2019. Transnational corporations and the challenge of biosphere stewardship. Nat Ecol Evol 3, 1396–1403. https://doi.org/10.1038/s41559-019-0978-z.
Fundación Ingenio, 2020. La Agricultura del Futuro en el Campo de Cartagena: innovadora, eficiente y ambientalmente sostenible.
Galaz, V., Metzler, H., Daume, S., et al., 2023. AI Could Create a Perfect Storm of Climate Misinformation.
Galdeano-Gómez, E., Pérez-Mesa, J.C., Giagnocavo, C.L., 2015. Food exporters and co-opetition relationships: an analysis on the vegetable supply chain. British Food Journal 117, 1596–1609. https://doi.org/10.1108/BFJ-07-2014-0255.
Gash, A., 2016a. Collaborative governance. In: Christopher Ansell, J.T. (Ed.), Handbook on Theories of Governance. Edward Elgar Publishing, Cheltenham, UK, Northampton, MA, USA, pp. 454–467.
Gash, A., 2016b. 37. Collaborative governance. In: Ansell, C., Torfing, J. (Eds.), Handbook on Theories of Governance. Edward Elgar Publishing, pp. 454–467.
Giagnocavo, C., 2020. The development of the cooperative movement and civil society in almeria, Spain: something from nothing? Sustainability 12, 1–23. https://doi.org/10.3390/su12239820.
Giagnocavo, C., Gerez, S., Sforzi, J., 2012. Cooperative bank strategies for social-economic problem solving: supporting social enterprise and local development. Annals of Public and Cooperative Economics 83, 281–315. https://doi.org/10.1111/j.1467-8292.2012.00464.x.
Giagnocavo, C., Gerez, S., Campos i Climent, V., 2014. Paths to cooperative survival: structure, strategy and regeneration of fruit and vegetables cooperatives in almería and valencia, Spain. Annals of Public and Cooperative Economics 85, 617–639. https://doi.org/10.1111/apce.12054.
Gil-Meseguer, E., Bernabé-Crespo, M.B., Gómez-Espín, J.M., 2018. Recycled sewage - a water resource for dry regions of southeastern Spain. Water Resources Management 33 (2), 725–737. https://doi.org/10.1007/s11269-018-2136-9.
González de Molina, M., et al., 2020. The Social Metabolism of Spanish Agriculture, 1900–2008: the Mediterranean Way towards Industrialization. Springer.
Grafton, R.Q., Williams, J., Perry, C.J., et al., 2018. The Paradox of Irrigation Efficiency, vol. 361, pp. 748–750. https://doi.org/10.2307/26505182.
Guaita-García, N., et al., 2022. Stakeholder analysis and prioritization of management measures for a sustainable development in the social-ecological system of the Mar Menor (SE, Spain). Environmental Development 42, 100701. https://doi.org/10.1016/j.envdev.2022.100701.
Halabi, S.F., Ching-Fu, L., 2017. Assessing the relative influence and efficacy of public and private food safety regulation regimes: comparing codex and global. G.A.P. standards. Food Drug Law J 72, 262–294.
Herrero, M., Thornton, P.K., Power, B., et al., 2017. Farming and the geography of nutrient production for human use: a transdisciplinary analysis. Lancet Planet Health 1, e33–e42. https://doi.org/10.1016/S2542-5196(17)30007-4.
Hidalgo Pérez, M., O'Kean Alonso, J.M., Rodríguez López, J., 2016. Labor demand and ICT adoption in Spain. Telecommunications Policy 40 (5), 450–470. https://doi.org/10.1016/j.telpol.2015.07.004.
Ibarrola-Rivas, M.J., Castro, A.J., Kastner, T., et al., 2018. Telecoupling through Tomato Trade: what consumers do not know about the tomato on their plate. Global Sustainability.
ICEX, 2021. Estadísticas españolas de comercio exterior.
INE, 2024. Insituto Nacional de Estadística.
Jiménez-Martínez, J., et al., 2016. The role of groundwater in highly human-modified hydrosystems: a review of impacts and mitigation options in the Campo de Cartagena-Mar Menor coastal plain (SE Spain). Environmental Reviews 24 (4), 377–392. https://doi.org/10.1139/er-2015-0089.
