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Social Life Cycle Assessment of Innovative Products from Solar Evaporation Iberian Saltworks: A Descriptive Approach to the Implementation of Halotolerant Crops and Microorganisms

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Abstract: Soil salinization and land abandonment pose significant socio-economic and environmental challenges, particularly in the Iberian Peninsula, where traditional saltworks and agricultural lands have been increasingly degraded. Innovative approaches, such as the implementation of halotolerant crops and microorganisms, offer a promising strategy to revitalize these underutilized areas. This study applies the Social Life Cycle Assessment (S-LCA) methodology to evaluate the socio-economic benefits of halotolerant agriculture in abandoned saltworks and salinized lands. Data were collected through interviews with key stakeholders, literature reviews, and case studies of four enterprises actively engaged in sustainable salina restoration. Key social indicators, including employment creation, community participation, and cultural heritage conservation, were assessed using an expert-based weighting system. The findings indicate that enterprises involved in these initiatives demonstrated strong contributions to local economic resilience and cultural heritage preservation. However, challenges related to scalability and external economic influences remain key considerations. These results highlight the potential of biosaline agriculture as a viable solution to address land abandonment and food security challenges, while also contributing to rural socio-economic development.

Keywords: social life cycle assessment (S-LCA); halotolerant crops; microorganisms; salinized lands; sustainable agriculture; Iberian Peninsula saltworks; environmental sustainability; cultural heritage conservation; land degradation; food security

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1. Introduction

Mainstream agricultural practices face important challenges in the south of Europe, due to a variety of factors. The combined conditions of high rates of land abandonment on the one hand and, on the other, the prevalence of saline soils, are very specific to the Iberian Peninsula at a continental scale. According to an EU Joint Research Centre report [1], in the period 2015–2030, about 11% (more than 20 million ha) of agricultural land in the EU is at high potential risk of abandonment, being particularly severe in countries like Spain and Portugal, where farming conditions are difficult due to poor soil quality and climate change [2]. Spain will be the only EU country to lose more than 1 million ha (around

20% of all EU expected losses). Arable land is projected to account for the largest share of abandoned land, followed by pastures and permanent crops [1].

The salinization of soils occurs when there is an accumulation of salts in the soil profile due to high evaporative demand, sometimes worsened by factors such as the existence of shallow salt deposits, marine intrusions, or poor drainage of irrigation water. When soil salinity reaches a certain level, crops suffer reduced growth, and this may result in crop failure. Over 833 million hectares of soils worldwide—corresponding to more than 10% of cropland—is already salt-affected, according to the Global Map of Salt-affected Soils launched by the FAO [3]. The eastern half of Spain—where most of its inland solar evaporation saltworks are located—is rich in natural saline soils. Added to these, 3% of the 3.5 million hectares of irrigated land is severely affected by salinity [4]. Spain is the only European country identified as being at risk of soil salinization in the Desertification Map of the World by UNESCO [5]. Soil salinization in Portugal affects around 100,000 hectares, most of which is found around the estuaries of the Tagus, Sado, Mondego, and Vouga rivers [6], where the solar evaporation salinas of Alcochete, Sado, Figueira, and Aveiro, respectively, are found.

The issue of waste management in Iberian salinas is a crucial yet underexplored challenge that affects both environmental sustainability and local economies. In Spain, the total amount of urban waste collected in 2022 reached 23.0 million tons, with Andalusia, the Valencian Community, and the Murcia region—areas home to significant salt pan ecosystems—being among the top contributors to waste generation [7]. The improper disposal of waste in these areas can pose serious threats to the fragile biodiversity of salinas and hinder their potential for sustainable economic activities. Additionally, the generation of textile waste in Spain approaches one million tons annually, with only 12.16% collected separately for potential reuse or recycling, highlighting significant challenges in waste management systems [8]. Furthermore, a Greenpeace investigation revealed that a substantial portion of used clothing deposited in recycling containers is not adequately processed; instead, these garments often travel extensive distances, averaging over 8917 km, only to end up in landfills or be incinerated in developing countries [9]. These challenges emphasize the urgent need for tailored waste management strategies in Iberian salinas, ensuring the preservation of these unique environments while promoting circular economy models that benefit local communities.

Salinas, traditionally known for salt extraction [10], are unique ecosystems that hold untapped socio-economic potential beyond their historical function. These environments, characterized by their saline soils, have long been neglected, especially in regions like the Iberian Peninsula, where the economic viability of traditional salt production has significantly declined. Over recent decades, many of these areas have been abandoned [11,12] leading to a loss of cultural heritage and biodiversity. However, innovative agricultural practices, specifically the use of halotolerant crops and microorganisms [13], offer new possibilities for the revitalization of these lands. These practices can add significant value to the agricultural sector by leveraging biological mechanisms to thrive in saline conditions, which is increasingly important in the context of modern environmental challenges.

Agriculture is one of the primary drivers of economic and social development, but it also faces profound challenges, including the degradation of arable land due to poor irrigation practices, climate change, and the unsustainable use of natural resources. Soil salinization is becoming a critical issue globally, reducing the fertility and productivity of agricultural lands [14]. The continued increase in soil salinity threatens global food security by limiting the availability of arable land, especially as the world's population continues to rise and the demand for food escalates. As the amount of unusable land due to salinization expands, innovative solutions like halotolerant crops and microorganisms are emerging as essential tools for addressing this issue [15,16]. These biological tools can improve the productivity of degraded soils [17,18], thus expanding the agricultural frontier and contributing to the overall sustainability of the agricultural sector.

The significance of this research lies not only in its local impact on Iberian saltworks and salinized lands but also in its global implications for sustainable agriculture. Halotolerant [19] crops—plants that can tolerate high salinity—and microorganisms that support plant growth in saline conditions represent a novel approach to enhancing food production in challenging environments. While halotolerant crops inherently withstand salt stress, halotolerant microorganisms can interact symbiotically with non-tolerant crops to improve their growth in saline soils, making them a viable and versatile option for salinized soils too. By implementing these tools, we can transform abandoned saline lands into productive areas, supporting food production while simultaneously restoring ecosystems that are vital for biodiversity.

