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Article

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Abstract: Agriculture is an important sector of European Union in societal , economic and environmental dimensions. Sustainability of the sector require improvements in its key operations. Weeding is one of the crucial operation having impact on farms' productivity, safety for farmers, food security and environmental state. To achieve EU policy goals of sustainable agriculture there are needed new technical and organizational solutions. One of the advanced techniques are laser based weeding technique. It is important to understand   well the impacts of introduction of these techniques to the markets and agricultural practice in sustainability context. For that reason Social Life Cycle Assessment was performed. The method was based on participatory   approach. The assessment was carried in three perspectives: general society, farmers, and business perspective related to agriculture. Expert interviews based on questionnaires and workshops were realized to get the opinions on the impacts of a new laser technique on particular aspects of its implementation. The results show generally positive impact in all perspectives, especially in the perspective of farmers.

Keywords: precision agriculture; weeding; laser based system; sustainability; Social Life Cycle Assessment

1. Introduction

Innovation in the agricultural sector is one of the key factor of its sustainable development [5]. Innovation covers many aspects: technical, social and economic. One of the crucial aspects is Precision Agriculture encompassing digitalisation as well as robotisation. There are many benefits for farmers related to productivity and profitability of the farm, automation on the machines improves comfort, and reduce environmental impacts related to agricultural operations. Precision agriculture apart from potential economic and environmental benefits can have a wide societal impact. I can influence demographic changes in the sector [6], impact rural development opportunities, improve public image of farming in wide society.

Precision agriculture provide opportunities to farmers to better adjust to policy requirements concerning environmental protection. This is especially related to use of chemicals, among them herbicides in weeding operations. European policy consequently tend to reduce or eliminate use of herbicides in crop production. The use of herbicides on organic farms is already banned or reduced in Europe [7–9] stimulating changes in the crop production systems. Moreover, the consumers habits, expectations and concerns related to food safety are steadily rising. To meet the demand changes in the production systems are required.

Precision agriculture, if applied in a wise way can be in the core of agricultural sustainability. Sustainability in agriculture concerns impacts of production processes, materials, energy, machinery and services, so that these can be made more ecologically friendly, economically profitable, and socially suitable [10]. Sustainability in agriculture has to be considered within the framework of Life Cycle Thinking (LCT). For the purpose of assessing the level of sustainability a number of tools have been developed to assess different sorts of impacts deriving from the life cycles of goods and services.

Life Cycle Assessment (LCA) is applicable to environmental goods and services, whereas Life Cycle Costing (LCC) is used to analyze all relevant costs expressed in monetary value. Social Life Cycle Assessment (S-LCA) allows for the evaluation of social implications.

Socio-economic aspects of introducing field crop robots are not yet well researched in this scope. The increasing interest in the field of crop robots need appropriate assessment to better understand the societal impacts including threats and benefits. Despite the importance of integrating social issues in LCA studies, consensus has not yet been reached on a specific methodology for S-LCA. Different and sometimes divergent theoretical and practical approaches have been proposed [11,12]. Publications related to social aspect of field crop robots focus heavily on technology and programming. Publications concerned with environmental or socioeconomic aspects are scarce despite an overall increasing interest in the field of field crop robots [13].

Weeding is one of the most important factors in agricultural production. Weeds can lower essentially the productivity in the crop systems. There are new developments to provide new weeding techniques [14] as an alternative for use of chemicals to meet the challenges of sustainable production. These concerns mechanical, tools, laser based, techniques using high energies. Combinations of various technics are also considered. A novel technique of weed control developed was researched under the HORIZON 2020 project WeLASER. Its objective is to reduce the use of herbicides while improving productivity and competitiveness. The WeLASER weeder is an autonomous mobile robot using high-power laser to eliminate weeds. It is a complex solution using autonomous systems, artificial intelligence (AI), and advanced geo-positioning. The invention is developed, integrated, and tested in the project "Sustainable Weed Management In Agriculture With Laser-based Autonomous Tools - WeLASER". It comprises a mobile autonomous platform, a laser weeding unit, and supportive components. In the WeLASER project, a weeding system with two lasers was tested to achieve the Technology Readiness Level 7 (TRL 7). To be commercialized, the product must attain in further development Technology Readiness Level 9 (TRL 9).