Kalantaryan, S., et al., 2021. Immigration and integration in rural areas and the agricultural sector: an EU perspective. Journal of Rural Studies 88, 462–472. https://doi.org/10.1016/j.jrurstud.2021.04.017.
Kofman, E., 2023. Integration discourses, the purification of gender and interventions in family migrations. Ethn Racial Stud 46, 3037–3057. https://doi.org/10.1080/01419870.2023.2166791.
Kosack, S., Fung, A., 2014. Does transparency improve governance? Annual Review of Political Science 17 (1), 65–87. https://doi.org/10.1146/annurev-polisci-032210-144356.
La Roca, F., Martínez, J., 2023. Retos de la planificación y gestión del agua en España. Informe 2023.. Observatorio de las Políticas del Agua (OPPA), Zaragoza, Spain.
Lloyd, T.M.S.M.W., 2023. Climate, Fossil Fuels and UK Food Prices.
López-Rodríguez, M.D., Ruiz-Mallén, I., Oteros-Rozas, E., et al., 2020. Delineating participation in conservation governance: Insights from the Sierra de Guadarrama National Park (Spain). Environ Sci Policy 114, 486–496. https://doi.org/10.1016/j.envsci.2020.09.019.
López-Rodríguez, M.D., Jiménez-Aceituno, A., Quintas-Soriano, C., et al., 2024. Applying the three Horizons approach in local and regional scenarios to support policy coherence in SDG implementation: insights from arid Spain. Global Environmental Change 89, 102922. https://doi.org/10.1016/j.gloenvcha.2024.102922.
Maani, K.E., Cavana, R.Y., 2007. Systems Thinking, System Dynamics: Managing Change and Complexity. Pearson Education, New Zealand.
MAPA, 2021. Estadísticas de la producción agrícola española. Spain.
Martin-Gorriz, B., et al., 2020. Life cycle assessment of fruit and vegetable production in the Region of Murcia (south-east Spain) and evaluation of impact mitigation practices. Journal of Cleaner Production 265, 121656. https://doi.org/10.1016/j.jclepro.2020.121656.
Martínez Veiga, J., 2014. The political economy of El Ejido: genealogy of the 2000 conflict: the social costs of eating fresh. In: Gertel, J., Sippel, S.R. (Eds.), Seasonal Workers in Mediterranean Agriculture. Routledge, pp. 37–48.
Mason-D'Croz, D., Bogard, J.R., Sulser, T.B., et al., 2019. Gaps between fruit and vegetable production, demand, and recommended consumption at global and national levels: an integrated modelling study. Lancet Planet Health 3, e318–e329. https://doi.org/10.1016/S2542-5196(19)30095-6.
Maté-Sánchez-Val, M., Aparicio-Serrano, G., 2023. The impact of marine pollution on the probability of business failure: a case study of the Mar Menor lagoon. Journal of Environmental Management 332, 117381. https://doi.org/10.1016/j.jenvman.2023.117381.
McCollum, D., Findlay, A., 2018. Oiling the wheels? Flexible labour markets and the migration industry. Journal of Ethnic and Migration Studies 44 (4), 558–574. https://doi.org/10.1080/1369183x.2017.1315505.
MDSA2030, 2022. Diagnóstico sobre los asentamientos de personas trabajadoras agrícolas en Andalucía. Castilla la Mancha y Murcia.
Medland, L., 2017. Misconceiving 'seasons' in global food systems: the case of the EU seasonal workers directive. European Law Journal 23, 157–171. https://doi.org/10.1111/eulj.12235.
Milford, A.B., Lien, G., Reed, M., 2021. Different sales channels for different farmers: local and mainstream marketing of organic fruits and vegetables in Norway. J Rural Stud 88, 279–288. https://doi.org/10.1016/j.jrurstud.2021.08.018.
Miller, V., Yusuf, S., Chow, C.K., et al., 2016. Availability, affordability, and consumption of fruits and vegetables in 18 countries across income levels: findings from the Prospective Urban Rural Epidemiology (PURE) study. Lancet Glob Health 4, e695–e703. https://doi.org/10.1016/S2214-109X(16)30186-3.