This research is closely aligned with the United Nations' 2030 Agenda for Sustainable Development [20], which calls for global action to eradicate poverty, protect the planet, and ensure prosperity for all. Specifically, this study contributes to the achievement of several Sustainable Development Goals (SDGs), including SDG 2, "Zero Hunger"; SDG 9, "Industry, Innovation, and Infrastructure"; SDG 11, "Sustainable Cities and Communities"; and SDG 12, "Responsible Consumption and Production". Addressing these objectives requires innovative approaches like halotolerant crops and microorganisms to increase food production on lands that are otherwise deemed unfit for cultivation [21]. Additionally, these tools provide a transformative perspective for agriculture initiatives facing the challenge of salinized arable lands, which aligns with the goals of innovation and sustainable infrastructure. The creation of new, sustainable ecosystems around these once-abandoned lands also supports the development of sustainable communities, particularly in rural areas that have experienced depopulation due to agricultural decline.

The primary objective of this study is to explore the positive socio-economic impacts of implementing halotolerant crops and microorganisms in the salinized lands and abandoned saltworks of the Iberian Peninsula. Utilizing the framework of Social Life Cycle Assessment (S-LCA), this research evaluates the potential benefits that these practices could offer to local communities, businesses, and the environment. The S-LCA method, as applied here, provides a holistic view of the social implications of agricultural innovations, assessing how these practices can enhance community well-being, create employment, and contribute to sustainable rural development. Moreover, this study aims to promote broader awareness of these innovative tools, encouraging their adoption by farmers, policymakers, and investors who seek to develop resilient, climate-adaptive agricultural systems.

As agricultural conditions worsen due to ongoing climate change and unsustainable land management practices, the need for sustainable solutions is becoming more pressing. In the Iberian Peninsula, where large swaths of land have already been lost to salinization [19–22], the adoption of halotolerant crops and microorganisms offers a timely solution. These tools not only enhance soil fertility and resilience but also create new opportunities for local economies and contribute to broader ecological sustainability. By revitalizing saline landscapes, this research aims to foster a socio-economic model that integrates environmental conservation with agricultural productivity, helping to mitigate the risks of food insecurity and land degradation.

In summary, the introduction of halotolerant crops and microorganisms represents a key innovation in the drive towards sustainable agriculture. These biological tools offer significant promise in reversing the degradation of salinized arable lands, transforming abandoned saltworks into productive, sustainable ecosystems [23–25]. Through this study, the aim is to highlight the socio-economic benefits of these innovations, advocating for their broader implementation as part of a comprehensive strategy to meet global agricultural challenges and achieve sustainable development.

2. Material and Methods

2.1. Definition and Conceptual Framework

The Social Life Cycle Assessment (S-LCA) is a methodology developed to evaluate and communicate the social conditions and impacts associated with the production and consumption of products or services throughout their life cycle [26]. According to the United Nations Environment Programme (UNEP), S-LCA is designed to measure these social impacts by focusing on the stakeholders involved, such as workers, local communities, consumers, and society at large [27]. This tool is particularly valuable for assessing the broader socio-economic effects of productive activities, helping decision-makers to foster sustainable development in various industries.

As a relatively novel methodology, S-LCA has only just been fully standardized [28], offering flexibility in its application [29]. This adaptability can be seen as an opportunity to tailor the assessment framework to the specific characteristics of each project, allowing for a more versatile and context-specific analysis. The flexibility of S-LCA is crucial when addressing complex socio-ecosystems, such as those related to halotolerant crops and microorganisms, where social impacts can vary significantly across regions and stakeholder groups.

The origins of the broader Life Cycle Assessment (LCA) methodology date back to 1969, when it was first developed as a pioneering technique to evaluate the environmental impacts of products across their life cycles [30]. Over the years, LCA has been refined and established as a key tool for assessing environmental sustainability [31]. However, the recognition of the need to include social dimensions in life-cycle thinking emerged in the 1990s, leading to the development of S-LCA as a complementary tool to LCA [32].

In 2009, the UNEP published a set of guidelines for the practical implementation of S-LCA [33], providing professionals with essential tools to assess social impacts. More recently, the "Methodological Sheets for Subcategories in Social Life Cycle Assessment" (2021) [34] were released, offering further clarification on how to measure and quantify social impacts. These methodological sheets include indicators, units of measurement, and potential data sources, providing a structured approach to S-LCA that is applied in this study.

S-LCA typically addresses three main dimensions of social impact:

- Behaviors: The social impacts that result from specific behaviors or decisions.
- Socio-economic processes: The broader socio-economic effects that emerge from decisions made at different levels of society.
- Human, social, and cultural capital: The attributes and resources that individuals or groups possess, which influence their ability to respond to socio-economic changes.

In this study, a bibliometric study was conducted by analyzing a set of scientific documents related to S-LCA from the Scopus database. The dataset included 428 documents published between 2008 and 2023, with a significant increase in publications over the last five years. Figure 1 presents the word map generated from this analysis, highlighting the most frequent terms, such as "local community", "needs", "worker", "indicator", and "development". These terms offer a conceptual structure that supports the S-LCA framework and indicates the growing relevance of social life-cycle thinking in various sectors.

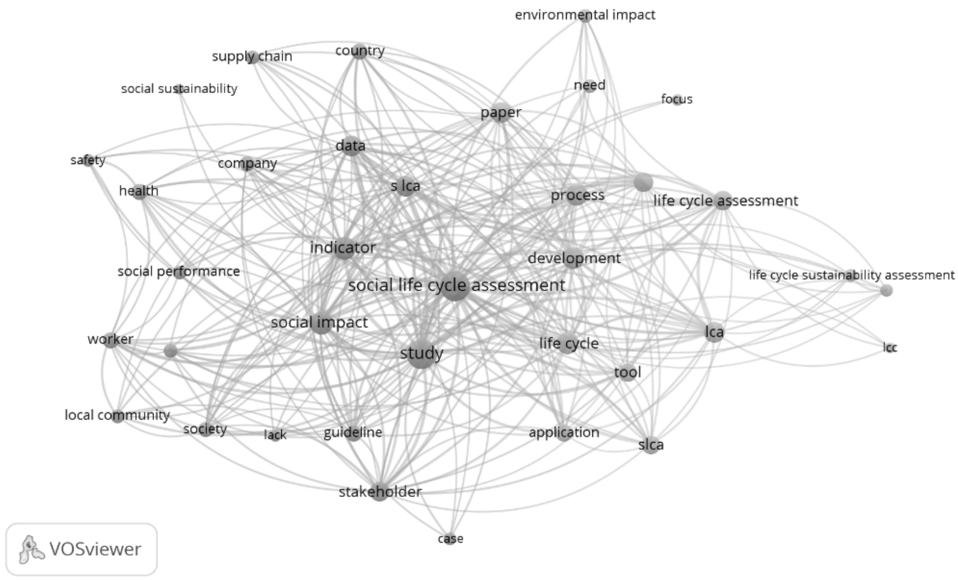


Figure 1. Word map of Social Life Cycle Analysis.

