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Journal of Rural Studies

journal homepage: www.elsevier.com/locate/jrurstud

Less is more? Differences of social impacts on farm workers in short/long agricultural supply chains in Spain

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ARTICLE INFO

Keywords:

Farming systems
Fruit and vegetable productions
Social life cycle assessment
Psychosocial risk factor
Agro-industrial model
Diversification

ABSTRACT

Agriculture is one of the most dangerous occupations in Europe. Practices such as the use of pesticides, physically demanding tasks, and long working hours are more common than in other sectors. Health risks jeopardise the transition to sustainable agriculture, affecting the well-being of farmers and workers. Although the economic and environmental sustainability of development strategies adopted by farms to thrive (i.e., economies of scale or specialisation vs. economies of scope or diversification) have been extensively studied, there is comparatively less research on how these different models affect workers' and farmers' health. This paper assesses the social impacts of six farms in two farming systems in northeastern Spain to disentangle the effect that their contrasted productive strategies and value chain structures have on the social impacts of agricultural production. For this purpose, the Psychosocial Risk Factor (PRF) methodology was used. PRF is an impact pathway method within Social Life Cycle Assessment. It was used to establish an impact pathway between agricultural tasks, working conditions, and possible social risks, which allowed the quantification of impacts. Specific data on working hours allocated to each farm task were collected through a farmer survey. The results showed that farms in both case studies had the highest impacts related to the musculoskeletal system and articulations, even in farms that operate in the highly mechanised agro-industrial model. Since harvesting is the task to which they dedicate more time and remains mostly manual, mechanisation of certain tasks may not lead to an improvement in terms of hours of exposure to these risks. Regarding PRF hours per hectare, farms specialised in fruit production are less sustainable, since they are more intensive in labour demand. The smaller and more diversified farms use fewer mechanical labour and chemical pesticides per hectare, resulting in minor exposure to the overall health risks. Finally, our research highlights the crucial role of middle ground practices in improving sustainability by integrating agro-ecological methods into conventional agriculture, underscoring the importance of considering trade-offs between different productive and value chain structures.

1. Introduction

The agricultural sector has a key role to play in the transition to a sustainable society, which implies changing production practices to reduce their current environmental impact and adapting to new scenarios arising from climate change (IPCC, 2022). The agri-food system involves a wide range of actors, institutions, and practices operating within complex networks of relationships, which pose significant challenges to its sustainable transformation (Bryceson and Ross, 2020; Tragnone et al., 2022). Although the environmental impacts of the

current agri-food system have been extensively studied (IPCC, 2022), social impacts have received comparatively less attention. However, food products generate significant social impacts throughout their life cycle (Mancini et al., 2023), while agriculture is one of the most dangerous occupations in Europe, characterised by a high incidence of accidents and risks arising from agricultural activities (Caffaro et al., 2022; Jones et al., 2020). This is related to the nature of the work, where practices such as the use of pesticides, physically demanding tasks, and long working hours are more common than in other sectors (Jones et al., 2020). Furthermore, several studies have noted the prevalence of mental

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<https://doi.org/10.1016/j.jrurstud.2025.103765>

Received 2 July 2024; Received in revised form 2 June 2025; Accepted 22 June 2025

Available online 26 June 2025

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health problems among farmers as a result of the restructuring of the agricultural sector, where the risks of market uncertainty and declining incomes are seriously affecting farmers and farm workers (Hammersley et al., 2023). Health risks jeopardise the transition to sustainable agriculture, since a commitment to safety is at the core of sustainable business practices (Caffaro et al., 2019, 2022; Cunningham et al., 2010; Dumont and Baret, 2017).

Spanish agri-food systems have undergone profound changes since the 1960s; productivity has increased steadily, with the highest growth found in the fruit and vegetable sectors (Clar et al., 2018). The Spanish agri-food sector represents 5.8 % of the country's total economy where 20.4 % of its exports correspond to horticultural products. The sector is characterised by its high competitiveness, yet its intense dynamics frequently results in the overuse of environmental resources and lead to significant environmental impacts (Martín-Gorrioz et al., 2020; Muñoz Torres et al., 2022; Vinyes et al., 2015; Martínez-Valderrama et al., 2020). On the social dimension, the labour conditions under which fruit and vegetable workers operate has become a salient and contested issue in relation to sustainability transitions in agri-food systems, due to the prevalence of vulnerable and precarious employment situations (López et al., 2022; Molinero-Gerbeau et al., 2021). Despite the environmental impacts of Spanish agri-food systems have long been studied (Duarte et al., 2014) and the economic performance of the agrifood sector is carefully monitored (Maudos and Salamanca, 2020), its social performance as a crucial pillar of its sustainability has been comparatively less assessed (Martín-Retortillo et al., 2020).

Life cycle assessment (LCA) addresses impacts throughout the life cycle of a product by a functional unit, allowing for comparisons between production processes and decisions (Kloepffer, 2008). While this method is commonly used to measure the environmental impacts of agriculture, there has been increased attention to assessing social impacts through its social counterpart, the so-called social life cycle assessment (S-LCA) (e.g., Bouzid and Padilla, 2014; De Luca et al., 2015, 2018, 2023; D'Eusano et al., 2018; Petti et al., 2018a,b; Prasara and Gheewala, 2021; Rahmah et al., 2023; Tragnone et al., 2022; Brenes-Peralta et al., 2021). Nevertheless, few studies have considered the role that the organisational diversity of farms within farming systems may play in the occurrence of contrasted social impacts (Hannouf and Assefa, 2018; Rafiaani et al., 2020).

Farms can adopt diverse development strategies to thrive. These strategies can be broadly categorised into either specialised development strategies that emphasise farms based on economies of scale, or the diversified model encompassing farms based on economies of scope (de Roest et al., 2018; Huttunen, 2019; Lancaster and Torres, 2019). The former creates agro-industrial models that aim to increase production efficiency, reducing per-unit costs through specialisation in a single product type (de Roest et al., 2018). These farms are linked to global markets and large food retail chains (i.e., supermarkets). In contrast, the diversified farms are based on economies of scope which pursue a territorialised production model, aiming to reduce costs by synergically expanding the range of products realised. Typically, these farms focus on local markets through short supply chains (de Roest et al., 2018; Lancaster and Torres, 2019). This model is closely aligned with the principles of agroecology, understood as sustainable and locally adapted farming systems oriented towards community needs rather than profit. Peasant farming is characterised by small-scale, diversified, and ecological practices that support food sovereignty, environmental protection, and social justice (European Coordination Via Campesina, 2025). Disentangling these strategies is relevant since differences in company management can lead to unlike social impacts (D'Eusano et al., 2022; Martínez-Blanco et al., 2015; Rafiaani et al., 2020). While operating in supply chains with different configurations can also lead to differences in social impacts (Sureau et al., 2019; Dumont and Baret, 2017), these are rarely quantified in a systematic manner (Thom et al., 2024).