MITECO, 2021. Plan para la protección del borde litoral del Mar Menor (Murcia).
Moraes, N., Gadea, E., Pedreño, A., De Castro, C., 2012. Enclaves globales agrícolas y migraciones de trabajo: convergencias globales y regulaciones transnacionales. Politica y Sociedad 49, 13–34. https://doi.org/10.5209/rev_poso.2012.v49.n1.36517.
Morén-Alegret, R., Solana, M., 2004. Foreign immigration in Spanish rural areas and small towns: current situation and perspectives. Finisterra 39 (77). https://doi.org/10.18055/finis1559.
Mostazo, P., Asensio-Amador, C., Asensio, C., 2023. Soil erosion modeling and monitoring. Agriculture 13 (2), 447. https://doi.org/10.3390/agriculture13020447.
Olmos, F.C., Corrado, A., Saverio Caruso, F., 2018. Territories in transition. Migrations and agriculture in south of Europe. the case studies of Almeria (Spain) and Sibari (Italy). Cuadernos Geograficos 57, 313–337. https://doi.org/10.30827/cuadgeo.v57i3.6407.
Österblom, H., Jouffray, J.-B., Folke, C., et al., 2015. Transnational corporations as 'keystone actors' in marine ecosystems. PLoS One 10, e0127533. https://doi.org/10.1371/journal.pone.0127533.
Österblom, H., Folke, C., Rocha, J., et al., 2022. Scientific mobilization of keystone actors for biosphere stewardship. Sci Rep 12, 3802. https://doi.org/10.1038/s41598-022-07023-8.
Peet, M.M., Wolfe, D.W., 2000. Crop ecosystem responses to climatic change: vegetable crops. In: Climate Change and Global Crop Productivity. CABI Publishing, UK, pp. 213–243.
Pérez-Blanco, C.D., Loch, A., Ward, F., et al., 2021. Agricultural water saving through technologies: a zombie idea. Environmental Research Letters 16. https://doi.org/10.1088/1748-9326/ac2fe0.
Pérez-Mesa, J.C., Piedra-Muñoz, L., Galdeano-Gómez, E., Giagnocavo, C., 2021. Management strategies and collaborative relationships for sustainability in the agrifood supply chain. Sustainability 13, 749. https://doi.org/10.3390/su13020749.
Pumares, P., Jolivet, D., 2014. 'Origin matters': working conditions of Moroccans and Romanians in the greenhouses of almería: the social costs of eating fresh. In: Gertel, J., Sippel, S.R. (Eds.), Seasonal Workers in Mediterranean Agriculture. Routledge, pp. 130–140.
Quintas-Soriano, C., Castro, A.J., García-Llorente, M., et al., 2014. From supply to social demand: a landscape-scale analysis of the water regulation service. Landsc Ecol 29, 1069–1082. https://doi.org/10.1007/s10980-014-0032-0.
Quintas-Soriano, C., et al., 2016. Impacts of land use change on ecosystem services and implications for human well-being in Spanish drylands. Land Use Policy 54, 534–548. https://doi.org/10.1016/j.landusepol.2016.03.011.
Quintas-Soriano, C., García-Llorente, M., Castro, A.J., 2018. What has ecosystem service science achieved in Spanish drylands? Evidences of need for transdisciplinary science. J Arid Environ 159, 4–10. https://doi.org/10.1016/j.jaridenv.2018.01.004.

Reid, A., Ronda-Perez, E., Schenker, M.B., 2021. Migrant workers, essential work, and COVID-19. Am J Ind Med 64, 73–77. https://doi.org/10.1002/ajim.23209.
Rieckmann, M., 2012. Future-oriented higher education: which key competencies should be fostered through university teaching and learning? Futures 44 (2), 127–135. https://doi.org/10.1016/j.futures.2011.09.005.
Rieckmann, M., 2018. Learning to transform the world: key competencies in education for sustainable development. In: Leicht, A., Heiss, J., Byun, W.J. (Eds.), Issues and Trends in Education for Sustainable Development. UNESCO Publishing.
Ruiz-Nieto, Á., Gómez-Serrano, C., Acién, G., Castro, A.J., 2022. Farmers' knowledge and acceptance of microalgae in almería greenhouse horticulture. Agronomy 12, 2778. https://doi.org/10.3390/agronomy12112778.