2.2. Methodology

The S-LCA methodology employed in this study follows the guidelines established by ISO 14040 [26,35], which also underpin traditional LCA. This standardized approach consists of four main phases:

- Definition of goal and scope;
- Inventory analysis;
- Impact assessment;
- Interpretation of results.

2.2.1. Definition of Goal and Scope

The first phase involves defining the specific objectives of the study, the motivations behind addressing the selected topic, and the need for measuring social impacts. The goals of an S-LCA study can range from comparing the social impacts of different products or services to evaluating the potential for innovation or improvements in existing systems. In this study, the goal was to assess the social impacts of implementing halotolerant crops and microorganisms in salinized lands and abandoned saltworks within the Iberian Peninsula.

In this study, we defined the scope by focusing on local communities affected by salinization and assessing the potential of halotolerant organisms to address these socio-economic challenges. The boundaries of the system being studied were clearly defined to ensure that the analysis would cover all relevant aspects of the social impact of these innovative agricultural tools.

2.2.2. Inventory Analysis

The inventory phase involves the collection of relevant data to measure the social impacts under consideration. This is typically the most time-consuming stage, as it requires a thorough investigation of the socio-economic conditions related to the project. For this study, data were gathered from a variety of sources, including the scientific literature, policy documents, and media reports. Key for a deeper understanding were the in-depth online interviews conducted in the period 2023–2024 with the CEOs of the initiatives researched in the case studies, such as Carlos Moreno Cámara, managing partner of *La Espelta y la Sal*; Susana Martínez, CEO of *La Salá*; José Luis Sotillo Membibre, manager of *Sal de Saelices*; and Márcia de Carvalho Vaz Pinto, CEO of *Salina Greens*. These interviews were complemented by insights from representatives of research institutions and experts.

The interview process was designed to gather qualitative insights from key stakeholders, including corporate representatives and experts involved in halotolerant crop and microorganism initiatives. Given the small sample size, a structured interview guide was developed to ensure consistency across responses. The questions focused on key social impact indicators, such as employment generation, cultural heritage conservation, and community participation, aligning with the Social Life Cycle Assessment (S-LCA) framework. While data triangulation was not employed due to the limited number of interviewees, the validation of responses was conducted through expert assessment within the research team. This approach allowed for a critical review of the collected information, ensuring coherence and alignment with the existing literature and policy documents. Although this method has inherent limitations, it provides a focused, expert-driven validation process appropriate for exploratory research in this field.

Additionally, relevant contributions and documents from organizations like Salt Doctors, an independent social enterprise based in the Netherlands and specializing in resilient farming systems for salt-affected areas, provided valuable context.

The S-LCA approach often encounters challenges related to the availability and quality of data. In cases where data are lacking or difficult to quantify, assumptions may be made based on analogous sectors or regions. However, care was taken to minimize the use of assumptions and ensure transparency in the data collection process.

To enhance the reliability and accuracy of the data, a rigorous review process was employed to cross-check the information obtained from different sources. This process was essential to ensure the transparency and reproducibility of this study's findings. Furthermore, detailed documentation of the data collection methods, as well as the instruments used to measure social impacts, was maintained to support the validity of the results.

2.2.3. Impact Assessment

The third phase involves the evaluation of the collected data to determine the social impacts. In S-LCA, two main approaches can be used for impact assessment [26]:

- Type I—Reference Scale Approach: This approach focuses on describing the current and historical states of a system or product, providing a baseline for comparison.
- Type II—Impact Pathway Approach: This approach seeks to predict the long-term consequences of social impacts based on current or projected conditions. It often involves mapping causal relationships between variables to understand how social outcomes evolve over time.

Given the innovative and experimental nature of halotolerant crops and microorganisms, this study adopted the Type II—Impact Pathway Approach to predict the potential long-term social impacts on local communities in Spain and Portugal. The primary aim was to assess how these practices can improve social well-being, employment, and community resilience in areas affected by salinization.

The selection of the Impact Pathway Approach (Type II S-LCA) in this study was grounded in its ability to establish causal relationships between specific social indicators and the broader socio-economic impacts of implementing halotolerant crops and microorganisms in Iberian salinas. This method enables the identification of cause–effect mechanisms by mapping how changes in one factor (e.g., employment opportunities) propagate through social structures to generate long-term outcomes (e.g., regional economic revitalization). The chosen indicators—employment creation, community participation, cultural heritage conservation, access to resources, public sustainability commitments, and economic development contribution—align with this approach, as they reflect both direct and indirect effects on local communities. For instance, an increase in employment in salt-pan-related activities leads to greater financial stability among workers, which, in turn, fosters higher community engagement in environmental conservation and sustainable tourism initiatives. This example illustrates how the Impact Pathway Approach allows us to trace the evolution of social benefits, offering a comprehensive understanding of the systemic effects of introducing halotolerant crops and microorganisms.

In line with the UNEP's guidelines, social impact categories were selected based on stakeholder groups and decision-makers. Table 1 outlines the main categories and subcategories used in this study, following the latest UNEP classification from the 2021 "Methodological Sheets for Subcategories in Social Life Cycle Assessment".

Table 1. Social impact categories and subcategories.

Groups of Interest	Subcategories
Local Community	Access to resources, cultural heritage, community participation and employment
Society	Public commitments to sustainability and economic development contribution

2.2.4. Interpretation

The final phase of the S-LCA involves interpreting the results, identifying key insights, and offering conclusions and recommendations. Throughout this process, any limitations or challenges encountered are documented, including the assumptions made during the inventory phase and any constraints in data availability or quality.

A thorough evaluation was conducted to ensure the transparency and consistency of the findings, with special attention given to aligning the results with the original goals of this study. The interpretation phase also included a critical reflection on the limitations of the methodology, particularly in terms of the subjective nature of certain social indicators and the need for future refinement of the S-LCA framework.