Its application depends among others on economic, environmental as well as social aspects. Issues related to farmers, societal and business perspective has to be clarified in the context of its implementation in wide agricultural practice. To achieve this, Social Life Cycle Assessment was carried out. The aim of the study was to determine the impact of WeLASER implementation in a wide societal context on sustainability of weeding in agriculture, in Life Cycle Perspective. Risks for particular actors, societal domains, barriers, opportunities and benefits were identified, characterized and assessed. In the study Social Life Cycle Assessment (SLCA) was applied. Because the methodology is not standardized as it is for its environmental and economic peers, i.e. Life Cycle Assessment (E-LCA or LCA) and Life Cycle Costing (LCC) a dedicated approach was proposed. It has to be noted that there is neither consensus about the impact assessment methods, nor clarity on the underlying social sustainability concepts. Consequently, many different methodologies have been proposed, whose objectives put attention to different aspects [15]. This is due to social impacts that depend not only on production processes themselves but often also on actors' behavior and specific contexts. In this study participatory and multi-criterial tools were implemented in an S-LCA application by experts qualitative and, participatory approach [16]. The method was applied in accordance to UNEP guidelines concerning S-LCA: The Life Cycle Initiative United Nations Environment Programme-Society of Environmental Toxicology and Chemistry (UNEP-SETAC) [17].

2. Materials and Methods

UNEP guidelines prepared by The Life Cycle Initiative United Nations Environment Programme-Society of Environmental Toxicology and Chemistry [17,18] concerning S-LCA were applied to set the general outline of the study. In the methodology it was considered more robust approach relevant to the conceptual framework of LCT, to enable the prediction of the social consequences of choices concerning the creation, use and recycling of products [12].

It is pointed out that no agreed method S-LCIA is available for the selection of impact categories and the measurement of indicators [11]. The UNEP Guidelines suggested a top-down method of S-LCIA. Hybrid approach that combines the top-down and bottom-up methods for determining the

indicators was proposed by some authors [19]. Integration of the participatory approach in S-LCA, as opinions of various stakeholders can be collected so that relevant indicators can be defined [20]. The approach to use a unique assessment tool, based on two steps of a S-LCA [11] are: 1) the selection of groups of affected actors, categories, subcategories and their relation, and 2) how to determine the importance of every category and subcategory for a given range of different actors.

2.1. Methodological Concept

In characterization of the impacts in the study Multi-Criteria Decision Analysis (MCDA) was applied. It allowed for direct incorporation of the preferences of different interest groups or stakeholders [21]. Categories and subcategories have been weighted by way of calculations made using the Analytic Hierarchy Process (AHP), a multi-criteria method developed by Saaty [22]. The Analytic Hierarchy Process (AHP) was conducted with the involvement of relevant stakeholders in each area (workers, members of local communities, and members of society).

The first phase of the AHP is the development of a hierarchical structure through the decomposition of the problem into levels and sublevels. The second AHP phase consisted in pairwise comparison at each level: stakeholders, divided in 3 expert groups, were interviewed to compare each subcategory and category of impact. Each element of the AHP priority matrix had been normalized and a consistency ratio (CR) of the pairwise comparison matrix [23] had been calculated. A pairwise comparison allowed the attribution of a relative weight to each of them. The same comparison was made at 3 hierarchical levels: for categories, subcategories, and groups of stakeholders. The AHP allowed for the transformation of qualitative judgments into quantitative elements. The outline of the method used in the study is presented in figure below (Figure 1).
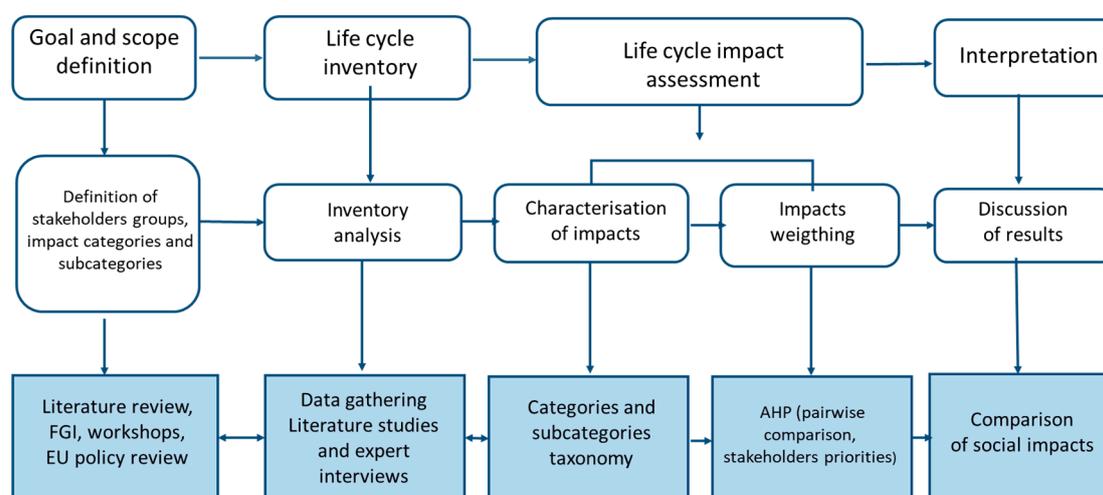

Figure 1. Outline of the S-LCA process applied in the study.

