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CASE STUDY

Social life cycle assessment in the context of bioeconomy: a comparative study of fertilizer value chains

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Abstract

Bioeconomy as a model for sustainable development is gaining momentum; however, its environmental aspects are commonly weighted more heavily than its social ones. As a potentially more sustainable alternative, the bioeconomy is increasingly gaining prominence within evaluation models that adopt a life cycle approach, such as Social Life Cycle Assessment (S-LCA). In this sense, we present a comparative case study of bio-based and mineral fertilizers carried out in an agri-food region of Spain, where the bioeconomy is perceived as an opportunity. Nowadays, S-LCA is presented as a powerful tool to measure the social impacts throughout product life cycles; nevertheless, the most common tools in this area have several limitations at the data level, thus organization-specific data need to be collected to broaden results. In order to address these limitations, we employ a dual impact assessment methodology, combining a generic analysis with one of the most used databases (Social Hotspot Database -SHDB-) and with a specific analysis through an organizational approach developed from the UNEP Guidelines (2020), employing the Performance Reference Points method. Data were gathered through participant observation and direct collaboration with the organizations involved in the study. The results show that both methods can provide holistic information relevant for organizations' decision making and confirm that biofertilizer is more socially sustainable when compared to conventional fertilizer, in addition the former boasts greater scope for social improvement. However, inadequate social performance in areas such as gender equality, quality employment, and customer complaints suggests that the biofertilizer is not fostering social sustainability. Finally, achieving social sustainability requires organizations to proactively address social dimensions in their practices.

Keywords S-LCA · Social life cycle assessment · Bioeconomy · Biofertilizers · Agriculture · Social impacts

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1 Introduction

Bioeconomy is a new model whose aim is to replace an economic system which is highly dependent on fossil and finite resources with one based on renewable biological resources, by focusing on current biotechnological processes and applications to promote sustainable development (Mattila et al., 2018; Sanz-Hernández et al., 2020). The model includes circular economy principles (D'Amato et al., 2017) and all sectors related to biological resources (agriculture, forestry, fisheries, food and paper production, as well as areas of biotechnological, energy and chemical industries) offering significant potential for innovation (European Commission, 2018). At present, bioeconomy has been placed high on the political agenda of more than 50 countries as the opportunities for positive impacts are fundamentally connected to environmental, economic, social and ethical dimensions (Ingrao et al., 2018; Sanz-Hernández et al., 2019). These new policies seek to contribute to a range of policy objectives and sustainable development goals (SDG) (Ronzon et al., 2022; Salvador et al., 2021) to achieve sustainability, which is seen as the result of striking a balance between socioeconomic practices and ecological systems (Ahlström et al., 2020).

Consequently, the agricultural sector is essential to the bioeconomy, providing both food security and biomass as a renewable raw material for bio-based industries (Woźniak et al., 2021). The food regime and contemporary models of agriculture are linked to significant environmental, social, and economic impacts at a global scale, calling for a paradigm shift to ensure equitable global food security and enhance environmental conservation (Pritchard, 2016). Due to the increasing importance of climate change and population growth, the transformation of agri-food systems towards sustainability is paramount among the primary global challenges (Faucon et al., 2023). In this context, biofertilizers represent a more sustainable alternative within the agriculture for the transformation of global agri-food systems (Daniel et al., 2022). For instance, in Europe, the significance of biofertilizers in enhancing soil fertility is driving the adoption of new agri-food strategies aimed at achieving greater resource independence, ensuring food security, and reinforcing the socioeconomic fabric of rural areas (European Commission, 2023). This increasing political commitment aligns with long-term objectives that advocate for a transition towards more organic agricultural production, with the goal of partially or completely substituting mineral fertilizers (Kurniawati et al., 2023). Thus, the discourse regarding the transformation of the global food system to improve its sustainability, as well as the evaluation of these transformations, is gaining prominence (De Luca et al., 2017).

The consideration at value chain level has been recognized as a priority that requires systematic study in sustainability context (Muñoz-Torres et al., 2021), where stakeholder pressure plays a large role in the increased focus on supply chain management (Ayassamy, 2024; Bubicz et al., 2019). Organizations are under increasing expectations to quantify and mitigate their impacts and make sustainable decisions that could influence the entire value chain and their stakeholders (D'Eusanio et al., 2019). This brings into sharp focus the three dimensions of sustainability, environment, economy and society, all of which should be considered by a company wishing to partake in the bio-based economy (Rafiaani et al., 2018). In the assessment of sustainability transformations within a bioeconomy, Life Cycle Assessment (LCA) methodologies hold significant promise, as they offer comprehensive evaluation tools that address the three dimensions of sustainability (Ferreira et al., 2022). In this context, Life Cycle Sustainability Assessment

(LCSA) represents a comprehensive approach that integrates the dimensions of sustainability through three assessment methods: Environmental Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) (Valdivia et al., 2021). While the question of whether the bioeconomy is more environmentally friendly commonly arises the concept of being more aware of social impacts is usually more neglected, which positions S-LCA as a relatively recent area of development compared to the other two life cycle approaches (Spierling et al., 2018). Moreover, demand for assessing potential social effects has been increasing due to the implementation of corporate social responsibility policies (Siebert et al., 2018a). And while papers on social sustainability transformations have increased in number in recent years (Sanz-Hernández et al., 2019), there is increasing pressure to improve social impact assessment tools to give more complete sustainability perspectives (Spierling et al., 2018). Therefore, the transitions to bioeconomy are starting discussions about how to be more social, comprehensive and inclusive (Sanz-Hernández et al., 2022), emphasizing the need to evaluate social transformations through S-LCA (Zarauz et al., 2025).

Within the agri-food sector, there is an increasing emphasis on investigating the social impacts associated with existing global value chains from the perspective of S-LCA (Tragnone et al., 2022). Nonetheless, studies addressing the bioeconomy in agriculture remain limited in this context and there persists a requirement for more in-depth research concentrating on the transformative capacity of the bioeconomy on the social dimension. To date, only one article has utilized the S-LCA methodology to analyze the social impacts associated with the bioeconomy within the biofertilizer subsector (Martínez-Blanco et al., 2014). However, there are currently no studies within this context that thoroughly examine the evaluation of a bioeconomy as a potential opportunity for transforming the social dimension of agri-food value chains in the fertilizer sector.

Against this background, this paper aims to contribute to the existing literature related to agri-food bioeconomy and social sustainability, comparing biobased models to conventional ones. Specifically, the authors aim to assess the social opportunities and risks along the value chains of two types of fertilizers, one biobased and the other conventional. The aim of this research is to assess whether bioeconomic models are contributing to a socially sustainable transition, alongside their environmental and economic dimensions. For this purpose, this research has employed the most effective technique for evaluating social impacts from the life cycle perspective today: Social Life Cycle Assessment (S-LCA) (Macombe et al., 2018a). Additionally, a methodological proposal has been established to achieve broader results through a dual impact assessment method. It focuses on organizational performance and explores social impacts more closely linked to suppliers and supply chain origins. Thus, we seek to address the following questions: Is the bioeconomy generating more social transformations along the value chain compared to conventional models? And, what are the barriers and opportunities towards a social sustainability within the value chains of the bioeconomy?

This paper is structured as follows: The next section frames the social assessment on bioeconomy and the importance of the fertilizer sector in our case study. Section 3 explains the approaches and methods adopted, which are based on the UNEP guidelines and the Social Hotspot Database (SHDB), and presents a descriptive analysis of the assessment. Section 4 summarizes the results and discussion and finally, Section 4.3 presents the main conclusions and recommendations for future research.