2.3. Limitations and Considerations

As a relatively new methodology, S-LCA presents several challenges. First, the lack of standardized procedures can lead to variability in how different practitioners apply the tool, making it essential to clearly define the study's scope and methodology. Moreover, the social data required for S-LCA are often difficult to obtain and quantify, adding to the complexity of the assessment process. Many social impacts are inherently subjective and context-dependent, requiring careful documentation of assumptions and methods.

Until recently, the absence of a universally accepted methodological framework resulted in inconsistencies in its application, making it difficult to compare findings across different studies. However, with the publication of ISO 14075:2024, S-LCA now has an internationally recognized standard that provides guidelines for its implementation. This standardization is expected to enhance the consistency and credibility of S-LCA applications, facilitating more robust comparisons and broader adoption of this methodology in sustainability assessments.

Finally, the involvement of stakeholders is crucial in S-LCA, as their participation ensures that the social impacts are accurately represented. Nevertheless, this engagement can introduce biases depending on which stakeholders are included in the process.

3. Results

This section presents the detailed results of the Social Life Cycle Assessment (S-LCA) applied to halotolerant crops and microorganisms in the Iberian Peninsula. The goal of the S-LCA was to evaluate the social impacts of these innovative practices on local communities, with particular attention to indicators such as employment, community participation, cultural heritage conservation, access to resources, public sustainability commitments, and economic development contribution. The results are presented through a series of tables, each offering quantitative insights into the social effects measured across four case studies: La Espelta y la Sal, La Salá, Saelices de la Sal, and Salina Greens.

The selection of case studies in this research was inherently constrained by the limited number of operational salt-related enterprises in the Iberian Peninsula. Given the specific ecological and economic characteristics of these environments, the chosen cases were selected to represent the main types of saline ecosystems and business models currently present in the region. These include traditional salt extraction (Sal de Saelices), diversified agricultural initiatives incorporating halophytes (La Espelta y la Sal), experimental sustainable practices in abandoned salinas (La Salá), and commercial cultivation of halotolerant species (Salina Greens). While the sample size is small, it encompasses a diversity of approaches within the sector, offering a meaningful perspective on the socio-economic potential of halotolerant crop and microorganism applications. However, we must acknowledge the limitation that unsuccessful or discontinued initiatives were not included in the analysis. Future research should explore these cases to provide a more comprehensive assessment of the challenges and barriers faced in the implementation of such projects.

3.1. Social Life Cycle Inventory

As agricultural practices evolve, halotolerant crops and microorganisms represent a promising solution to combat soil salinization and its detrimental effects on arable land. Given the increasing threat of salinization due to climate change and unsustainable irrigation practices, these organisms offer a way to revitalize abandoned lands while addressing broader socio-economic challenges.

The social indicators selected for this study provide a comprehensive framework to assess the social benefits and potential drawbacks of implementing halotolerant organisms in agricultural systems. Table 2 provides a summary of the key social indicators used in the S-LCA, each chosen for its relevance to improving the well-being of local communities and promoting sustainable agricultural practices.

Table 2. Social indicators measured.

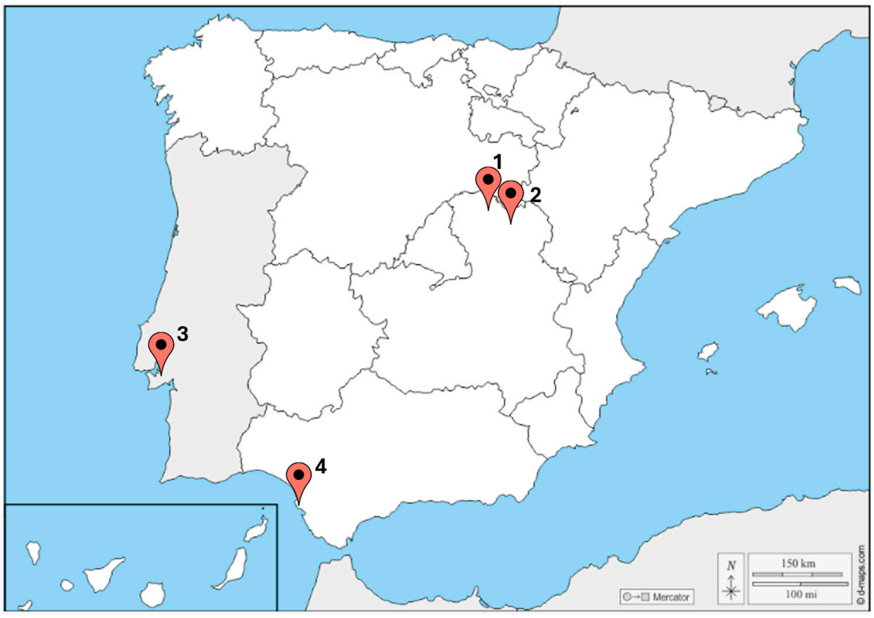
Indicator	Definition
Employment	Creation of jobs directly or indirectly through the implementation of halotolerant crops/microorganisms
Community Participation	Involvement of the local population in decisions and activities related to the project
Cultural Heritage Conservation	Actions taken to preserve cultural heritage, particularly related to traditional salt harvesting
Access to Material Resources	Improvement in access to resources such as water, land, and other necessary inputs
Public Commitments to Sustainability	Engagement with public sustainability goals and policies
Economic Development Contribution	Contribution to the local economy and poverty alleviation

The selection of social indicators in this study followed established S-LCA frameworks, prioritizing aspects most relevant to rural communities engaged in agricultural and environmental restoration activities. Employment, community participation, and cultural heritage conservation were chosen as key indicators because they are directly impacted by local economic and environmental initiatives rather than broader macroeconomic trends. While it is acknowledged that social well-being can be influenced by multiple factors, the assessment methodology used in this study relied on direct stakeholder input from individuals actively involved in halotolerant crop and microorganism initiatives. This approach ensured that the improvements reported were closely linked to these interventions, although we recognize that further research incorporating comparative control groups could provide additional validation.

These indicators are critical to understanding the broader social implications of introducing halotolerant crops and microorganisms. Employment directly reflects the number of jobs created, while community participation reflects the involvement of local populations in project activities. Cultural heritage conservation is especially relevant in areas where traditional agricultural practices, such as salt production, are part of the local history. Access to material resources ensures that communities benefit from enhanced use of water, land, and other inputs. Public commitments to sustainability and economic development reflect the broader social and environmental policies that these innovations align with, especially in relation to national and global sustainability goals.