Social Life Cycle Assessment (S-LCA) measures the positive and

negative impacts of a product on different stakeholders from a life cycle perspective to address the social pillar of production sustainability (UNEP et al., 2020). Type II impact assessment in S-LCA establishes cause-effect relationships through impact pathways between life cycle stages and protected areas. It is framed in a post-positivist paradigm and uses dynamic indicators based on statistical significance and mathematical relationships (Iofrida et al., 2018; Petti et al., 2018). It requires a deep understanding of the relationship between life cycle stages and their potential social impacts, identifying the contribution of each action to an impact (Ugaya et al., 2023) with a distinction between intermediate and final indicators, depending on their position in the causal chain (UNEP et al., 2020).

To quantify the link between activities and social impacts (UNEP et al., 2020), it is necessary to define a quantitative activity variable (e.g., the number of hours spent on a particular activity in the production cycle) and to develop a characterization model. Since social impacts can be both subjective and objective and strongly influenced by their context, the identification, quantification, and interpretation of indicators is a challenging activity (Siebert, O'Keeffe et al., 2018; Tragnone et al., 2022) that hinders the systematic and standardised assessment of these impacts (Iofrida et al., 2018). Accordingly, studies using this type of approach show great heterogeneity in the description of cause-effect chains, measurement models and data (Ugaya et al., 2023; Sureau et al., 2020). Sureau et al. (2020) classify these studies into: i) those that identify and propose variables composing impact pathways; ii) those that empirically investigate new pathways and, finally, iii) those that apply known characterisation models or factors from previous research in new case studies. Although the objectives, impacts, data collection and results differ from one study to another, Sureau et al. (2020) highlight the importance of considering impacts not in isolation, but to link them to their source or social aspects.

Iofrida et al. (2019) developed the Psychosocial Risk Factor (PRF), within the type II impact pathway studies, to assess how the working conditions of the productive life cycle may expose people to the risk of health problems. PRF is a method that applies known characteristic factors from previous medical studies to assess health impacts on workers exposed to specific working conditions. It uses a statistical measure of intensity, the odds ratio, to establish the impact pathway between working conditions and health risks (Sureau et al., 2020). The PRF impact pathway has been tested in various sectors, such as olive fruit production and the production of garments (Iofrida et al., 2024), proving to be a suitable method for measuring the psychosocial impacts of agricultural production (De Luca et al., 2023; Iofrida et al., 2019; Iofrida et al., 2020; Stillitano et al., 2022).

This paper aims to assess the social impacts of six farms during a productive year in two farming systems in northeastern Spain to disentangle the effect that contrasted productive strategies and value chain structures have on the social impacts of agricultural production. Half of the sample was located in the *Bajo Cinca*, in the region of Aragon. It is an agro-industrial area dominated by fruit production, mainly for export and large food retail chains. The other half belongs to the *Baix Llobregat* area in the region of Catalonia. It is a peri-urban area known for its diverse farming system of vegetable crops, with a particular emphasis on supplying local markets through short supply chains.

2. Materials and methods

2.1. Study areas

The work was conducted in two areas producing fruit and vegetables in Spain – the *Bajo Cinca* and the *Baix Llobregat* (Fig. 1) – representing contrasting farming systems in terms of production, commercialisation and farm trajectories: the agro-industrial model based on economies of scale in *Bajo Cinca* and the territorialised model based on economies of scope in *Baix Llobregat* (de Roest et al., 2018). The distinction between the two cases is based on two main criteria: (1) production

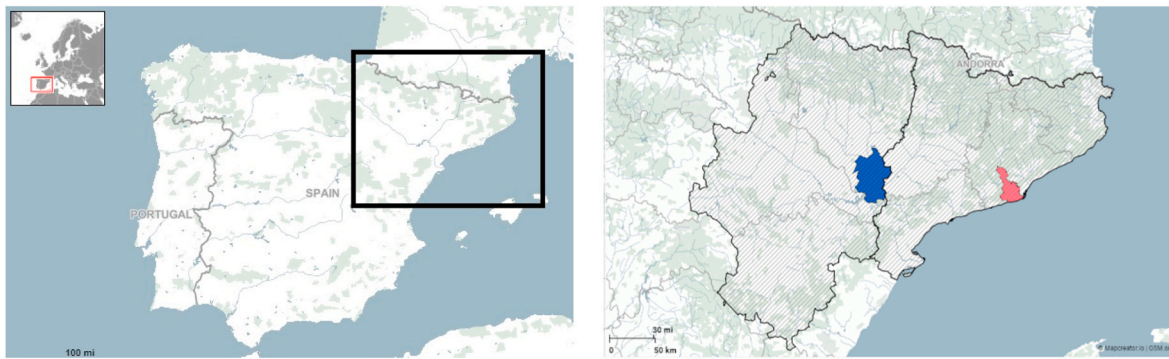


Fig. 1. Location of Bajo Cinca (blue) and Baix Llobregat (red) in Spain. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

strategy—specialisation in Bajo Cinca versus diversification in Baix Llobregat—and (2) the final destination of production, which determines the value-chain structure—export-oriented in Bajo Cinca and locally focused in Baix Llobregat. In applying this classification, we draw on the definition by Lancaster and Torres (2019), who assess farm diversification on a continuum ranging from specialised farms (cultivating 1 to 4 crops) to highly diversified farms (cultivating 29 or more crops).

All farms included in this study are conventional and have different sustainable certifications (Integrated Production and *Global GAP*).

The Bajo Cinca (BC) is a rural area in the Aragón region where an agro-industrial model predominates (de Roest et al., 2018). It is characterised by medium and large farms specialised in stone fruits such as peaches and nectarines for European markets and large food retail chains (i.e., supermarkets) (Hueso and Cuevas, 2014). The farms belonging to this group had similar characteristics in terms of specialised fruit production and show a higher degree of mechanisation (see section 2.3). In this area, there are 663 farms specialised in fruit production whose average size is 58 ha (INE, 2022).

In contrast, Baix Llobregat (BL) is a peri-urban area close to Barcelona, where small farms predominate, with a diversified production of fruit and vegetables. It represents the territorialised farming model (de Roest et al., 2018). Traditionally, agricultural products were distributed through the central wholesale market of Barcelona (Mercabarna), which has a local and regional scope. Recently, the public administration has promoted the creation of short supply chains, such as farmers’ markets in the main municipalities. The assessed farms were heterogenous and combine fruit and vegetable production, with different volume of final products (see section 2.3). The average farm size in BL is 14 ha (INE, 2022).

2.2. Social life cycle assessment (S-LCA) methodology

Psychosocial Risk Factor (PRF) treats social impacts as objective, quantitative, and measurable aspects that do not need the validation of the stakeholders involved (Iofrida et al., 2019).