2 Background

2.1 Social life cycle assessment in bioeconomy

S-LCA is an iterative methodology that can be applied either independently or in conjunction with other life cycle assessment tools (LCA and/or LCC). This methodology distinguishes itself from other social assessment techniques in terms of its object, scope, and measurement process, with evaluations focusing on the social impacts associated with products and services over the entire life cycle, from raw material extraction to the disposal or recycling of the product (UNEP, 2020). The primary objective of conducting an S-LCA is to support decision-makers in selecting alternatives with social implications that affect the lives of workers, consumers, society, and other key stakeholders within the evaluated value chain (Huertas-Valdivia et al., 2020). Therefore, the S-LCA assesses social impacts in relation to their effects on stakeholders, highlighting the critical role of identifying and addressing impacts on affected or involved individuals (UNEP, 2020).

The main guidelines for the development of an S-LCA have been published in the Guidelines for Social Life Cycle Assessment of Products and Organizations (UNEP, 2020), henceforth UNEP guidelines. Additionally, a framework of proposed social indicators is provided to guide data collection during the process (Benoît-Norris et al., 2011), as detailed in the publication Methodological Sheets for Subcategories in Social Life Cycle Assessment, hereafter referred to as methodological sheets (UNEP, 2021). These publications are grounded in fundamental international standards, including the Global Reporting Initiative (GRI), ISO 26000, SA 8000, the OECD Guidelines for Multinational Enterprises, and AccountAbility, among others (UNEP, 2020). Collectively, these guidelines are the most widely used and frequently applied references to date, serving as the principal framework for developing an S-LCA (Ramos Huarachi et al., 2020).

In accordance with the UNEP guidelines, it is important to emphasize that S-LCA encompasses two distinct, yet potentially complementary, approaches: a specific assessment and a generic assessment (UNEP, 2020). First, for specific assessments, the standard framework commonly employed is based on the use of methodological sheets (UNEP, 2021). Such assessment arises from the need for site-specific data analysis to achieve a more accurate S-LCA (Jørgensen et al., 2008). Indeed, there are increasing concerns regarding the complexity of gathering primary data essential for the effective implementation of these assessments (Ayassamy & Pellerin, 2023). Nevertheless, site-specific data, which are considered more valuable, are typically acquired through the active involvement of stakeholders, employing a range of sociological techniques (Pollok et al., 2021). This requires considerable effort to gather primary, context-specific social data from the value chain, and poses greater challenges for replicating and/or comparing such studies (Siebert et al., 2018b). Secondly, generic studies primarily focus on identifying critical points, such as risks related to human and/or labor rights violations, as well as organizational reputation, in addition to opportunities for social improvements (Benoît-Norris et al., 2011). This generic approach has gained prominence in recent years, particularly with the standardization of S-LCA calculations through the development of databases such as the Social Hotspots Database (SHDB) (Benoît-Norris et al., 2012) and the Product Social Impact Life Cycle Assessment (PSILCA) database (Ciroth & Eisfeldt, 2016). This advancement provides significant support for conducting generic assessments of social hotspots and for utilizing software in S-LCA, such as SimaPro (for SHDB) and OpenLCA (for both SHDB and PSILCA) (Ramos Huarachi et al., 2020). In the context of a generic study, data are typically gathered at international, national, and/or sectoral levels to identify critical points throughout the value chain, without the need for specific data on individual production plants or local particularities (Huertas-Valdivia et al., 2020). In recent years many S-LCA studies have leveraged these tools to obtain a better and more common assessment. However, in the context of bioeconomy studies, the applicability of these databases is limited as the social implications of this bio-based model are primarily local and rooted in the biological resources within a specific territory (Zarauz et al., 2025).

Despite the strong local nature of the bioeconomy, it is integrated also into a globalized economy characterized by diverse and interconnected international value chains, ranging from the cultivation of raw materials to the final disposal or valorization of bioproducts. Therefore, it is imperative to understand the cumulative impacts associated with the contributions of each sector along the value chain in order to effectively assess sustainability (Rebolledo-Leiva et al., 2023). While S-LCA remains in a developmental phase and requires further maturation, it already emerges as a promising instrument for the social sustainability assessment of a bioeconomy (Ramos Huarachi et al., 2020). In this sense, Zarauz et al. (2025) argue that S-LCA studies in the bioeconomy have yet to assess the transformations needed for social sustainability, underscoring the need for a more critical approach.

Nowadays, research specifically focused on the development of S-LCA within the bioeconomy has progressively increased over time. These studies address both regional and local perspectives in European bioeconomy that emphasize opportunities for regional development (Rafiaani et al., 2020; Siebert et al., 2018a, b), as well as a global bioeconomy perspective that assesses social risks associated with supply chains (Cadena et al., 2019; Panoutsou et al., 2022). Additionally, Mattila et al. (2018) establish a joint vision of both local and global social impacts within forest bioeconomy. However, local and global assessments of social impacts have yet to be addressed within the agri-food sector of the bioeconomy. Thus, this paper aims to address the existing limitations in both types of evaluation by combining them through an innovative proposal within the S-LCA framework and the study of the bioeconomy, and more specifically, within the fertilization sector.

2.2 Socially sustainable challenges in the fertilizer sector

The selection of the fertilizer sector is due to the importance of the agri-food sector in Spain, which is the main protagonist of the Spanish bioeconomy (Ferreira et al., 2021) and the primary activity in rural areas, while also being a strategic sector for the Spanish economy (9.6% of the GDP) (Ministry of Spain, 2021). Currently, it is paramount that the fertilizer industry pivot to sustainable production processes with a holistic sustainability perspective (Daniel et al., 2022). Indeed, the majority of current crop farming methods are based on the inappropriate use of fertilizers that have contributed to poverty, hunger, land and water degradation, deforestation, loss of biodiversity and climate change (FAO, 2014). There is an urgent need for agricultural transformation driven by initiatives such as agroecology, permaculture, organic and regenerative agriculture (Gordon et al., 2021), which could help face the challenge of poverty, food insecurity and climate change (Schulte et al., 2021). For this transformation, it is crucial to explore new approaches to biofertilization and biostimulation that improve the availability and absorption of nutrients in the soil creating more sustainable food systems (Mahanty et al., 2017; Mahapatra et al., 2022).

All these problems related to the agri-food sector are present in the Spanish context together with another issue, depopulation. Spanish rural areas make up 84% of the national territory land but are home to only 16% of the population. In fact, the Spanish government states that the main social challenge is to build territories that are efficient, competitive and sustainable by increasing the social and economic structure (Ministry of Spain, 2021). The bioeconomy along with the new Common Agricultural Policy (CAP) will provide new opportunities for all the agents in the food value chain given that food, water and nutrients are considered key value chains for the sustainability challenge (European Commission, 2019b). In this context, transition will be the key to ensuring that Spanish agriculture will continue providing food security, while also acting as one of the economic pillars of rural communities. In fact, increased knowledge, research and innovation in biological resources could socially transform rural areas into resilient communities (European Commission, 2019b).

In Europe, many recent strategies include the transformation of the agricultural sector, for instance, the Bioeconomy Strategy, European Green Deal, Circular Economy Action Plan, Farm to Fork Strategy and Biodiversity Strategy (European Commission, 2018; 2019a; 2020a; 2020b; 2021a). One of the main goals of these strategies and policies is to accelerate the transition to a sustainable food system which will provide environmental and social benefits, as well as economic advantages. On this matter, a bioeconomy is proposed as a largely untapped opportunity for the transition to a climate-neutral European economy and the creation of new jobs in primary production (European Commission, 2018).