3.2. Social Impact Assessment of Case Studies

Four companies—*La Espelta y la Sal*, *La Salá*, *Sal de Saelices*, and *Salina Greens*—were selected as case studies to assess the social impacts of halotolerant crops and microorganisms. *La Espelta y la Sal*, located in the region of Sigüenza (Guadalajara), offers organic spelt flour, flour made from ancient revived grains, and high-quality pasta. *La Salá*, part of the Central Research Services in Salt Pans at the University of Cádiz, is dedicated to the artisanal collection of salt and *Salicornia*, as well as the development of innovative food products made with Salicornia. *Sal de Saelices*, salt pans located in the town of Saelices de la Sal (province of Guadalajara), is a salt production site specializing in the harvesting of virgin salt, fleur de sel, and gourmet salt. The primary objective of the foundation is to create employment opportunities in the area surrounding the salt pans, a region severely affected by depopulation. *Salina Greens* is a company based in the Alcochete region of Portugal. Its business model focuses on the cultivation of native edible halophyte species and the diversification of products and services. Figures 2 and 3 present the locations and images of these sites.



1. La Espelta y la Sal, **2.** Sal de Saelices, **3.** Salina Greens, **4.** La Salá

Figure 2. The map (adapted from d-maps.com, 2023) highlights the locations relevant to this study.

Figure 3. Authors' photo (2024). Photograph of the salt pans of Saelices de la Sal.

Each company was evaluated based on the six social indicators outlined in Table 2, with scores assigned on a scale from 0 to 3, where 3 represents high performance and 0 indicates no impact or very low performance. Figure 4 summarizes the social performance of each company.

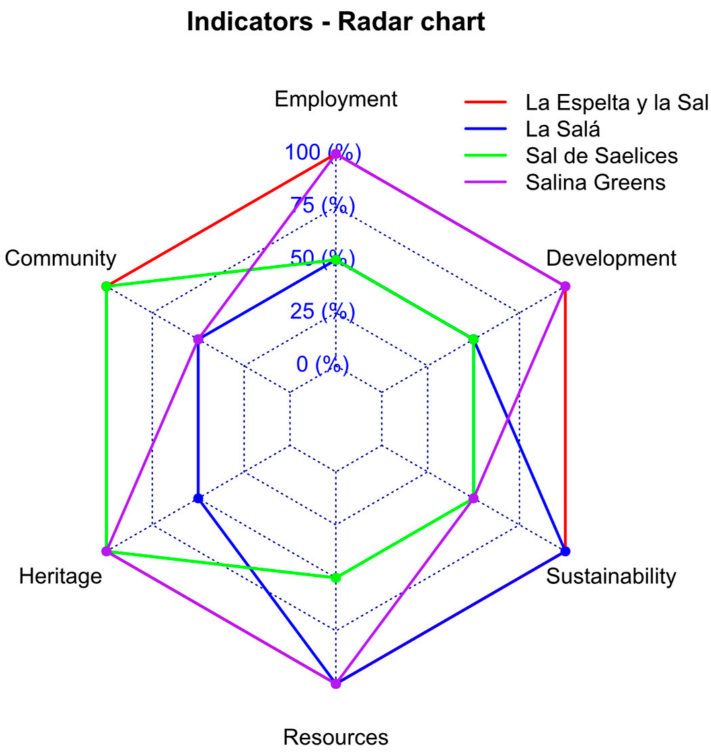


Figure 4. Radar chart comparison of the four salt companies analyzed.

La Espelta y la Sal and *Salina Greens* were the top performers, scoring consistently high across all social indicators, especially in employment, cultural heritage conservation, and access to material resources. These companies have shown strong leadership in adopting sustainable practices and generating local economic benefits. *La Salá* and *Sal de Saelices*, while still contributing positively, showed slightly lower scores in several categories, particularly in community participation and economic development contribution.

3.2.1. Indicator Weighting

To account for the relative importance of each indicator, weights were assigned to reflect their significance in promoting social sustainability. As shown in Table 3 employment, cultural heritage conservation, and access to material resources were weighted more heavily due to their critical role in revitalizing communities and promoting sustainable livelihoods.

Table 3. Weighting of social indicators.

Indicator	Weighting (%)
Employment	20%
Community Participation	13.3%
Cultural Heritage Conservation	20%
Access to Material Resources	20%
Public Commitments to Sustainability	13.3%
Economic Development Contribution	13.3%

This weighting system allows for a more precise evaluation of the impact of each company, as not all social indicators carry the same level of importance for sustainable development.

The weighting of social indicators in this study was based on expert judgment within the research team, reflecting the specific socio-economic dynamics of salt pan ecosystems. Given the absence of universally accepted weighting standards in Social Life Cycle Assessment (S-LCA), expert-driven allocation remains a widely used approach in studies applying this methodology. The assigned weights prioritize key impact areas such as employment generation and cultural heritage conservation, which are particularly relevant in the studied context. However, we acknowledge that this weighting system is not definitive, and further refinement through more quantitative methods (e.g., stakeholder surveys, multi-criteria decision analysis) could strengthen future analyses. The primary contribution of this study lies in the application of the S-LCA framework to halotolerant crop- and microorganism-based projects, while the development of a standardized weighting scheme remains an open avenue for future research.

3.2.2. Adjusted Indicator Scores by Company

By applying the weightings to the raw scores, the adjusted scores for each company were calculated. Figure 5 shows the adjusted scores, which provide a more accurate representation of each company's social impact.

The adjusted scores further highlight the strengths of *La Espelta y la Sal* and *Salina Greens*, with both companies achieving the highest possible scores in several categories. These scores reflect their strong commitment to creating jobs, improving access to material resources, and preserving cultural heritage.

3.2.3. Total Social Impact per Company

Adding up the scores across all indicators provides the total social impact for each company. Table 4 shows the total social impact score for each company, indicating the overall contribution each company makes to local communities.