2.2.1. Product system definition

We aimed to assess the social impact of different farm models within farming systems (Hannouf and Assefa, 2018; Rafiaani et al., 2020). To this end, we adopted an organizational perspective in S-LCA analysis rather than focusing on product types, as social impacts often arise from management decisions (Zamagni et al., 2011; Martínez-Blanco et al., 2015; D’Eusanio et al., 2022). Therefore, the system boundaries were defined to encompass all farm activities for which the farmer is responsible and that are carried out by in-house workers, adopting a “cradle-to-market gate” approach. Since the farm models differ, the activities included in each farm in BC and BL also vary. Figs. 2 and 3 show system boundaries and agricultural activities examined for farms in BC and BL.

In BC farms, the specialisation in stone fruit implied that the work was concentrated on fewer tasks, mainly during the growing phase (pruning and weed removal) and harvest (Fig. 4). Chemical weeding, pesticide application and weed mowing were mechanised (carried out with tractors), while pruning and harvesting were done manually; thus, these tasks required a significant amount of labour. In these farms, the farmer was not responsible for distribution-related tasks, as these were carried out at the fruit centre. A fruit centre is a facility where harvested fruit is received, graded, packed, and prepared for distribution or sale. This phase was excluded from the assessment. No new fruit trees were planted during the reporting period, so soil and crop preparation tasks were not included.

In BL farms, the diversification of vegetable crops was reflected in the higher number of tasks and the distribution of hours devoted to them (Fig. 4). Moreover, in these farms, the farmer was also in charge of the commercialisation, which involves the product commercialisation to the selling point (i.e. central wholesaler markets or final consumers) and attending the farmer markets once or twice per week. These farms showed less mechanisation of tasks than BC farms: tillage, manure application, hoeing and furrowing were mechanised tasks, while pesticide application, planting, pruning, harvesting and packaging were done manually. Although they were not organic certified, some agroecological techniques, i.e. green manure, was used in some cases.

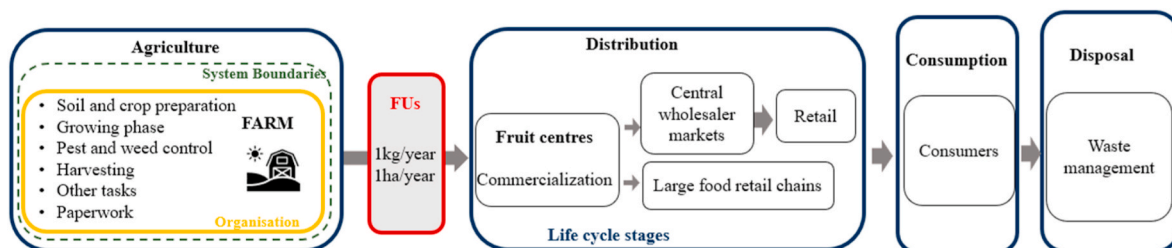


Fig. 2. Flow chart of the fruit production life cycle in Bajo Cinca farms (BC1, BC2, BC3) and the defined organisation, Functional Units (FUs) and system boundary.

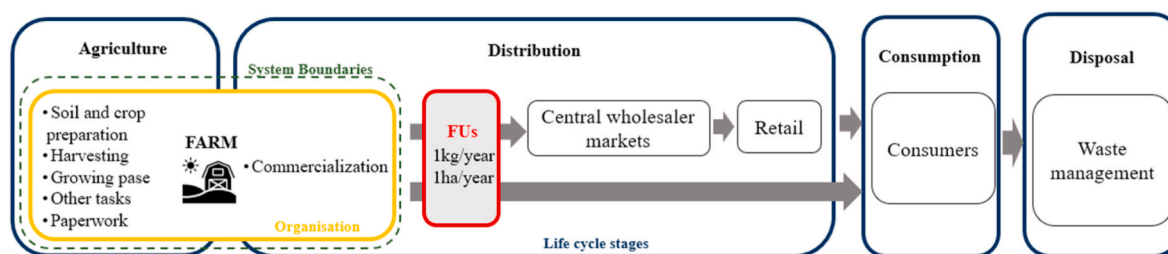


Fig. 3. Flow chart of the fruit and vegetable production life cycle in Baix Llobregat farms (BLL4, BLL5, BLL6) and the defined organisation, Functional Units (FUs) and system boundary.

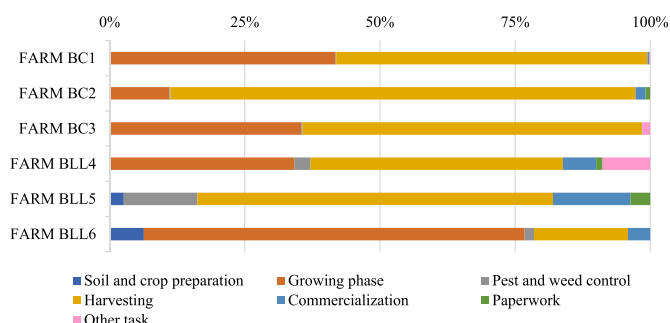


Fig. 4. Share (%) of hours devoted to farming tasks for each farm.

2.2.2. Functional unit

The Functional Unit (FU) quantitatively defines the focus of the study. It represents the unit of process output that enables comparisons between production systems by linking social impacts to a specific amount of product, service or function (UNEP et al., 2020). The identification of the FU is often one of the weaknesses of S-LCA studies (Zamagni et al., 2011). For this reason, many of the studies that adopt a company-level approach do not establish a link between the FU and the indicators (Martínez-Blanco et al., 2015; D'Eusano et al., 2022). However, the establishment of a FU is fundamental to the development of the S-LCA methodology and its comparative ambition (Zamagni et al., 2011). Following other S-LCA studies, we adopted the two most common FUs in the agri-food sector: 1 ha of production over a year (1 ha/year) (e.g. Prasara and Gheewala, 2021; De Luca et al., 2015) and one kg of product during the full production period (concerning permanent crops) (1 kg/year) (e.g. Bouzid and Padilla, 2014; Brenes-Peralta et al., 2021). Simultaneously considering two FUs provides complementary information on production systems by taking into account different product utilities and functions (UNEP et al., 2020; Zamagni et al., 2011). While the FU per hectare allows contextualising the impacts and land used change caused by an activity in an area (Loiseau et al., 2018), the FU per kg enables a standardised comparison of production systems, supply chains and crops.

Since the production processes of the farms analysed included both permanent and annual crops, the social impacts of one productive year were compared to harmonise the different life cycles. Although the farms analysed had diverse production profiles, we argue that the combination of these two FUs together with the company-level perspective, enables the comparability of different farm development trajectories using standardised units. Therefore, we performed two separate analyses using both FUs.