It is evident that the fertilizer sector is essential to meeting global challenges for sustainable development. In fact, we are currently witnessing historic policy changes that promote sustainable food systems (Schulte et al., 2021). More specifically, the Farm to Fork Strategy highlights the environmental degradation being caused by intensive agriculture and prioritizes the reduction of the use of fertilizers by at least 20% by 2030 in an effort to restore biodiversity. Europe aims to achieve 25% of the EU's agricultural land under organic farming by the year 2030 (European Commission, 2020a). Hence, employing life cycle assessment tools to evaluate sustainability impacts across its three dimensions within the agri-food sector is crucial, particularly in the social dimension, which remains underexplored (Tragnone et al., 2022). From an environmental and costing perspective, LCA and LCC studies of biological and mineral fertilizers have been developed by Martínez-Blanco et al., (2013a, b). To the best of the authors' knowledge, apart from the current paper, only one other S-LCA study has assessed fertilizer systems. Again, Martínez-Blanco et al. (2014) introduce an application of the S-LCA guidelines and attempt to explain social potential through the SHDB in an LCA case study of three fertilizers, one of which is biobased. However, there is a significant lack of in-depth empirical research on the social impacts of biofertilizer systems at the life cycle level. Consequently, this study aims to fill this knowledge gap by analyzing the transformative capacity for social sustainability in bioeconomic systems compared to conventional ones.

3 Methodology

To answer the research questions, a compound methodology is proposed that allows linking product assessments to social impact and performance results from a life cycle perspective, thereby ensuring results with greater rigor and scope. The distinctions between social impact and social performance are outlined in the UNEP guidelines. In relation to this, social risk is associated with generic assessments and lower-resolution data, as it derives social impacts from generic data at the national or sectoral level without specifying social performance by any given organization, where primary and specific data are typically analyzed throughout specific assessment (UNEP, 2020).

The two assessments used in the compound methodology -generic and specific- implement the main steps of S-LCA according to UNEP guideline, which follow the same general four steps of LCA as indicated by ISO 14040 (2006a) and ISO14044 (2006b): goal and scope definition; inventory analysis; impact assessment; and interpretation. These steps are explained in the following section. Figure 1 shows the focus of each evaluation approach framed within the analysis of the value chain. The first of which, designated as the supplier approach, focuses on a generic analysis by assessing social impact through the calculation of social risks. This supplier approach is based on the methodology proposed by SHDB, one of the most used S-LCA database applied in several products and sectors to date (Ramos-Huarachi et al., 2020). This database provides product hotspots through the use of software and the utilization of generic and secondary data from national and international organizations, employing a calculation procedure similar to LCA to associate impacts to a product (UNEP, 2020).

The second method, designated as the organizational approach, evaluates social performance based on specific organizational data collection. This approach measures corporate social performance (Wood, 2010) and has focused on the Reference Scale Assessment (formerly Type I or RS S-LCIA), where data is gathered through the collaboration of the companies in the study. In this approach, social indicators were evaluated based on primary data provided by the companies, which were then aligned with the subcategories and categories defined in the methodological sheets (UNEP, 2020, 2021). Consequently, all indicators are derived from information provided by the company and subsequently associated with the corresponding stakeholder group (e.g., the percentage of female employees is associated with the workers' group).

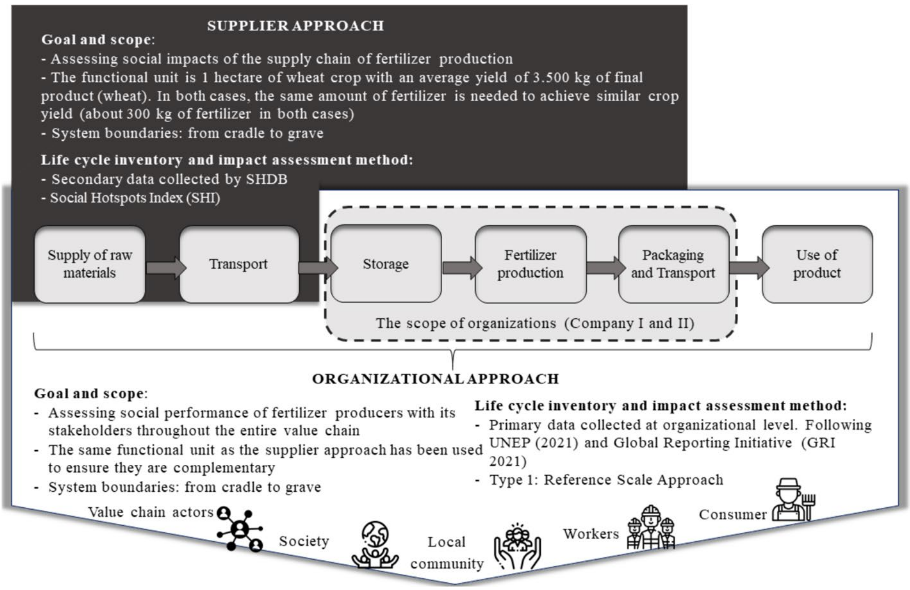

Fig. 1 Methodological S-LCA proposal with a dual approach

In S-LCA, some aspects related to the selection of different stakeholder categories, impact subcategories, indicators, and weighting methods continue to be a challenge (Macombe et al., 2018a). In several cases, this is due to the complexity of data collection (Ayassamy & Pellerin, 2023). Moreover, studies employing an S-LCA database in bioeconomy often overlook specific local impacts (Huertas-Valdivia et al., 2020). Consequently, and similar to previous studies in bioeconomy that aim to account for both global and local impacts (Mattila et al., 2018), our novel methodological approach seeks to enhance the scope of the results and provide a more comprehensive diagnosis of both value chains using primary and secondary sources. Moreover, the focus of the study is consistently cradle-to-grave to consider the complete life cycle, both upstream and downstream. Thus, the product usage phase is taken into consideration, as the comparison is based on two comparable fertilizers in terms of crop yields, evaluating comparable alternatives for both farmers and production organizations. Finally, Table 1 shows the limitations of the two approaches individually, some of which have been overcome by using both methods together.

3.1 Defining the goal and scope

The goal of this study is to identify the main social impacts and performances along value chains in order to evaluate whether bioeconomy better contributes to social sustainability through a comparative analysis of a biofertilizer and a conventional mineral fertilizer from the chemical industry.

A corporate fertilizer group has been selected for our study. It has been active for over thirty years in a sparsely populated region of inland Spain, which the presence of the agricultural sector is strong. Furthermore, Spain is one of the largest consumers of fertilizers within the European Union, which has raised significant environmental concerns (European Commission, 2021b). The selection of this business group is justified due to its significance within the region, as it is one of the primary private organizations generating direct employment. Currently, this group has several industrial plants and offices in the same region with around 600 employees. Its name is not declared to preserve its anonymity. The group is made up of different types of companies, most of which are chemical industries, but there are also some companies focused on the production of bio-based fertilizers. It has been decided to select the most significant products from the most representative companies for each economic model within the business group (bioeconomic and conventional). We have selected two companies from the group, Company I, which is the main producer of biofertilizers, and Company II, which is the organization with the highest production of mineral fertilizers within the group. Company I develops biofertilizers through a composting processes and is located in Subregion I, while Company II manufactures conventional mineral granulated fertilizers and carries out activities associated with the chemical industry in Subregion II.