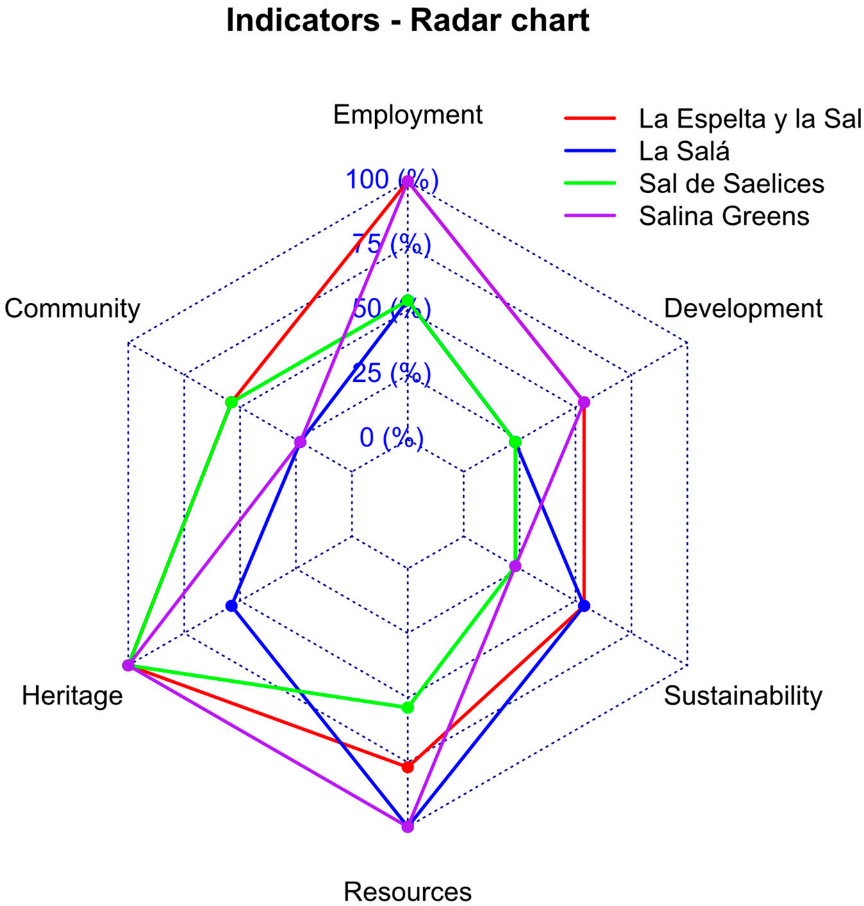


Figure 5. Adjusted scores by company after weighting.

Table 4. Total social impact of each company.

Company	Total Social Impact Score
La Espelta y la Sal	17.4
La Salá	14
Sal de Saelices	14
Salina Greens	16.4

As mentioned above, the total social impact scores in this study were derived from the weighted sum of six individual social indicators: employment, community participation, cultural heritage conservation, access to material resources, public commitments to sustainability, and economic development contribution. Each indicator is scored on a scale from 0 to 3, where 0 represents no impact, 1 indicates limited impact, 2 corresponds to moderate impact, and 3 denotes high impact. The total social impact score ranges from 0 (no social impact) to 18 (maximum social impact). To facilitate interpretation, the scores were categorized into five levels: 0–3 (no impact), 4–7 (low impact), 8–11 (moderate impact), 12–15 (significant impact), and 16–18 (high impact). These values were established based on expert judgment within the research team, ensuring a meaningful distinction between different levels of social impact. The values are relative in the sense that they are calibrated to the specific cases analyzed in this study and do not constitute an absolute or universally applicable classification system for all S-LCA studies. Rather, they serve as a practical framework for comparing the social impact of halotolerant crop- and microorganism-based initiatives within the context of Iberian salinas. Future studies could refine these thresholds by incorporating a larger dataset or employing statistical methods to establish more standardized cut-off points applicable to a broader range of contexts.

3.2.4. Social Impact Classification

Based on the total social impact scores, each company was classified into different levels of social impact. As shown in Table 5, *La Espelta y La Sal* and *Salina Greens* fall within the "High" impact category, and *La Salá* and *Sal de Saelices* into the "Significant" category, demonstrating that these companies are making meaningful contributions to social sustainability in their communities.

Table 5. Social impact classification.

Range	Impact
0–3	None
4–7	Low
8–11	Moderate
12–15	Significant
16–18	High

The classification ranges presented in Table 5 were determined through a combination of empirical data from the case studies and expert judgment, ensuring that they reflect meaningful distinctions in social impact levels within the specific context of halotolerant crop- and microorganism-based initiatives in Iberian saltworks. It is important to note that these values are relative rather than absolute, meaning that they are intended as a comparative framework within the scope of this study rather than a universally applicable classification for all Social Life Cycle Assessment (S-LCA) studies. The thresholds were defined to facilitate interpretation of the results and provide a structured way to compare different initiatives in the context of sustainable agriculture in saline environments. However, these classifications should not be extrapolated beyond the specific conditions and methodological approach used in this research without further validation.

3.3. Innovation Potential

An innovation potential indicator was introduced to assess the companies' capacity to adopt halotolerant crops and microorganisms. This is a qualitative indicator to understand how open and involved each company is with respect to implementing new technologies. Table 6 defines the levels of innovation potential, while Table 7 presents the scores assigned to each company.

Table 6. Innovation potential indicator.

Value	Description
0	Initial curiosity and awareness
1	Interest and consideration
2	Commitment to exploring and planning implementation
3	Active implementation and support

The innovation potential indicator values were assigned based on qualitative assessments conducted through direct interviews with company representatives and an expert evaluation within the research team. The scoring system (0–3) reflects the level of engagement and commitment demonstrated by each company toward the adoption of halotolerant crops and microorganisms. A score of 0 corresponds to companies with only an initial curiosity or awareness of the approach, while a score of 3 indicates active implementation and support for innovation in the field. This classification was developed based on observable company activities, including investments in halotolerant agriculture, research collaborations, and participation in sustainability initiatives. Given the exploratory nature of this assessment, these values are relative to the studied cases and are not intended as a universally applicable innovation metric. Future studies could refine this indicator through stakeholder surveys or quantitative scoring methodologies to enhance its robustness.

Table 7. Innovation potential scores of participating companies.

Company	Innovation Potential
La Espelta y la Sal	2
La Salá	3
Sal de Saelices	2
Salina Greens	3

Both La Salá and Salina Greens demonstrated a high level of innovation potential, actively engaging in the implementation and support of halotolerant crops and microorganisms. La Espelta y la Sal and Sal de Saelices showed strong interest and commitment to adopting these new technologies, albeit at a slightly slower pace.

3.4. Interpretation of Results

The results of this Social Life Cycle Assessment provide significant insights into the social benefits and challenges associated with the introduction of halotolerant crops and microorganisms in the Iberian Peninsula. Overall, the findings suggest that these innovations can have a substantial positive social impact, particularly in terms of job creation, community engagement, cultural preservation, and sustainability.