Rye, J.F., O'Reilly, K., 2021. International Labour Migration to Europe's Rural Regions. Routledge, Oxford, U.K.
Salmerón, A.M.G., 2020. Almería's fruit and vegetable competitive advantage and the growth of GDP per capita. Small Business International Review 4 (2), 18–29. https://doi.org/10.26784/sbir.v4i2.265.
Sánchez-Picón, A., Aznar-Sánchez, J.A., García-Latorre, J., 2011. Economic cycles and environmental crisis in arid southeastern Spain. A historical perspective. J Arid Environ 75, 1360–1367. https://doi.org/10.1016/j.jaridenv.2010.12.014.
Scheelbeek, P.F.D., Bird, F.A., Tuomisto, H.L., et al., 2018. Effect of environmental changes on vegetable and legume yields and nutritional quality. Proceedings of the National Academy of Sciences 115, 6804–6809. https://doi.org/10.1073/pnas.1800442115.
Schneider, A., Hinton, J., Collste, D., et al., 2020. Can transnational corporations leverage systemic change towards a 'sustainable' future? Nat Ecol Evol 4, 491–492. https://doi.org/10.1038/s41559-020-1143-4.
Sellberg, M.M., Norström, A.V., Peterson, G.D., Gordon, L.J., 2020. Using local initiatives to envision sustainable and resilient food systems in the Stockholm city-region. Glob Food Sec.
Siegel, K.R., Ali, M.K., Srinivasiah, A., et al., 2014. Do we produce enough fruits and vegetables to meet global health need? PLoS One 9. https://doi.org/10.1371/journal.pone.0104059.
Springmann, M., Clark, M., Mason-D'Croz, D., et al., 2018. Options for keeping the food system within environmental limits. Nature 562, 519–525. https://doi.org/10.1038/s41586-018-0594-0.
Sterman, J., 2000. Business Dynamics: system thinking and modeling for a complex world. http://lst-iiep.iiep-unesco.org/cgi-bin/wwwi32.exe/[in=epidoc1.in]/?t2000=013598/(100. (Accessed 19 May 2024).
Stratton, A.E., Finley, J.W., Gustafson, D.I., et al., 2021. Mitigating sustainability tradeoffs as global fruit and vegetable systems expand to meet dietary recommendations. Environmental Research Letters 16. https://doi.org/10.1088/1748-9326/abe25a.
Taylor, J.E., Charlton, D., 2019. Agricultural Labor Demand. Elsevier eBooks, pp. 21–46. https://doi.org/10.1016/b978-0-12-816409-9.00002-1.
Van Der Grijp, N.M., Marsden, T., Cavalcanti, J.S.B., 2005. European retailers as agents of change towards sustainability: the case of fruit production in Brazil. Environ Sci (Ruse) 2, 445–460. https://doi.org/10.1080/15693430512331333384.
Velasco, A.M., Pérez-Ruzafa, A., Martínez-Paz, J.M., Marcos, C., 2018. Ecosystem services and main environmental risks in a coastal lagoon (Mar Menor, Murcia, SE Spain): the public perception. J Nat Conserv 43, 180–189. https://doi.org/10.1016/j.jnc.2017.11.002.
Whitfield, S., Hermans, T., Naess, L.O., et al., 2023. Editorial: equity and trade-offs in agriculture and food system transformation. Front Sustain Food Syst 7. https://doi.org/10.3389/fsufs.2023.1258372.
WHO/FAO, 2003. Diet, Nutrition and the Prevention of Chronic Diseases: Report of a Joint WHO/FAO Expert Consultation. Geneva, Switzerland.
Wiek, A., Withycombe, L., Redman, C.L., 2011. Key competencies in sustainability : a reference framework for academic program development. Sustain Sci 6, 203–218. https://doi.org/10.1007/s11625-011-0132-6.
Willett, W., Rockström, J., Loken, B., et al., 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet 393, 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.
Zarzo, D., Campos, E., Terrero, P., 2013. Spanish experience in desalination for agriculture. Desalination and Water Treatment 51 (1–3), 53–66. https://doi.org/10.1080/19443994.2012.708155.