The selected biofertilizer, recognized as the highest-selling product in Company I, contains 80% biological material and is a clear example of bioeconomy (NPK 5–3–10), with environmental advantages focused on the conservation and improvement of soils and biodiversity by incorporating a percentage of biostimulants (Mahanty et al., 2017; Mahapatra et al., 2022). Within Company I, products in the bioeconomy are marked by high circularity, utilizing local by-products for fertilizer production. This approach cultivates new value chains, yielding substantial direct socioeconomic impacts in the region. The conventional fertilizer selected from Company II is mineral and chemical based (NPK 15–15-15), and is the most commonly used fertilizer by farmers due to its efficiency in crop yields. There is

Table 1 Challenges and limitations of both approaches of study individually

	Supplier Approach	Organizational Approach
Limitations	No organizational performance Social indicators and indices presented by general sectors without specific delineation of activities It lacks details about social variability within a nation More focused on international supply chains Only social risks are being considered	No specific benchmarks Subjective social indicators, bottleneck selection process and different indicators and functional unit regarding available databases Difficulties to get social indirect impacts along the stakeholder's value chain, i.e., suppliers' performance Lack of database and indicators related with context benchmarks

currently a reluctance among farmers to try new bio-based products as the percentage of nutrients (NPK) per kilo of fertilizer are lower in the bioproduct. However, because some biofertilizers contain biostimulants that promote microbial flora, crop yields can be exactly the same as with conventional fertilizers (Faucon et al., 2023; Mahapatra et al., 2022).

The original motivation of this study was to extend the life cycle analysis results developed internally by the organizations under study to include a social perspective in order to obtain a holistic and comparative view of the sustainability profile of both products. To achieve this, we defined a common FU of 1 Ha of crop, yielding around 3.500 kg of wheat. We also assumed that the application method was typical for an inland Mediterranean climate of Spain. The supply of fertilizer for both cases is similar, requiring 300 kg of the final product to achieve a yield of 3.500 kg of wheat. However, the amount of nutrients contained in each case differs, as the biofertilizer requires a lower amount of nutrients to achieve the same yield as the mineral fertilizer. This is due to the enhancement of soil fertility and the increased availability and absorption of nutrients (Faucon et al., 2023). Furthermore, both approaches (supplier and organizational) have the same subject of study, a product, and are designed to yield results associated with the identical functional unit, facilitating a comparative analysis of impacts and social returns for both products.

Figure 2 shows the scope of our study with detailed characteristics for the calculation of the supplier approach conducted using SimaPro V9 software and the SHDB. Meanwhile, Fig. 3 presents the characteristics of the organizational approach, where the same indicators were assessed for both organizations. In this approach, the main stakeholders involved were the workers, followed by the value chain agents (suppliers) and the consumers (farmers), since they are the direct agents linked with management and operational development. In order to consider more stakeholders, the organizational approach broadened the regional evaluation to include local stakeholders as local community and society. Finally, the entire case study was limited to a cradle-to-grave perspective; the boundaries were the same for both products. The system boundaries were focused on the entire value chain; from the extraction of the raw materials consumed in the manufacturing process to the final use of the fertilizer.

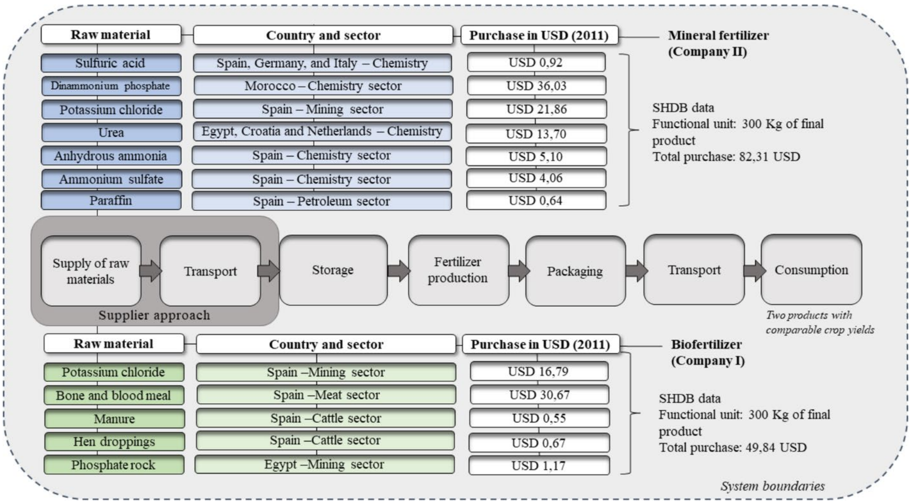

Fig. 2 Scope of the study (system boundaries) and characteristics of the Supplier Approach

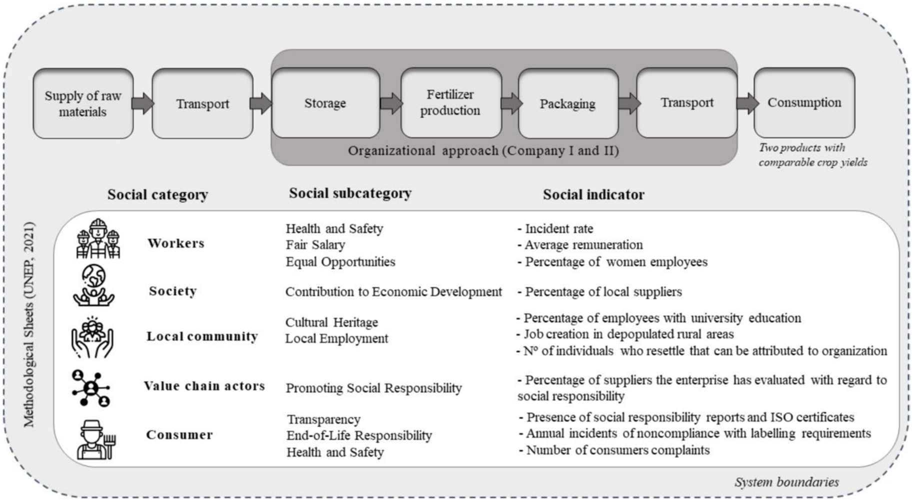

Fig. 3 Scope of the study (system boundaries) and characteristics of the Organizational Approach

3.2 Life cycle inventory: selection of indicators

The compound methodology of this research allowed for two data collection methods: by using a dedicated database (SHDB) and through the collection of site-specific data (UNEP, 2020). Regarding the life cycle inventory, two phases of complementary analysis were divided. First, a supplier approach of both products using the SHDB with the SimaPro V9 software was developed. The selection of this database is due to the fact that it allows analysis of potential impacts rather than actual ones by not including site-specific information (Ekener-Petersen et al., 2014).

Based on the Global Trade Analysis Project (GTAP), SHDB is an efficient tool for conducting a top-down analysis (Spierling et al., 2018). Furthermore, it is capable of scanning global product lifecycles to identify countries or specific sectors that face a significant social risk (UNEP/SETAC, 2009). Thus, the database has geographical and sectoral precision and approach, where the data is gathered at country-sector level. This makes it unsuitable for the contrast of the social impacts of similar sectors (for instance, chemicals, plastics, and rubber are aggregated into the same sector in SHDB) (Du et al., 2019), so site-specific data need to be collected. While there is a good amount of data on the environmental aspects of bioeconomy, the social data are lacking (Rafiaani et al., 2018). Furthermore, this sectoral approach focuses on the impacts of suppliers, organizational performance is not reflected in the results. The latter varies depending on the culture and context, which limits the applicability of global performance indicators on social assessments. Organizational assessment may complement S-LCA (UNEP, 2020), so there is a trend to understand organizational behavior as a key element in the assessment results, thereby increasing the need for site-specific assessment and data (Jørgensen et al., 2008). Indeed, rising concerns about the complexity of collecting primary data in S-LCA (Ayassamy & Pellerin, 2023).