2.3. Psychosocial risk factors (PRF)

We applied the PRF pathway developed by Iofrida et al. (2019) to assess social impacts of citrus farming in Italy. PRF impact pathway is a type II method for Social Life Cycle Assessment, formerly developed by Silveri et al. (2014) and then improved and implemented by Iofrida et al.

(2019). It is a quantitative approach to evaluate the social impacts deriving from the functioning of the life cycle of a product or service. The impact category considered is the health risk linked to working or living conditions, by means of the odds ratio, a statistical measure of the intensity of association between two variables (Iofrida et al., 2019). These odds ratios were retrieved from scientific literature, especially epidemiologic studies, using repository databases like Scopus and Web of Science. Psychosocial Risk Factors are defined as the aspects and characteristics within work planning and management that have the potential to result in physical or psychological harm (Cox et al., 2000; Iofrida et al., 2019). The odds ratio quantifies the likelihood of a specific disease or disorder occurring as a result of a particular exposure, such as the probability of developing a typology of cancer due to general or specific pesticide exposure, in comparison to the likelihood of experiencing the disease or disorder without that exposure (Iofrida et al., 2019; Szumilas, 2010; George et al., 2020). It is widely used in epidemiological studies providing information about the likelihood of a particular consequence (De Luca et al., 2023; Iofrida et al., 2019). It is expressed with a non-dimensional value higher than 0, where a value of 1 indicates that there is no association between the disease and the exposure while values higher than 1 indicate a positive association (the risk factor may cause the disease) where the association increases with higher values (Iofrida et al., 2019). Following Bottarelli and Ostanello (2011), Chen et al. (2010), and Rosenthal (1996), the odds ratio (OR) can be classified according to their level of intensity of association: weak association when $1 < OR < 1.3$; moderate when $1.3 < OR < 1.7$; strong when $1.7 < OR < 8$ and very strong when $OR > 8$.

The information about OR was gathered from published scientific research that analysed and proved the connections between specific working conditions and one or more diseases (or disorders), for example, the health consequences of farming occupation and the use of pesticides. The list of odds ratio used in Iofrida et al. (2019) was updated with the most recent studies available (see Supplementary Material. Table A.1). The search was conducted in Scopus and Web of Sciences in December 2022 employing the keywords "odds ratio" coupled with every kind of working conditions involved in the processes under study to find scientific studies that correlated each situation (noise exposure, vibrations, manual tools, postures, chemical use, etc.) with health risks (Supplementary Material. Table A.1). The health risks considered can be both physical and psychological, such as wheezing, muscle pain (back, neck or lower back), diabetes, cancers, stress, anxiety, etc.

A PRF matrix was constructed matching working conditions with particular physical or psychological risks in terms of odds ratio, according to the reviewed literature. An inventory of working tasks and input was developed (see section 2.4); it included a list of hours allocated to different agricultural tasks (e.g., pruning, thinning, tractor operations, phytosanitary treatment using a tractor or without it). Subsequently, each task was linked to a set of working conditions (e.g., exposure to vibrations, noise, certain chemicals, etc.) and then also to health risks, expressed through the odds ratio. When a task involved multiple risks, such as both body vibrations and exposure to chemicals, the duration of the tasks was counted multiple times. For example, if the task "tractor operations: mechanical clearing" required 1 h of work per

hectare per year, it entailed the following working conditions: i.e. 1 h of “Exposure to Diesel Exhaust”, 1 h of “driving tractors”, 1 h of “exposure to minor noise and vibrations”, 1 h of “sedentary posture” and 1 h of “total body vibrations”. Each of these working conditions is associated with one or more health risks. Thus, this task implied 5 h of exposure to different health risks. The odds ratio indicates whether there is an association between the working condition and the risk and the degree of intensity (high, moderate or weak). Finally, the Psychosocial Risk Factors are calculated by adding the total hours of exposure to each psychosocial risk.

Therefore, social impacts are calculated and characterised through the quantification of hours of exposure and the intensity of the association to a particular working condition and, as a result, to one or more psychosocial risks (Iofrida et al., 2019; Iofrida et al., 2020).

2.4. Data collection and farm cases

The farms were chosen for their representativeness of the farming systems in each area. Data for the analysis were obtained through face-to-face interviews with structured questionnaires administered to farmers in the six farms. Field work was carried out during summer 2021 and farmers were asked about their productions in the reference year 2020. The questionnaire allowed to gather specific data regarding the following items: I) Type of crops, surface, total production and harvest season. II) Farming tasks related to work organization: working hours, number of times per year and task, person in charge and way of undertaking it. III) Farming tasks related to each crop: working hours per hectare, time of the year, person in charge, necessary tools and method of execution. Moreover, the missing data about production were complemented with official Spanish statistics on agrarian production (INE, 2022). The information collected was used to compile the inventory of working tasks and inputs needed to calculate: i) the hours spent on each task, ii) the working conditions associated, iii) the pesticides used and finally, iv) the production per kg and ha (Table 1).

The selected farms were managed by a single farmer who was responsible for both productive and commercial decisions. The farmer

carried out specific tasks such as soil and crop preparation, pest and weed control, commercialisation, harvesting, paperwork, and other tasks. The workforce requirements varied depending on the type of farm (Table 2).

In BC, farms BC1 and BC2 depended on family labour, mainly carried out by the farmer. In both cases, their retired father would assist the farmer in specific tasks that did not require significant physical effort, such as operating tractors. In addition to family labour, these farms employed two full-time salaried workers who focused on pruning, planting, and harvesting tasks. Farm BC3, by contrast, was managed by two brothers who worked full-time on the farm. During the summer harvest season, all three farms hired temporary migrant workers from African or Eastern European countries (Moliner-Gerbeau et al., 2021).

In BL, farms BLL4 and BLL5 relied on family labour provided by the farmer with the support of their retired father. In BLL5, the farmer's wife was also involved, particularly in commercialisation tasks. Farm BLL6 was managed by two brothers and employed one full-time and one part-

Table 2

Distribution of active workers and hours worked in FTE (per type, per kg and per hectare).

Type	FTE				
	Family	Full-time salaried	Temporal	per kg	Per ha
Farm BC1	2	2	3.69	0.0000031	0.0107103
Farm BC2	2	2	3.46	0.0000124	0.2486667
Farm BC3	2	0	1.62	0.0000036	0.1428571
Farm BLL4	2	0	0.01	0.0000111	0.0893333
Farm BLL5	3	6	0	0.0000104	0.1799640
Farm BLL6	2	1.5	2.08	0.0000467	0.8584615

* FTE: Full Time Equivalent. It represents the number of total hours worked divided by the number of hours considered full-time (1 FTE = 1 Full-time worker: 2080h/year).