One of the most significant findings of this study is the potential for job creation. The implementation of halotolerant organisms can directly generate employment opportunities, particularly in agricultural production, processing, and distribution. This is crucial in rural areas where unemployment and outmigration are often major challenges. Companies like La Espelta y la Sal and Salina Greens demonstrated a strong capacity to generate employment, helping to revitalize local economies.

Another important finding is the role of these innovations in cultural heritage conservation. In regions where traditional salt production has been a cornerstone of local culture, the introduction of new agricultural practices can help preserve this heritage. For example, Sal de Saelices and La Espelta y la Sal scored highly in this area, showing a clear commitment to safeguarding local traditions while embracing modern sustainable practices.

The results also highlight the importance of community participation in ensuring the success of these innovations. By involving local populations in decision-making and project activities, companies can foster stronger social cohesion and a greater sense of ownership over the projects. Additionally, access to material resources was improved in areas where halotolerant crops were implemented, ensuring more efficient use of water, land, and other inputs.

In terms of public commitments to sustainability and economic development, this study found that companies are aligning their operations with broader national and global sustainability goals. This alignment not only improves the environmental outcomes of their activities but also contributes to long-term economic development in rural areas.

Finally, the innovation potential of halotolerant organisms presents exciting opportunities for the future. As seen in La Salá and Salina Greens, companies that are proactive in adopting these new technologies are better positioned to lead in the fight against land degradation and food insecurity. The readiness of these companies to implement innovative practices underscores the broader relevance of halotolerant organisms for sustainable agriculture globally.

In conclusion, the introduction of halotolerant crops and microorganisms offers a powerful tool to address the dual challenges of environmental degradation and socio-economic development. The results of this S-LCA demonstrate that these innovations can deliver significant social benefits, particularly in employment, cultural heritage conservation, and economic development, while aligning with global sustainability goals.

4. Discussion and Conclusions

The implementation of halotolerant crops and microorganisms offers significant socio-economic and environmental benefits, particularly in regions affected by soil salinization. The findings from this study provide an opportunity to discuss the broader implications of the Social Life Cycle Assessment (S-LCA) conducted, its relevance to sustainable development, and the potential for future expansion of these practices in the Iberian Peninsula.

4.1. Discussion

The results of the S-LCA presented in the previous section demonstrate that halotolerant crops and microorganisms contribute positively to local communities, fostering employment, enhancing cultural heritage preservation, and improving access to material resources. These findings align with the overarching goals of sustainable development, particularly the United Nations' Sustainable Development Goals (SDGs), which emphasize environmental protection, socio-economic progress, and innovation.

The results of the Social Life Cycle Assessment (S-LCA) reveal notable differences in the social impact scores across the four case studies, highlighting the varying degrees of socio-economic benefits derived from the implementation of halotolerant crops and microorganisms. The highest-scoring cases, La Espelta y la Sal and Salina Greens, achieved strong performance in employment generation and cultural heritage conservation, reflecting their well-established business models and commitment to sustainable practices. In contrast, La Salá and Sal de Saelices obtained slightly lower scores in categories such as community participation and economic development contribution, suggesting potential areas for further engagement and investment. These results emphasize the role of business structure, market positioning, and community involvement in shaping social impacts. Additionally, the findings support the argument that halotolerant agriculture and salt pan revitalization can serve as viable strategies for socio-economic development in degraded and abandoned saline landscapes. While these results provide valuable insights, they are specific to the selected case studies, and future research should explore a broader range of cases, including those with different operational challenges, to further validate these observations.

While this study has identified positive socio-economic changes linked to the implementation of halotolerant crops and microorganisms in salt-affected lands, we acknowledge that external economic and social factors may also contribute to improvements in employment, community engagement, and local economic development. This study is case-specific and does not seek to isolate the impact of halotolerant agriculture from broader macroeconomic trends. However, direct interviews and case study assessments indicate that the observed improvements were directly associated with these initiatives. Future research could further strengthen this analysis by incorporating control groups or statistical approaches to quantify the relative contributions of these interventions compared to other economic factors.

4.1.1. Employment and Economic Development

One of the key findings from this assessment is the capacity of halotolerant practices to generate employment in rural areas where job opportunities are limited. As seen in the case studies of La Espelta y la Sal and Salina Greens, the introduction of halotolerant crops can stimulate local economies by creating new agricultural jobs, increasing productivity, and encouraging long-term investment in these regions. For example, both companies were able to provide jobs not only in agriculture but also in related industries such as processing, marketing, and distribution. This can have a cascade effect on other local businesses in the services sector, such as hospitality or wellness, which can be significant in areas with extremely low population density, such as where La Espelta y la Sal or Sal de Saelices are located.

This positive impact on employment is particularly relevant for regions struggling with depopulation and economic stagnation. By reviving abandoned salinized lands, these initiatives create a sustainable agricultural model that benefits both the environment and the local workforce. Additionally, these jobs are tied to a broader development strategy aimed at reducing poverty and fostering inclusive economic growth, as seen in the economic contributions made by these companies. Former traditional salinas are gradually moving from a paradigm of salt production to a multifaceted production- and service-based activity, where the harvesting of salt and other byproducts such as muds, brine, mother clay, or halophytes coexists with tourism, gastronomy, wellness, education, and innovation. Gradually, these onsite activities have a cascade effect on the local economy and build synergies with other businesses that strengthen the local socio-economic fabric [35,36]. Areas like Aveiro in Portugal, Guérande in France, or Sečovlje in Slovenia have recovered saltscapes and generated businesses around salt after decades of decline in the old-fashioned production of industrial salt [12].

4.1.2. Community Participation and Cultural Heritage Conservation

Community participation is another crucial element highlighted by this study. The success of these projects hinges on the active involvement of local populations in decision-making processes and day-to-day activities. By engaging the community, companies like Saelices de la Sal and La Salá were able to foster a sense of ownership and responsibility among local residents. This not only helps ensure the sustainability of the projects but also promotes social cohesion within the community.

Traditional salt-making has shaped landscapes and identities across the world and over the centuries. In many regions, local identity is tightly linked with the production of salt and even bears it in the name. In Spain and Portugal alone, toponyms of varied linguistic origin, such as Salinas de Añana, La Malahá, Leintz Gatzagak, O Salnés, and Alcácer do Sal, give an idea of the diversity of saltscapes and cultures found in the Iberian Peninsula. The loss of salt-making activity in over 90% of the salinas in the past decades has triggered an interest in recovering them with more diversified activity that involves tourism, gastronomy, well-being, and innovation. This diversification has enabled local communities to engage in businesses that support these uses [12,37].