Due to the lack of a site-specific data, an organizational assessment approach was carried out according to the latest UNEP guidelines. This approach focuses on the organization and its behavior, addressing issues and indicators that involve the entire value chain and all key stakeholders. The data inventory adheres to the methodological sheets, which provides a set of indicators with recommendations about metrics for both generic and specific analysis, and also notes whether data are available in quantitative or qualitative form. These guidelines also suggest the need for case and context-specific indicators through the development of additional social categories and complementary social impacts (UNEP/SETAC, 2013; UNEP, 2021). In this study, data were gathered through the participant observation method, facilitated by direct collaboration with the evaluated organizations, which employed various indicators in accordance with the Global Reporting Initiative (GRI, 2021) standard for the development of sustainability reports. Nevertheless, due to the focus of this study on examining social impacts in regions with sociodemographic challenges, and recognizing the limitations of the GRI framework as an inventory of relevant indicators, two indicators pertinent to this subject have been defined and incorporated. The selection of indicators was primarily based on ensuring a broad scope, covering as many social subcategories and stakeholders as possible, while also ensuring reliability and comparability in the performance assessment of both companies. Thus, the primary limitations encountered during the indicator selection process arose from the availability of primary data (organizational data) and secondary data (references essential for fulfilling the fundamental evaluation requirements). These indicators have been defined according to the availability of information within both organizations included in the case study, leading to the establishment of two indicators concerning the number of employees and their educational level. Ultimately, all indicators have been aligned with a social subcategory and category outlined in the methodological frameworks.

A suitable selection of such indicators remains one of the biggest challenges in S-LCA (Siebert et al., 2016), where a huge number of indicators during the selection process generates a bottleneck on a crucial step to define the results (Fürtner et al., 2021; Valente et al., 2018). The greatest limitation has emerged within the secondary data, which has consequently determined the total number of quantitative and semi-quantitative indicators assessed. To obtain quantitative performance indicators, it is essential to have an average value for the relevant sector, region, or country. This enables the data to be properly contextualized and categorized based on its performance. In the absence of available secondary reference data, this limitation necessitates the use of semi-quantitative indicators, which are based on qualitative criteria for reference. In this sense, the Performance Reference Points method (PRPs) is well suited for approximating the social impacts associated with a lifecycle (UNEP, 2020). Moreover, it facilitates the integration of both quantitative and semi-quantitative indicators within the same social assessment, enabling the generation of results that reflect the magnitude and significance of the collected data (UNEP/SETAC, 2009).

3.3 Impact assessment

3.3.1 Supplier assessment

Bioeconomy studies, primarily focused on scientific approaches, require greater attention to social risks, particularly those arising from resource competition and ensuing conflicts, which necessitate the establishment of appropriate international regulatory frameworks (Sanz-Hernández et al., 2019). The SHDB database offers comprehensive information on social risks across 140 countries and 57 economic sectors, utilizing 160 indicators organized into 27 social impact subcategories and 6 overarching social impact categories, addressing four stakeholder groups: workers, local communities, value chain actors, and society (UNEP, 2020). Within this framework, impact assessment is conducted through the calculation of the Social Hotspot Index (SHI). The SHI is based on the cost of production represented as medium risk hours equivalent (Mrheq) to reveal social risks by sector and country (Takeda et al., 2019). The Mrheq is calculated based on three variables: the monetary cost associated with the production of a given product, the labor intensity in hours of work per process unit related to the product, and the risk of impacting relevant social issues based on the severity of the assessed social problem (Takeda et al., 2019). Consequently, the social footprint result consists of the total Mrheq of the purchase supply chains by category, subcategory and indicator level. Social hotspots are the individual activities which most contribute to risk (Benoît-Norris et al., 2012). SHDB reflects the most relevant social aspects based on the main international legal framework and references of social responsibility such as GRI (2021), ISO 26000 (2010), AA1000 (AccountAbility, 2008), S-LCA Guidelines and SA 8000 (Social Accountability International, 2014). For our SHDB evaluation we used the purchase costs of each quantity of final product needed to fertilize one hectare of wheat (see details in Fig. 2). Therefore, internal data on raw material purchase prices were obtained, highlighting a limitation in the evaluation results, as these are influenced by a specific economic context.

3.3.2 Organizational assessment

The social assessment at the organizational level was developed according to the availability of benchmarks and organizational information, and has a total of 11 indicators, 7 semi-quantitative and 4 quantitative. Those with qualitative characteristics were characterized by the scarcity of quantitative reference sources for comparison. Therefore, both measurement methods were based on PRPs methodology and proposed as calculating and scoring indicators in order to produce a comparable social impact analysis. Both models were based on the case study proposed by Rafiaani et al. (2020), which assesses the social impacts of a company using existing approaches for both quantitative and semi-quantitative measurements without applying weighting system in their analysis. These approaches are detailed below.

- ***Quantitative measurement***

The quantitative model contained four levels (from 1 to 4- the higher the better) (Table 2). This allowed us to unify the criteria by obtaining a comparable methodology between the quantitative and semi-quantitative measurements of the case study. In order to evaluate the performance of companies from a quantitative social perspective, data from the sector and the region are necessary. In this case, we established three types of PRPs: national, regional and sectoral. Different sources of statistical data were used at the sectoral level, such as the information provided by the Spanish Business Federation of the Chemical Industry (FEIQUE), and at the regional level, such as the databases of the Aragón Institute of Statistics (IAEST) or the Aragón Institute for Occupational Safety and Health (ISSLA).

As the table shows, a score of 1 to 4 is assigned to each quantitative indicator according to the social impact percentage, which is the result of comparing the data of company inventory with the statistical data at the sectoral or territorial level. Table 3 shows the selected quantitative indicators, they were chosen according to the benchmarks selected. We followed the methodological sheets and GRI standards, but we specifically proposed several indicators to be able to report information relevant to the context of the study. This

Table 2 Scoring system for quantitative indicators for S-LCA proposed by Rafiaani et al. (2020)

Indicator	Sector and regional PRPs (benchmark data)	Company data	Social impact percentage* (%)	Score	
				Positive indicator	Negative indicator
Quantitative indicator	Statical data from FEIQUE, IAEST and ISSLA	Internal company information	0 to 50	1	4
			50 to 100	2	3
			100 to 150	3	2
			> 150	4	1

*Social impact percentage = company data/industry data

Table 3 Description and references of the quantitative indicators

Stakeholder	Subcategory	Inventory indicator	Reference
Local community	Cultural Heritage	Preservation and improvement of cultural heritage (percentage of employees with university education) *	IAEST (2016a, b)
Workers	Health and Safety	Incident rate (UNEP, 2021)	ISSLA (2020)
	Fair Salary	Average remuneration (UNEP, 2021)	FEIQUE (2019)
	Equal Opportunities	Percentage of women employees (UNEP, 2021)	FEIQUE (2019)

*Proposed new case study indicator

allowed for the inclusion of indicators focused on positive impacts within rural territories which are closely linked to sustainable bioeconomic development. The proposed indicator focused on the local community stakeholder and specifically on cultural heritage with the aim of encouraging research on rural areas. The two subregions have a population density of less than 10 inhabitants/km^2 (Subregion I: 6.32/km^2; Subregion II: 3.54/km^2) and meet all the criteria established by the Ministry of Territorial Policy and Civil Service of Spain to be considered subregions at risk of depopulation (Ministry of Spain, 2019). Therefore, our indicators focus on the development and improvement of the socio-economic impacts of fertilizer production in each territory. The rest of the indicators were GRI (UNEP, 2021) based and were compared with the averages from the chemical sector, except for the incident rate, where the comparison was made with the sector specific regional average.