Table 1

Main characteristics of the farms studied.

Farm	Area (ha)	Case Study	Crops	Ha	Production (kg)	Total production (kg)
Farm BC1	718	BC	Peach	30	106,000	2,481,500
			Almond trees	27	n.a.	
			Rainfed cereal	650	1,350,000	
Farm BC2	30	BC	Irrigated cereal	11	71,500	600,000
			Peach	32	600,000	
			Fallow	2.5	n.a.	
Farm BC3	23	BC	Peach	14	560,000	560,000
			Fallow	23	n.a.	
			Cherry	6	30,000	
Farm BLL4	20.6	BL	Peach, apricot	9	121,500	195,074
			Prune	1.5	3000	
			Pear	1	18,403*	
			Olive trees	2.5	7547*	
			Artichoke	1	14,624*	
			Fallow	1.5	n.a.	
			Artichoke	35	600,000	
			Broad bean	5	10,500*	
			Melon	1.5	10,500	
			Col, broccoli	2	47,400*	
Farm BLL5	50	BL	Sweet onion (<i>Calçots</i>)	0.5	3500*	8,614,789
			Pumpkin	2	6000	
			Tomatoes	0.67	1500	
			Pepper	0.67	12,000	
			Aubergine	0.67	1500	
			Celery	4	88,948*	
			Potatoes	2.5	79,630,909	
			Artichoke	0.75	25,000	
			Col, broccoli	3.25	60,000	
			Peach	2.5	14,000	
Farm BLL6	6.5	BL	Artichoke	0.75	25,000	99,000
			Col, broccoli	3.25	60,000	
			Peach	2.5	14,000	

n.a.: not applicable /* data from Spanish Ministry of Agriculture, Fisheries and Food (2019).

time worker throughout the year. Additionally, temporary migrant workers were hired during the artichoke harvesting period. Farm BLL5 employed six full-time workers who carried out both fieldwork and commercialisation tasks.

Farmers typically worked between 8 and 12 h a day, with their schedules varying based on the season and the nature of the tasks. During winter, they worked fewer hours compared to the busy summer harvesting season. Certain activities, such as attending farmers' markets required longer working hours. Hours of work of salaried workers were subjected to working agreement (8h/day) although extra hours were common to cover peaks of production (9–10h/day).

3. Results

A total of 28 health risks are identified in association with the working conditions of the six farms. Each risk is analysed individually according to its intensity level (weak, moderate, or strong). Subsequently, all odds ratios reported in the literature are grouped according to the relevant health macro-categories, as defined by medical science: oncological, musculoskeletal and articulations, psychological, metabolic, neurological, and respiratory (see Table 3). The PRF for each health risk is then summed to calculate the PRF for each category. The results present the PRF in relation to the number of hours per hectare and the number of hours per unit of product.

3.1. Psychosocial risk factors per hectare in a year

When examining the social impact per hectare per year (Figs. 5 and 6), the main impact observed across all farms corresponds to risks related to the musculoskeletal system and articulations, representing between 75 % and 78 % of the PRF in the BC farms, and between 83 % and 88 % in the BL farms. These risks are primarily associated with neck and shoulder pain, as well as low back pain. The former shows a strong odds ratio association between health impacts and farming tasks in BC1 (119 h/ha) and BC2 (2984 h/ha), while the association is mostly moderate or weak in BC3 (2784 h/ha), BLL4 (1246 h/ha), BLL5 (4062 h/ha), and BLL6 (1238 h/ha). Low back pain shows a strong association across

Table 3
Health risks grouped into health macro-categories.

Macrocategories	Specific Diseases
Oncological	Genotoxic damage
	Colorectal Carcinoma
	Myelodysplastic syndromes
	Cutaneous melanoma
	Non-Hodgkin's lymphoma
	Renal cell carcinoma
Musculoskeletal system and articulations	Multiple myelomas
	Injuries
	Low Back Pain
	Neck shoulder pain
	Sciatic Pain
	Upper limbs pain
	Osteoarthritis
	Back Pain
	Muscle weakness
	REM sleep behaviour disorder
Neurological	Age-related Macular Degeneration (AMD)
	Parkinson disease
	Numbness
	Amyotrophic Lateral Sclerosis
Psychological	Anxiety
	Lower self-esteem
	High level of stress perceived
Respiratory	Wheeze
	Asthma
Metabolic	Diabetes
	Metabolic syndrome

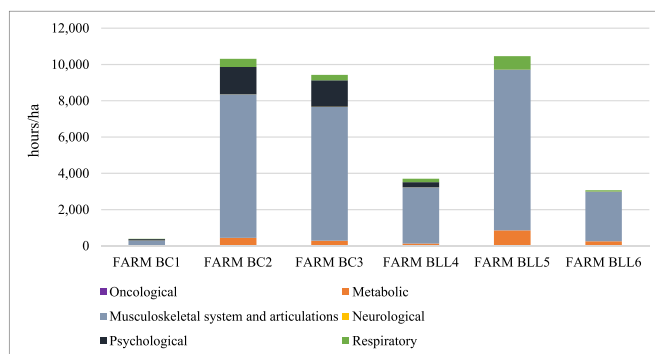


Fig. 5. Psychosocial Risk Factor of the six farms measured in number of hours per hectare.

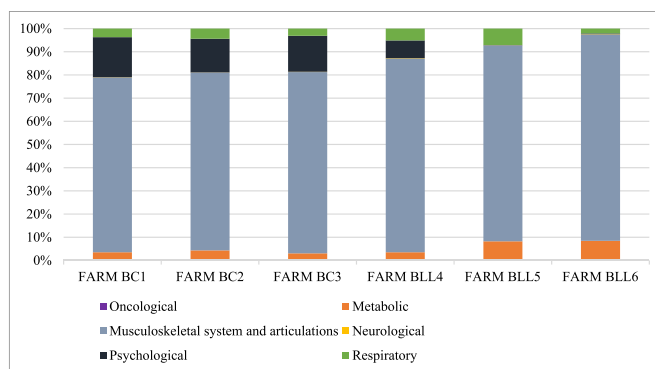


Fig. 6. Psychosocial Risk Factor of the six farms measured in percentage of each risk category over the total number of hours per hectare.

all farms (100 h/ha in BC1; 2667 h/ha in BC2; 2281 h/ha in BC3; 1062 h/ha in BLL4; 3217 h/ha in BLL5; and 1029 h/ha in BLL6). This risk is frequently linked to tasks such as tractor driving, manual pruning and thinning of fruit trees, or planting vegetable crops, which involve working conditions such as exposure to noise, high concentration demands, physical and repetitive workloads, sedentary and uncomfortable postures, or whole-body vibrations (Supplementary Material, Table A.1). In the case of BC, they are more closely associated with mechanised agricultural operations involving the use of tractors, whereas in BL it is related to manual tasks such as planting and applying pesticides with backpack sprayers, carried out by farmers walking through the fields.