Hence, a significant social benefit is the preservation of cultural heritage. In many of these regions, traditional salt production methods have been passed down through generations and are integral to local history and culture. Reviving these practices through sustainable approaches such as halotolerant crops can help maintain these cultural traditions while simultaneously introducing innovative agricultural techniques. The case of Saelices de la Sal, where historical salt extraction practices were reintroduced, exemplifies how cultural heritage and sustainability can coexist.

4.1.3. Environmental Sustainability and Access to Material Resources

From an environmental standpoint, the introduction of halotolerant crops and microorganisms also contributes to the preservation of ecosystems and the sustainable use of natural resources. As discussed in the results, these practices enhance access to material resources, particularly water and land, which are critical in regions affected by salinization. The ability of halotolerant organisms to thrive in saline environments reduces the need for freshwater resources, a key advantage in regions facing water scarcity due to climate change.

Halophytes are an underutilized type of plants with nutritional value or that can be used as a healthier form of *green* salt [38]. Harvesting wild populations of *Salicornia ramossisima* in former saltworks may seem to be unattractive, as shown by a study in the Odiel saltworks in Spain. Plants found at higher elevations showed denser stands than those at lower elevations, where the salt pans are usually located [39]. However, irrigation with natural brackish water may prove useful to enhance the success of these crops. Cultivated plants seem to have a higher nutritional value than their wild counterparts. A study in Portugal with six species of halophytes showed the viability of these highly nutritious and healthy crops [40,41].

The cultivation of halotolerant crops or crops aided by halotolerant microorganisms in arid and semiarid regions is envisioned as a sustainable agriculture solution and has been widely applied across these areas (e.g., [42,43]). However, no studies have been conducted for the application of halotolerant microorganisms or crops for the recovery of former saltworks.

These practices support the regeneration of degraded soils, improving their fertility and long-term productivity. This not only helps ensure food security but also mitigates the environmental impact of unsustainable agricultural practices. The alignment of these practices with SDG 15 (Life on Land), which focuses on protecting, restoring, and promoting the sustainable use of terrestrial ecosystems, underscores the broader environmental significance of these findings.

4.1.4. Innovation and Long-Term Potential

One of the most exciting aspects of this study is the innovation potential associated with halotolerant crops and microorganisms. As shown in the innovation scores of companies like La Salá and Salina Greens, there is a high level of interest in and commitment to adopting new technologies that can address the challenges posed by land degradation and salinization. This innovative potential is crucial for the long-term success of these projects, as it enables companies to remain adaptable and responsive to emerging environmental and economic conditions.

The cultivation of halophile microorganisms for the obtention of novel, functional foodstuffs, bioactive pharmaceutical compounds, or substances for other uses is a common activity in former saltworks, or even in active ones. Initiatives exist across the world, with nearby examples in Spain (e.g., Odiel, Huelva) or Portugal (e.g., Necton, in Olhão, Algarve) [44,45]. These activities are included in what is known as the "blue economy", where innovation is key to supporting communities linked to water in one way or another, with sustainability as a key parameter linking the production of food and energy [46]. However, the "blue economy" or water-based economy is not that common in inland regions or in former saltworks. No references have been found on the potential of inland saltworks for sustainable and innovative food production.

In the broader context, the innovative nature of these practices positions them as key solutions for addressing global agricultural challenges, including climate change, food security, and resource management. The potential for scaling up these practices is substantial, particularly in regions like the Iberian Peninsula that face significant agricultural pressures due to changing climate patterns.

4.2. Conclusions

The results of the S-LCA clearly indicate that the introduction of halotolerant crops and microorganisms can deliver substantial socio-economic and environmental benefits to regions affected by soil salinization. By promoting sustainable agricultural practices, these innovations offer a pathway toward restoring degraded lands, enhancing food security, and fostering local economic development. The following key conclusions can be drawn from this study:

Positive Socio-Economic Impacts: Halotolerant crops and microorganisms generate employment, boost local economies, and foster community participation. These practices provide a sustainable solution to revitalizing abandoned lands, creating job opportunities in regions facing depopulation and economic decline.

Cultural and Environmental Benefits: These agricultural practices contribute to the preservation of cultural heritage by maintaining traditional methods of land use, such as salt production, while introducing modern techniques. At the same time, they enhance environmental sustainability by reducing freshwater usage, improving soil fertility, and supporting ecosystem regeneration.

Alignment with Global Sustainability Goals: The findings of this study align with several SDGs, including SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land). The integration of halotolerant crops into agricultural systems offers a sustainable approach to addressing global challenges related to food production, environmental protection, and economic development.

Innovation and Future Potential: There is significant innovation potential associated with halotolerant crops and microorganisms, particularly in terms of scaling up these practices to meet the challenges posed by climate change and resource scarcity. Companies that embrace these innovations are better positioned to lead in the global effort to combat land degradation and ensure food security.

4.3. Recommendations for Future Research and Implementation

The study highlights several areas where further research and action are needed:

- Expansion of Case Studies: While this study focused on four companies, expanding the scope of future research to include more case studies across different regions would provide a more comprehensive understanding of the social and environmental impacts of halotolerant practices.
- Longitudinal Studies: Future research should also focus on conducting longitudinal studies to assess the long-term socio-economic and environmental benefits of these practices over time. This would provide valuable insights into the sustainability and scalability of halotolerant crops and microorganisms.
- Government and Policy Support: The successful implementation of halotolerant practices requires support from policymakers. Future efforts should focus on advocating for policies that incentivize the use of sustainable agricultural practices, such as providing subsidies or tax incentives for companies adopting halotolerant technologies.
- Scaling and Replicability: There is a need to explore the potential for scaling up these practices beyond the Iberian Peninsula and into other regions facing similar challenges. Research into the replicability of these practices in different climatic and geographic contexts would be beneficial for global agricultural sustainability.

In conclusion, halotolerant crops and microorganisms represent a transformative approach to addressing the challenges posed by soil salinization, land degradation, and climate change. The findings of this study demonstrate the substantial social, economic, and environmental benefits that these practices can deliver, along with their potential to contribute to a more sustainable and resilient future for agriculture.

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