- ***Semi-quantitative measurement***

The Subcategory Assessment Method (SAM) is a type of PRPs based on the subcategories and indicators set out in the UNEP guidelines. SAM is considered a semi-quantitative method, as it can transform qualitative data into quantitative data (Rafiaani et al., 2020). There are several studies that work on the semi-quantitative social impacts from the perspective of the lifecycle in different sectors, so this method is frequently used in S-LCA. In fact, the only study conducted by Martínez-Blanco et al. (2014) within the context of S-LCA and biofertilizers also employs the SAM in its social impact assessment. In our study, SAM has a scale of four levels to enable comparable scoring between both quantitative and semi-quantitative measures, thus, both analyses can be integrated at the same level of scoring (Tables 4 and 5).

Table 4 Levels in subcategory assessment method (SAM) proposed by Rafiaani et al. (2020)

Level	Description	Score	Score definition
A	The company has a proactive performance along all the value chain	4	Very good performance
B	The company meets the BR	3	Satisfactory performance
C	The company does not meet the BR; it is situated in a desirable context to the fulfillment of BR	2	Inadequate performance
D	The company does not meet the BR—it is situated in an undesirable context to the fulfillment of BR	1	Bad performance

Table 5 Levels of the SAM scale for the stakeholder's groups in each semi-quantitative indicators

	Subcategory	Inventory indicator	Level A	Level B (BR)	Level C	Level D
Local community	Local Employment	Number of individuals who resettle that can be attributed to organization (UNEP, 2021)	100% of employees live in the subregion	More than 50% of employees live in the subregion	Between 20 and 50% of employees live in the subregion	Less than 20% of employees live in the subregion
		Job creation in depopulated rural areas *	Medium-sized company	Small company	Micro company	Without employees
Consumers	Transparency	Presence of social responsibility reports and ISO certificates (UNEP, 2021)	The company has a sustainability report and certifications in this area, promoting these actions along the value chain	The company has a sustainability report and certifications in this area	The company has some certifications but not a sustainability report	No certifications or sustainability report
	Health and Safety	Number of consumer complaints (UNEP, 2021)	The company and its value chain have no claim	The company has quality procedures and controls its claims, reducing them annually	The company has quality procedures and controls its claims, increasing them annually	The company has no quality procedures and does not control its claims
	End-of-Life Responsibility	Annual incidents of noncompliance with regulatory labelling requirements (UNEP, 2021)	The company and its value chain have no requirements	The company has quality procedures and controls its requirements, reducing them annually	The company has quality procedures and controls its requirements, increasing them annually	The company has not quality procedures and not controls its requirements
Society	Contribution to Economic Development	Percentage of local suppliers (UNEP, 2021)	100% of suppliers are local to the subregion	More than 50% of suppliers are local to the subregion	Between 20 and 50% of suppliers are local to the subregion	Less than 20% of suppliers are local to the subregion
Value chain actors	Promoting Social Responsibility	Percentage of suppliers the enterprise has evaluated with regard to social responsibility in the last year (UNEP, 2021)	100% of the suppliers have been evaluated with sustainability criteria	More than 50% of the suppliers have been evaluated with sustainability criteria	Between 20 and 50% of the suppliers have been evaluated with sustainability criteria	Less than 20% of the suppliers have been evaluated with sustainability criteria

Most of the indicators have been based on the methodological sheets, with the exception of the sections on local employment *, which are defined internally due to the absence of indicators related with rural repopulation subject on these guidelines

This method analyzes the performance of the company during the value chain of a product/organization in relation to compliance with the Basic Requirement (BR) that was taken as a benchmark. This study applied a total of 7 social indicators evaluated in these four levels in relation to the BR (Table 5):

– The first level (level A) refers to a proactive company within the value chain. That is, the company promote actions that positively affect its stakeholders, for example by encouraging suppliers to comply with an ethical code of conduct or to publish sustainability reports, or by guaranteeing and providing resources for workers to settle in the rural territory, thereby improving the socio-economic conditions.
– The second level (level B) refers to companies that meet the BR to be considered as good performers in the field according to the context.
– Levels C and D are allocated to enterprises that do not comply with the BR in their given social context. This consideration is very important, as a company operating in a negative context may have greater difficulties in implementing actions. Therefore, Levels C and D refer to a company that does not comply with BR in positive or negative contexts, respectively (Rafiaani et al., 2020).

3.4 Interpretation

The results of the supplier and organizational approaches are evaluated jointly in order to highlight the main findings of our analysis. These approaches have not been integrated methodologically due to their differing characteristics, but they do complement each other in the analysis, enriching the results, which are presented in Section 4.

4 Results and discussion

This section offers an overview of the results and main discussion of the assessments carried out in this paper. Thus, the data obtained has enabled the identification of critical points of improvement and a greater understanding of the main weaknesses and strengths of both products on the social dimension.

4.1 Supplier approach results

The SHDB method provides an overview of the main social hotspots along the supply chains and was used through the Social Hotspot 2019 Subcategories & Category Method to identify the most important social issues in both supply chains. Due to insufficient information to assign varying weights to results and reflect their relative importance, the subcategory equal weighting method was applied, providing results with greater detail and breadth for each subcategory and process contribution (UNEP, 2020).

Figure 4 shows the results of each social footprint separated by main social categories. Biofertilizer has almost a third less social footprint than the mineral fertilizer, this is due to the difference in imports or foreign dependence between both products, and also, because the SHI method is based on the cost of purchase. The high cost of mineral fertilizer increases its social footprint when compared to the cheaper biological one. The biofertilizer social footprint is 36 Mrheq per 300 kg of final product (to fertilizer 1 Ha of wheat crop) and is made mainly of biological raw materials, although it contains some non-renewable raw materials to provide the necessary nutrients (Fig. 2).

The raw material of meat meal generates high risks (68%) because it is the most expensive component and is associated with the high accident rates for this industry illustrated in the 'Occupational injuries and deaths' subcategory. The risks of the potash chloride (18%) and phosphoric rock (10%) are the next largest impact generators in the supply chain. The remaining raw materials, manure and hens, do not significantly affect the results. The resulting social impact breakdown shows 'Health and safety' to be the major issue for social sustainability (30%), followed by 'Governance' (23%), 'Labor rights and decent work' (18%), 'Human rights' (15%) and 'Community' (14%). These issues are related to the phosphoric rock imported from Egypt, with hotspots in indicators related to corruption, legal system and high conflict areas. Despite this, in this supply chain 97% of the manufacturing cost is spent in Spain, which highlights the high cost of the meat flour raw material.