Psychological risks represent the second most significant impact on farms with the largest areas dedicated to fruit production, ranging from 17 % to 7.7 % of the total PRF: BC1 (67 h/ha), BC2 (1498 h/ha), BC3 (1455 h/ha), and BLL4 (285 h/ha). These risks are associated with temporary labour, typically hired for fruit harvesting. They include low self-esteem (strong association) and high levels of perceived stress (moderate association) (Domenighetti et al., 2000).

Metabolic risks (i.e. diabetes and metabolic syndrome) are present across all farms and represent the third most significant impact in the BC farms (BC1: 13 h/ha; BC2: 425 h/ha; BC3: 268 h/ha) and the second most significant in the BL farms (BLL4: 125 h/ha; BLL5: 856 h/ha; BLL6: 251 h/ha).

Respiratory risks include wheezing (moderate and weak associations) and asthma (strong association). Wheezing is linked to tractor driving and hand-picking tasks, while asthma is associated with pesticide exposure. In the BC farms, these risks represent the fourth most significant impacts: BC1 (14 h/ha), BC2 (451 h/ha), and BC3 (296 h/ha), primarily due to the high number of hours dedicated to chemical weeding and pesticide application using tractors. In the BL farms (BLL4:

189 h/ha; BLL5: 742 h/ha; BLL6: 64 h/ha), the PRF mainly derives from time spent on vegetable hand-picking.

Neurological and oncological macro-categories show the lowest PRF values and are associated with the use of chemical pesticides. The proportion of oncological risks relative to the total PRF varies considerably across farms: approximately 0.19 % in BC1 and BC2; around 0.24 % in BC3 and BLL6; 0.15 % in BLL4; and 0.04 % in BLL5. Two farms in BC exhibit the highest impacts in this category, with strong and moderate associations: 19.4 h/ha in BC2 and 22.55 h/ha in BC1, compared to the BL farms (5.5 h/ha in BLL4; 4.68 h/ha in BLL5; and 7.73 h/ha in BLL6). The BLL6 farm shows the lowest exposure levels overall, as it implements practices such as green manuring and avoids the use of synthetic chemical products in vegetable crops.

In the agro-industrial model in BC, the BC1 farm shows minimal impact per hectare, as it allocates more land to cereal cultivation than the average in the case study, which requires less labour than fruit production. Moreover, cereals are produced for the animal feed market, whereas fruit is destined for human consumption. The BC2 farm shows a higher impact per hectare and per unit of production compared to its counterparts in BC, due to its focus on the national rather than the export market. This strategy involves picking and packing fruit directly in the field, a process that proves more time-consuming than sorting it later at the fruit centre.

In BL, the BLL5 farm displays distinctive characteristics. It is oriented towards vegetable production, which is more labour-intensive, and its produce is sold both at Mercabarna (Europe's largest fresh food wholesale market, located in Barcelona) and through short supply chains such as farmers' markets and its own fruit shop. The BLL6 farm stands out for its low social impacts compared to the other farms in both BC and BL. It follows an economy of scope strategy, reducing production in favour of implementing alternative production methods (e.g., green manuring) and marketing practices (e.g., prioritising direct sales through farmers' markets). However, these alternatives to the dominant conventional production model also entail associated risks, including lower back, neck, and shoulder pain.

Overall, high estimates of psychosocial risk factors, measured in hours per hectare, are observed in farms from both BC and BL (notably BC2 and BLL5), indicating that pursuing distinctive strategies does not necessarily lead to significant differences in psychosocial risks. In BC, the BC2 farm records the highest social impact (10,311 h/ha), followed by BC3 (9427 h/ha). The BC1 farm, with a large area under cereal cultivation requiring fewer working hours, shows a very low impact per hectare (390 h/ha). In BL, BLL5 shows the highest impact (104,511 h/ha), with a substantial difference compared to BLL4 (3706 h/ha) and BLL6 (3066 h/ha). Conversely, when expressed as a percentage, some differential patterns emerge: BC farms exhibit distinctly higher values of psychological risks than the BL farms, which appears to be linked to the seasonality of fruit production.

3.2. Psychosocial risk factor per unit of production (kg)

When considering PRF per kilogram, notable differences emerge compared to the previous analysis (Figs. 7 and 8). These differences are largely explained by variations in productivity, crop types, and labour requirements across farms. For instance, the BLL5 farm shows the highest impact (0.6 h/kg). Although it is a specialised vegetable farm and larger than others in Baix Llobregat, its production involves labour-intensive tasks, contributing to a higher impact per unit. In contrast, BC1 records the lowest impact per unit (0.11 h/kg), as it produces large quantities of cereals and fruits, benefiting from economies of scale and mechanisation.

In BC, the highest impact per unit is observed in BC2 (0.51 h/kg), a farm oriented towards national markets. Its operations require specific forms of product processing, such as sorting fruit directly into boxes by size, which involves multiple passes and increases labour demands. Meanwhile, in BL, BLL6 shows the lowest impact (0.2 h/kg). This small

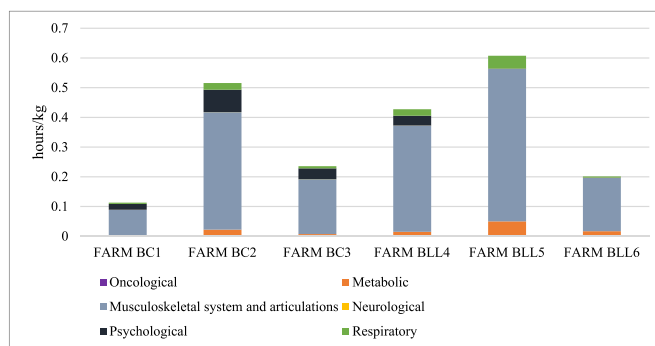


Fig. 7. Psychosocial Risk Factor of the six farms measured in number of hours per unit of production (kg).

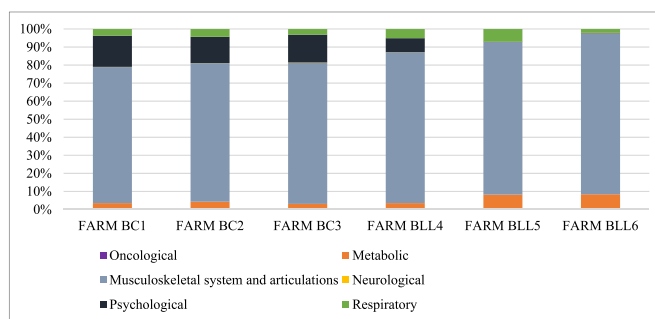


Fig. 8. Psychosocial Risk Factor of the six farms measured in percentage of each risk category over the total risks per unit of production (kg).

farm focuses on fruit and vegetable production for direct sale to consumers, which results in lower yields but also requires time-intensive marketing activities, such as attending local markets twice a week.