2.1.1. Goal and Scope Definition

The overall objective of the study was to determine the potential impact of WeLASER adoption taking into account a wide sustainability context of its implementation in Life Cycle Perspective. To determine the key elements of the S-LCA including its goal, scope and key categories and subcategories of assessment there was carried out literature study and interaction with stakeholders was performed in a participatory approach. A literature review constituted the basic information on which the specific method, tailored to the purpose of the study was developed. The review included peer-reviewed literature from scientific journals and official published literature analyzing the current statistics and the specific literature relevant to the contexts under study and face-to-face interviews with experts. The study was focused on well-being and quality of life in the domains of farmers, society and business. To combine the expert knowledge with stakeholders opinions focus groups has been structured. The purpose was to involve stakeholders from the three perspectives in

the process of identification of key domains and fields of assessment that have to be taken into account.

Four workshops were held as part of the WeLASER project with wide participation of the stakeholders. The workshops were organized on-line on European level and in three regional contexts, in Poland, Belgium and Spain. In each of the groups participated 15 -25 stakeholders representing business, NGO, administration, farmers and farmers associations (D1.3 available at www.welaser.eu). The FGI workshops consisted of two parts: 1) structured discussion and 2) SWOT analysis. Results of SWOT analysis are reported by Tran et al. [26]. In the events Strengths, Weaknesses, Opportunities and Threats of WeLASER implementation related to particular actors, societal domains, barriers, opportunities and benefits were identified, characterized and valuated. Unpublished results from the structured discussion part of the workshops were also used in this study. Both sources were provided valuable information for structuring the assessment hierarchy. These were evaluated in the context of the results of literature analysis and formed the basis for preparing the methodological details of S-LCA approach.

A wide use of weeding technologies such as WeLASER (unmanned, autonomous, weeding using laser energy) in agricultural practice in Europe was assumed as the subject of assessment. Weeding was recognized as activity in the whole crop production cycle allowing for generating crop at the sufficient level according to current agricultural practice. The subject of assessment was related to all potential applications of WeLASER in crop systems in agriculture - according to the experts knowledge.

Scope of analysis targeted: social, environmental and economic issues related to three societal perspectives. According to [27], S-LCA regards the consideration of "human well-being" as an overall social dimension. Specific three dimensions (perspectives) were defined as related to agricultural machinery usage in crop production systems: societal quality of life, well-being in farmers' perspective and business performance related to business responsibilities within the WeLASER life cycle. The perspectives were unique for a given group of stakeholders and the assessment was done separately for each perspective (Figure 1).

The assessment targeted in qualitative terms the two elements forming the system boundary:

- machine robot life cycle phases including production (need for critical materials, use and dismantling of the robot
- crop life cycle

Moreover, in developing of the categories (domains) and subcategories (fields) of assessment 5 stocks of capital, human, technical, financial, social, and institutional [27] were considering. Finally, taking into account all methodological aspects, S-LCA of WeLASER technology:

o was based on overall LCA framework [28]
o integrates participatory approach and multi-criterial tools of analysis
o follows the recommendations published by The Life Cycle Initiative United Nations Environment Programme-Society of Environmental Toxicology and Chemistry (UNEP-SETAC) [17,18].
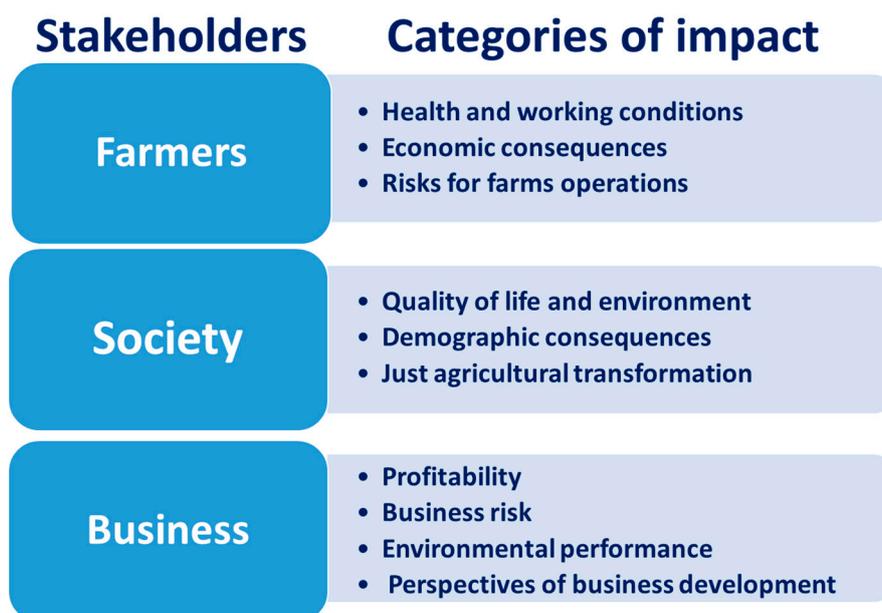
Stakeholders   Categories of impact