In the case of conventional fertilizer, a footprint result of 93 Mrheq was calculated for the production of 300 kg of final product, in addition it is composed mainly of non-renewable materials (Fig. 2). Within its supply chain the greatest impacts (80%) are generated by the raw material Diammonium phosphate (DAP) manufactured in Morocco and by the Urea imported from Egypt (8%). Primary hotspots are concentrated in the areas of 'Governance' (25%), 'Labor rights and decent work' (24%), and 'Community' (24%). Within governance, the risks produced by the problems in the 'Legal System' generate 17% of the total footprint. This is because Morocco is a country with problems of compliance with legal rules, which exercises a substantial influence on social structure and rates of economic growth (Sachs et al., 2021). 'Human rights' (15%) and 'Health and safety' (13%) generate lower hotspots, highlighting indicators related to 'Occupational injuries and deaths'.

In conclusion, the results of the S-LCA for the supplier approach have verified that the mineral fertilizer has a greater social footprint than biofertilizer. This is due to multiple reasons, firstly, the mineral fertilizer is almost twice as expensive to produce as the biofertilizer, because the raw materials it uses are high cost (international chemical manufacturing or mining) compared to raw materials encompassed by the concept of circular bioeconomy (nearby by-products and wastes). Secondly, the greater international presence in the supply chain of mineral fertilizer means that there are considerable social risks, primarily due to the concentration of phosphorus resources. Over 80% of the world's reserves are located in the Middle East and North Africa (MENA) region, with Morocco and Egypt being major suppliers (Jasinski, 2020). Social impacts in the phosphorus supply chain include geopolitical risks, such as the conflict over Western Sahara, as well as the rising fertilizer costs that affect farmers, environmental degradation caused by the use of phosphate fertilizers, and the threat to food security for future generations (Cordell et al., 2015). This is not the case with biofertilizer, since it is practically entirely supplied by local sources. Finally, biofertilizer has few social impacts stemming from its raw materials, with only meat flour standing out as a high impact item due to the riskiness of the meat industry in terms of health and safety.

4.2 Organizational approach results

The second approach focused on organizational assessment and measured the social impacts from a more local perspective. Starting with the quantitative analysis, the results of Company I (biofertilizer) show that the local community stakeholder is most favored

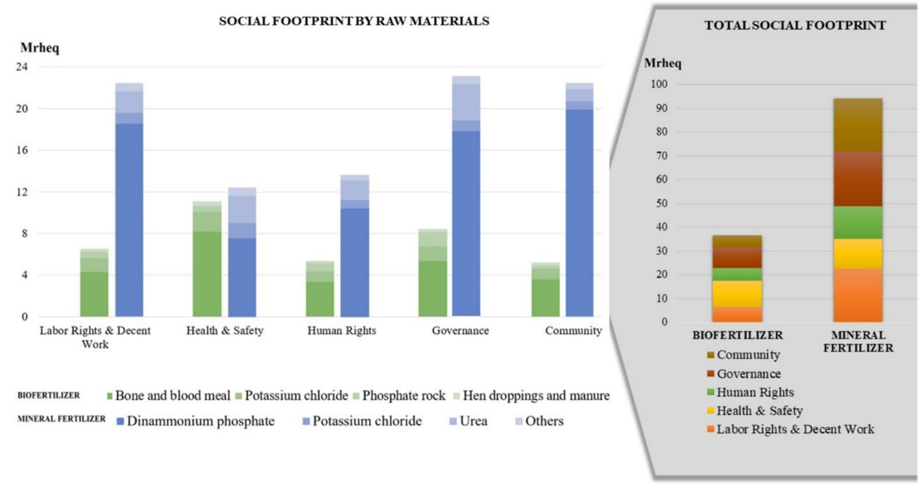

Fig. 4 Comparison of the aggregated and disaggregated social footprint in each fertilizer

by its performance, due to a substantial return of qualified personnel to rural areas. The impacts generated in the area of the worker are diverse, having satisfactory performance on 'Health and safety', inadequate performance on 'Fair salary' and bad performance on 'Gender equality' (Table 6).

Company II belongs to the same business group and presents similar scores to those of company I, except in the area of 'Gender equality', where the latter improves without achieving the BR (Table 7). When comparing both companies, the topic 'Equal opportunities' is the biggest hotspot, with the biofertilizer company obtaining worse results. The working conditions focused on remuneration reflect poor performance and are therefore another hotspot in both organizations. In the field of'Health and safety' they are within the BR but Company II presents higher results that represent a risk of worsening in the future.

Interpreting the semi-quantitative analysis (Table 8), we can see that, as in the previous evaluation, most of the indicators gave similar scores in both companies. This again highlights the strong performance for the local community stakeholder, where there are great opportunities with the creation of direct local employment in rural areas in the territories of both organizations.

The consumer stakeholder has satisfactory performance in the indicators related to transparency and responsibility. Since both products belong to the same corporate group they have the same sustainability report, certifications and management system (e.g., compliance department). However, the 'Health and safety' indicator based on consumer complaints about the quality of the product is worse in Company I, this is due to the increased complexity in the control of biological products, as they are based on feedstocks with more variable characteristics that make quality control and labelling more complex and riskier. This finding highlights the imperative to enhance public information for consumers, particularly through the inclusion of environmental impacts, in order to offer a holistic understanding of the product, given that health and safety are regarded as crucial factors within this stakeholder group (Falcone et al., 2019).

On the other hand, with regard to the stakeholder suppliers, the organization of biofertilizers is more likely to source material from its local environment (37% Subregion I) and national (97% in Spain), as most of its inputs originate in the rural territory, such as manure or hens. The opposite is true of conventional fertilizer, where there is a shortage of local suppliers as inputs mainly from international or national mining and the chemical industry make it more dependent on importing finite resources extracted from mineral-rich territories (61% of the manufacturing cost goes to other nations). Finally, both companies have inadequate performance in the Value chain actor variable, showing that neither are actively promoting the principles of accountability and sustainability from a life cycle perspective yet.

The organizational approach of both companies obtained largely similar scores as they belong to the same business group, although they do reflect some relevant differences. As part of the quantitative analysis, risks were identified with the stakeholder worker in terms of working conditions, where both products have shown inadequate performance in indicators relating to remuneration and gender equality. This highlights the poor score of biofertilizer in the latter item. Company I should strive to improve indicators of equal opportunities and discrimination. Regarding the SAM analysis, while Company II has its largest hotspot in the international supply chain with the lowest local impacts, Company I shows positive impacts in the territory to a greater degree with more local participation within its supply chain. On the other hand, the biofertilizer has exhibited greater risk or negative impacts among consumers as biological products are more variable and riskier than mineral and chemical processes over time.

Finally, both organizations need to improve the control and management of their value chains in order to contribute to sustainable development. Bad performances have been detected in the stakeholder categories of Society and Value chain actors, where neither of the companies has managed to reach the BR.

4.3 Discussion

Fertilizers are an important resource in current agricultural production processes and global challenges. They impose huge social and environmental impacts, which should be mitigated by the sector with innovations, and optimizations in production processes. Bio-based circular innovations could reduce these environmental impacts in concert with improvements in social and economic structures aimed at more sustainable development. As the bioeconomy in Spain is dominated by the agri-food sector, there is a distinct opportunity to generate green employment (Ferreira et al., 2021). Due to the significant knowledge gap in this sector within the social dimension of the bioeconomy, we aimed to analyze whether this new model is promoting more socially sustainable value chains than conventional ones and identify social risks and opportunities throughout it.

Since quantifying impacts is a challenge in S-LCA (Fürtner et al., 2021), the novel S-LCA method proposal allowed us to assess the social impacts and performances from a more holistic approach. Certainly, a diversity of approaches in S-LCA is indeed needed depending on the question to be answered (Macombe et al., 2018b), and in this case, a holistic approach was sought in the social dimension to improve the quality of the results. Moreover, the results obtained can enrich relevant corporate sustainability management data with their hotspot analysis, social risk and opportunities management and performance assessment. For instance, the supplier approach serves as a foundation for developing specific action plans within organizations concerning social aspects of due diligence (European Parliament & Council, 2024).