These findings highlight that impacts per hectare and per unit of product do not always align. BC farms generally achieve higher yields per hectare due to mechanisation and crop specialisation, which can reduce impacts per unit through economies of scale. Conversely, BL farms often produce more diverse crops with lower yields and higher labour intensity, leading to higher impacts per unit. This underscores the importance of using both metrics, per hectare and per unit, to capture a comprehensive picture of farm sustainability and labour dynamics.

4. Discussion

This study applies the Psychosocial Risk Factor (PRF) methodology as a Social Life Cycle Assessment (S-LCA) based on the impact pathways approach to assess the social impact of six farms operating within two farming systems characterised by distinct productive strategies: economies of scale and specialisation in BC, and economies of scope and diversification in BL.

4.1. Differences between farming models

The findings reveal key differences in social impacts between the two distinct productive strategies (i.e. specialised vs diversified models). When analysing PRF hours per hectare, larger farms focused on fruit production appear less sustainable, particularly those operating within the agro-industrial model in BC. Their specialisation in fruit production makes them more labour-intensive than farms specialised in vegetable or cereal production. Psychological risks in these farms rank second in terms of percentage of total risks. These are associated with the temporary nature of work during the harvesting phase, where a precarious and vulnerable migrant labour force predominates, undermining the sustainability of the entire farming system (Đokić et al., 2021;

Molinero-Gerbeau et al., 2021). Such risks are not observed in BL, not even in fruit-producing farms, suggesting that crop seasonality and production intensification within the agro-industrial model contribute to increased social impacts.

In terms of mechanisation and its associated impacts, marked differences are observed between farms in BC and BLL. Farms in BLL face greater challenges in mechanising tasks such as pesticide application, often reporting increased working hours, consistent with previous studies on agroecological farms (Bainville et al., 2025; Dumont and Baret, 2017). In contrast, the economy of scale strategy adopted by farms in BC is characterised by a high degree of mechanisation, where the use of machinery enhances operator comfort and reduces strain on articulations (Romano et al., 2020), thereby mitigating some of the social impacts typically associated with manual labour. As a result, agro-industrial farms appear to have a greater capacity to reduce physical social impacts compared to diversified farms, which often lack the financial resources to invest in modern equipment.

However, this increase in efficiency also enables farmers to manage larger plots of land independently, leading to prolonged exposure to various health risks—particularly those that are qualitatively more severe, such as oncological and neurological hazards (Blair et al., 2010; Jahangir Alam et al., 2016). Indeed, agro-industrial farms in BC exhibit higher risks in the oncological category. Although this category contributes relatively little to the total exposure time, it poses a disproportionately high threat to the health and well-being of both workers and farmers.

Our results show that more diversified farms exhibit a more balanced distribution of working hours across tasks compared to highly specialised farms. The model based on economies of scope involves activities such as commercialisation, which reduce exposure to certain risks associated with intensive production (e.g. pesticide use). This supports calls to promote alternative strategies for small farms in Europe that prioritise more than just economic performance, competitiveness, and growth, as an exclusive focus on these aspects may lead them down a path similar to that of agro-industrial farms, ultimately resulting in higher psychosocial impacts (Knickel et al., 2017).

Agro-industrial farms supplying supermarkets are subject to stringent quality standards, including strict limits on pesticide residues (Konefal et al., 2005). Certification schemes promoting these standards may encourage the adoption of more sustainable practices (Van Der Grijp et al., 2005). However, such demand-driven mechanisms have limitations, particularly for small farms, as they may compromise farmers' autonomy and reinforce market-driven pressures (Helander et al., 2024; Palmisano, 2023). In Bajo Cinca, some specialised fruit farms adopt alternatives to chemical pesticides—such as pheromone traps and biobased inputs—substantially reducing health risks and enhancing social sustainability (Maes et al., 2021).

In contrast, farms in Baix Llobregat are typically smaller and more diversified, which inherently reduces exposure to certain health hazards. These farms more commonly combine conventional chemical treatments with agroecological practices, such as green manuring and the use of organic products, resulting in lower oncological risk. However, the broader application of such practices in larger farms may face constraints, including increased labour demands or reduced productivity, thereby revealing trade-offs among environmental, social, and economic sustainability goals (Dumont and Baret, 2017).

The findings suggest that pesticide reduction strategies are not confined to either conventional or agroecological paradigms but can emerge across farming systems driven by diverse motivations (Palmisano, 2023). Promoting “middle ground” practices, that are hybrid strategies that fall between fully conventional and agroecological models, may therefore foster incremental sustainability gains. These approaches show potential to align environmental and social objectives, contributing meaningfully to the development of more sustainable agrifood systems (Cunningham et al., 2010).

Finally, the seasonality of fruit production—where the entire annual

harvest is concentrated into a few months—hinders the testing and eventual adoption of more sustainable practices in BC (Knickel et al., 2017), as it places the entire harvest, and thus the farm's financial viability, at risk. Efforts to reterritorialise farming systems must therefore address the trade-offs between new demands arising from product processing—which may increase exposure to certain risks—and the enhancement of farmers' autonomy, which can improve professional satisfaction and overall well-being (Dupré et al., 2017; Rissing et al., 2023).

Despite the commonalities identified across the case studies, a significant degree of heterogeneity is also observed. Our findings reinforce the importance of farm management in shaping agricultural social impacts (Muñoz Torres et al., 2022), demonstrating that market orientation—not solely the development strategy (i.e. specialisation versus diversification)—plays a crucial role in determining on-farm practices. These practices, in turn, lead to varying social impacts that help explain divergences within the same farming systems. As noted by Duval et al., these factors often interact closely, making it challenging to disentangle the specific source of each social impact. Nevertheless, our results align with previous research on the classification of agrarian systems (Therond et al., 2017), which highlights the need for a more nuanced and comprehensive typology. Broad categories such as “agro-industrial” or “diversified” risk overlooking critical specificities that influence both practices and outcomes.

Within BC farms, variations in psychosocial impacts can be attributed to the extensive cultivation of cereal crops for animal feed, which entails markedly different management practices compared to fruit production intended for direct human consumption. In this context, it is essential to consider the specific nutritional demands each farm seeks to address. These findings reinforce the argument that the social utility of the product under analysis must be considered to fully capture the social impacts of agricultural production (van Haaster et al., 2017). Accordingly, BC1 fulfils a distinct social function, rendering direct comparisons with other farms potentially incommensurable.

Within the BC farms, variations in psychosocial impacts can be attributed to the extensive cultivation of cereal crops for animal feed, which involves markedly different management practices compared to fruit production intended for direct human consumption. In this context, it is essential to consider the specific nutritional demands each farm seeks to address. These findings reinforce the argument that the social utility of the product under analysis must be taken into account to fully capture the social impacts of agricultural production (van Haaster et al., 2017). Accordingly, BC1 fulfils a distinct social function, rendering direct comparisons with other farms potentially incommensurable.

In BL, the diversification strategy adopted by larger farms such as BLL5 increases the need for coordination to manage a wider array of products. This added complexity hinders the repetitive mechanisation of tasks, thereby extending the working hours required in comparison with smaller farms within the same farming system. Consequently, the number of hours during which workers are exposed to health risks also increases. This suggests that the sustainability of farms focused on local markets may also require a certain degree of intensification and specialisation of production, which in turn may entail increased social impacts. However, this increase is likely to be shifted further downstream, affecting actors beyond the farm level.

4.2. Similarities between farming models

Our results also identify similarities between farms across BC and BLL. Farms in both case studies exhibit higher impacts related to the musculoskeletal system and articulations. Physical labour continues to play a prominent role in agriculture (Dumont and Baret, 2017; Jones et al., 2020), even in farms operating under the agro-industrial model, which is highly specialised and mechanised. Long working hours per day are common in both agro-industrial and diversified farms (Bainville et al., 2025; Dumont and Baret, 2017), particularly during the harvest

season, which further increases these risks. Harvesting remains the most time-consuming task, as it is still largely manual—even in the highly mechanised farms in BC.

Moreover, the diversity of crops and activities across farms, reflecting varying system boundaries, complicates the process of conducting meaningful comparisons of their social impacts. These outcomes reveal the limitations of the criteria used to define farming strategies, as dissimilar strategies may ultimately lead to similar impacts.

4.3. Methodological limitations and challenges

This work contributes to deepening and refining the application of the Psychosocial Risk Factor (PRF) impact pathway methodology proposed by Iofrida et al. (2019) to assess the impact of farming systems on the health and well-being of people. We expand its application beyond previous studies on agricultural production—such as olive (De Luca et al., 2023) and citrus (Iofrida et al., 2019) cultivation—by employing this method to assess fruit and vegetable farms with different development trajectories. Additionally, we broaden the database of odds ratios related to health impacts in agriculture. By integrating epidemiological research into S-LCA studies, it becomes possible to assess social impacts based on scientific evidence of cause-effect chains (Hannouf et al., 2021), thereby facilitating the application of Life Cycle Sustainability Assessment through the integration of the social dimension (Iofrida et al., 2024). Since the PRF relies on prior studies using odds ratios derived from different working contexts, certain assumptions must be made (Iofrida et al., 2019).

Its early stage of development presents methodological challenges, with data availability being a paramount concern. Obtaining site-specific data from companies in the supply chain is highly time-consuming (Chhipi-Shrestha et al., 2015; Sureau et al., 2020; Ugaya et al., 2023), particularly when assessing small-scale organisations that may not systematically record working hours (Sanchez Ramirez et al., 2016; Siebert et al., 2018a,b). In this study, data are collected through questionnaires addressed to farmers, which may introduce cognitive biases, as farmers might omit certain tasks either due to forgetfulness or because they do not consider them relevant. Furthermore, unforeseen tasks that arise during the production cycle (e.g. maintenance, repairs, impromptu trips) are not included in the task inventory. Future research should focus on improving data collection to support the standardisation of social impact assessment methods (Petti et al., 2018).

This work contributes to the quantitative analysis of social impacts (Thom et al., 2024) and demonstrates the applicability of the S-LCA methodology to empirical case studies. It identifies trends in social impacts and highlights social hotspots in production where impacts are more likely to occur. The PRF approach enables the establishment of causal relationships between social impacts and the functional unit, addressing one of the main challenges of the S-LCA methodology—namely, the standardisation of assessment methods to ensure replicability and comparability throughout the product life cycle (Petti et al., 2018; Ramos Huarachi et al., 2020; Siebert et al., 2018a,b). However, adopting a company-level perspective to consider the impacts of all crops within a farm also presents significant challenges. The variation in system boundaries makes it difficult to distinguish between the impacts generated by different products and across value chain phases, such as agricultural production and commercialisation. Future research should therefore aim to identify specific impacts related to life cycle stages, crop types (e.g. fruit and vegetables vs fallow), and labour characteristics (e.g. mechanised vs manual), in order to understand social impacts from an integrated perspective.

5. Conclusions

This study contributes to the analysis of social sustainability in agriculture by applying the Psychosocial Risk Factor (PRF) pathway—an approach that assesses health impacts using the statistical measure of

odds ratios. This innovative method for quantifying social impacts links farming tasks, working conditions, and health risks, thereby enhancing the comparative evaluation of productive systems.

Key findings indicate that the highest impacts occur in the musculoskeletal system and articulations across all farms, including highly mechanised industrial farms. Our results show that smaller and more diversified farms can reduce exposure to the most hazardous health risks (e.g. oncological) due to their lower use of chemical pesticides. However, this production model requires more working hours, which may hinder the scalability of such practices and increase exposure to other physical risks. These findings support the call to promote alternative strategies for small farms in Europe that do not focus solely on economic performance, competitiveness, and growth, as these often necessitate intensification and specialisation, potentially leading to increased social impacts.

In summary, our research shows that the transition towards reterritorialised and sustainable models introduces new working demands that reduce health risks associated with intensive fruit and vegetable production, while also posing significant challenges by increasing labour requirements. Our results, in line with previous research (Brock and Schewe, 2023; Rosin and Campbell, 2009), highlight the relevance of “middle ground” practices—neither purely conventional nor purely organic—in advancing the transition towards sustainable agriculture. This suggests that sustainability policies must account for the heterogeneity of farm types and support the integration of agroecological practices into conventional farming systems to mitigate risk exposure. Furthermore, it is essential to assess the trade-offs involved in changes to production and commercialisation in order to better understand farmers’ decision-making processes.

Future research should also explore differences in risk exposure between farmers (i.e. farm owners) and farmworkers, considering variables such as gender and origin (Janker and Thieme, 2021; Littig, 2018). Given the division of labour between these groups, it is reasonable to expect that social impacts are unevenly distributed. Therefore, further investigation into the specificities of labour relations in agriculture is necessary to ensure a more comprehensive and equitable approach to sustainability.

CRediT authorship contribution statement

Carmen Capdevila: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Nathalie Iofrida:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Anna De Luca:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Elsa Varela:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This paper is part of C. Capdevilas’ PhD thesis. She acknowledges the support of grant FPU19/01976 awarded by the Spanish Ministry of Science, Innovation and Universities. The authors are thankful to the farmers that participated in this study for their time and valuable information.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jrurstud.2025.103765>.

Data availability

Data will be made available on request.

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