Table 6 Score calculations of the quantitative data in the Company I

Stakeholder	Subcategory	Inventory indicator	Benchmark	Social impact percentage	Score	Data
Local community	Cultural Heritage	Preservation and improvement of cultural heritage (percentage of employees with university education)	7,4%	297%	4	2016
Workers	Health and Safety	Incident rate	38%	60%	3	2020
	Fair Salary	Average remuneration	38.336€	79%	2	2018
	Equal Opportunities	Percentage of women employees	41%	21%	1	2018

Table 7 Score calculations of the quantitative data in the Company II

Stakeholder	Subcategory	Inventory indicator	Benchmark	Social impact percentage	Score	Data
Local community	Cultural Heritage	Percentage of employees with university education	9,7%	237%	4	2016
Workers	Health and Safety	Incident rate	38	97%	3	2020
	Fair Salary	Average remuneration	38.336€	87%	2	2018
	Equal Opportunities	Percentage of women employees	41%	50%	2	2018

The proposed methodology effectively addresses the individual limitations of both approaches; however, it presents its own limitations that have conditioned the study's results. Some limitations are global and continue to pose challenges in the development of the S-LCA methodology, such as the criteria for selecting social indicators and the complexity of stakeholder participation throughout the process. Other more specific limitations in this research are associated with the correlation of the methodologies applied and the supplier and organizational approach results. Firstly, the two methods cannot be integrated as they involve different calculations and analyses that prevent such integration. However, the results are complementary and contribute to a more comprehensive understanding of the social impacts throughout the value chain. Secondly, the limitations identified in the supplier approach within the SHDB are related to the scope of the assessment (limited to the national level), as well as the insufficient specification of several biomass-related sectors (e.g., biomass waste) and the limited number and detail of available sectors. Additionally, the results are constrained by a specific economic context, relying on predetermined prices. Finally, the outcomes of the organizational approach were constrained by the lack of available data and well-established benchmarks to quantify the social indicators in a given scenario.

In the supplier approach, the results have enabled the identification of key critical points across supply chains, facilitating the diagnosis of major social risks in different countries and enhancing organizational knowledge. This generic evaluation has confirmed that the biofertilizer has a lower negative social impact when compared to conventional fertilizer. This result is mainly caused by the greater foreign dependence on raw materials, which increases social risks in the value chain. Despite this, the detailed study of organizational performance in the second approach highlighted that both possess social risks in their more direct activity with stakeholders. This confirmed that the bioeconomy is not presenting itself as a transformative model in the social realm, with no significant differences found in the comparison. In this regard, we confirmed that a barrier to transformation is caused by corporate culture and the organization's unwillingness to change. Regardless of whether a bioeconomy is developed or not, the organization should first ensure the fulfillment of minimum requirements to initiate a strategy for the implementation of social sustainability. Both cases have shown that the organization must first be proactive for it to be considered transformative towards social sustainability along the value chain.

Nonetheless, the biofertilizer emerges as a greater opportunity of social sustainability. We have shown that biofertilizer has a greater territorial impact, both regional and national, and is deeply rooted in the rural world. This allows us to state that bioeconomy can energize and socially transform a territory by having a greater local reach coupled with reduced

Table 8 Results of SAM analysis for the social performance of both companies

Stakeholder	Subcategory	Basic requirement	Evidence from Company I (biofertilizer)	Score	Evidence from Company II (mineral fertilizer)	Score
Local community	Local Employment	More than 50% of employees live in the subregion	90% employees live in the subregion	3	89% employees live in the subregion	3
		Small company	Medium-sized company	4	Medium-sized company	4
Consumer	Transparency	The company has a sustainability report and certifications in this area	Company has a sustainability report and a certificate of ISO 9001, 14000 and 18000	3	Company has a sustainability report and a certificate of ISO 9001, 14000, 18000 and 50001	3
	Health and Safety	The company has quality procedures and controls its claims, reducing them annually	The company manages quality but has increased its claims annually	2	The company manages quality and has reduced its claims annually	3
	End-of-Life Responsibility	The company has quality procedures and controls its requirements, reducing them annually	The company has quality procedures and controls its requirements, reducing them annually	3	The company has quality procedures and controls its requirements, reducing them annually	3
Society	Contribution to Economic Development	More than 50% of suppliers are local to the subregion	37% of local suppliers	2	17% of local suppliers	1
Value chain actors	Promoting Social Responsibility	More than 50% of the suppliers have been evaluated with sustainability criteria	25% of the suppliers have been evaluated with sustainability criteria	2	21% of the suppliers have been evaluated with sustainability criteria	2

social risks. Even though the bioeconomic organization did perform poorly in terms of job quality, equality and consumer complaints, it could have significant potential for social transformation in the territory, when compared to the mineral fertilizer value chain. Finally, it is necessary to improve the indicators related to workers and consumers to assert that job creation in the territory aligns with more rigorous and sustainable criteria. For that, developing proactive management of social improvement in an organization as well as throughout its value chain is a basic requirement to ensure that social sustainability is generated. That is the reason why organizations with successful social sustainability policies and practices can bring significant benefits to their value chain and stakeholders (Bubicz et al., 2019).

5 Conclusions

The S-LCA methodology proposed in this paper integrates generic and specific assessments, this dual approach allowed us to trace social impacts along fertilizer supply chains based on consumed raw materials, as well as to delve into critical points of organizational performance with a more localized perspective. Moreover, this proposal may also be useful for other organizations belonging to the bioeconomic sector and with potential local and global social impacts. And of course, it is also necessary to continue improving the methodologies for lifecycle measurement in the context of new sustainable models, such as the bioeconomy, to enable better indicators, measurement and comparison methods.

The conclusions derived from the application of this combined methodology indicate that the biofertilizer provides better social results under a combined approach, mainly thanks to the supply chain focus. The more organizational and local approach has shown that currently there are no significant differences in generating social improvements in the territory, despite the fact that the bioeconomy wields a greater transformative capacity both directly and indirectly. Therefore, the study has not found significant social transformations in the value chain of the bioproduct compared to the conventional one, confirming that bioeconomy is not sustainable per se. The main barriers to this transformation are related to the necessity of changing organizational cultures within bioeconomy companies to initiate behavioral changes towards social sustainability along value chain. This allowed us to conclude that organizations must be first proactive to ensure that social sustainability is promoted along the whole value chain.

Finally, agriculture is presented as an important bioeconomic engine in the region studied which is characterized by a predominant primary sector faced with socio-economic problems generated by a declining demography. This makes the present study and further developments in measuring the social impact of bioeconomy in the territory attractive. In this sense, we recommend to study why there are still cultural barriers to promoting further development and application of social sustainability through bioeconomy in the territory. Studying the political theoretical framework of the situation in this region to understand why organizations that focus on this multidisciplinary science are not developing on a larger scale could help to understand the need for improvement in the social impacts analyzed. Certainly, the management of public policy is a dynamic factor for territorial social development, which should be analyzed to understand the specific context of bioeconomic development, as well as the tools to measure the social implications exerted by organizations. Finally, we suggest that future research integrate the interests and needs of stakeholders into the analysis and establish a holistic approach which includes the consideration of trade-offs between the social, economic and environmental dimensions.

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Declarations

Conflict of interest The authors declare no competing interests.

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