Farmers
- **Health and working conditions**
- **Economic consequences**
- **Risks for farms operations**

Society
- **Quality of life and environment**
- **Demographic consequences**
- **Just agricultural transformation**

Business
- **Profitability**
- **Business risk**
- **Environmental performance**
- **Perspectives of business development**

Figure 2. Stakeholders perspectives and impact categories/domains.

2.1.2. Inventory and Characterization Analysis

Three groups of experts were formed in this study as a qualitative technique to involve experts with experience in agricultural domains, rural economics, business and local development. Groups of experts were formed in line with the recommendations of UNEP-SETAC [18]. Taking into account the scope system boundaries of this study the following groups of experts were formed:

- Farmers and farm workers: persons   who cultivates crops of his own and someone else filed.
- Society: local community as well as European society
- Institutions supporting business sector in rural areas - institutions include business organizations and supporting entities improving the knowledge and skills of farmers

Structure of the expert groups is presented in the Table 1.

Direct measurements was developed to make assessment through questionnaires. Secondary sources were used in development of the questionnaire and as a structured background for the interviewer for the purpose of moderating discussion during interview. Questionnaires were developed as a basis for direct experts' interviews.

Table 1. Description of expert group and experts taking part in the process of assessment.

Perspective	Description of expert group	Expert no	Experts description
Farmers	Experts represent both farmers managing farms (organic and/or conventional) and people cooperating and exchanging experiences between research institutions, industry, farmers and the local community, associated in producer group and/or fulfilling different functions, including international network dedicated to innovation-driven research in smart farming technology.	1	Polish farmer (organic)
		2	Researcher, coordinator of the European network dedicated to promotion of smart farming technologies
		3	Danish Farmer (conventional)
		4	Polish farmer (organic)
		5	Farmer, representative of the Polish agricultural production group.

Society	Experts are local activists, representatives of NGO and research organisations, involved in developing cooperation networks on rural areas development, as well as European organisation. Experts commit to support the sustainable development of rural areas, modernization and implementation of technologies and practices aimed at improving the high quality and safe agri-food products. They cooperate with organizations promoting agricultural practices that have a positive impact on the environment.	1	researcher, representative of international center for research in organic agriculture.
		2	Researcher, coordinator of the European network dedicated to sustainable rural development.
		3	President of the regional Chamber of Agriculture in Poland
		4	Member of European organization focused on organic farming, participant of international working groups, local activist.
		5	Manager of the Polish NGO which activities are focused on agricultural development
Business	Experts are representatives of companies offering innovative technological solutions for farmers, advice in the field of agricultural crops and applied techniques and technologies, including agricultural machinery as well as trainings for farmers. Some of them carries out research and development work for the implementation of innovative technologies in agricultural practice.	1	Representative of company of European coverage focused on cultivation and sale of agricultural produce.
		2	Innovation broker, representative of innovation network for Polish agriculture.
		3	Representative of Danish company proving service and advice to farmers and business operators.
		4	Representative of Polish company dedicated to precision agriculture implementation.
		5	Sales representative of the Danish company dealing with innovative agricultural robots.

The objective of the inventory was to collect relevant information according to the scope of the study. The interviews were structured in the following way: discussion based on the questionnaire and assessment of each of the fields representing societal relevant impact. Questionnaire and rationale for its structure is presented in Table 2.

Table 2. Questionnaire structure with justification of its formulation.

Perspective	Category/Domain	Literature	FGI	EU policy
Farmers	**Category: Health and working conditions**			
	Subcategories: What impact will the use of devices such as an autonomous laser weeder have on:			
	The farmer's working time?	[13,29–31]	x	[1]
	Comfort of work?	[13,29,34,3033]	x	[1]
	Work safety and accidents?	[33,35–38]	x	[1]
	Health conditions (chemical hazards caused by the use of chemical plant protection products, back problems due to manual weeding)?	[29,30,33,39–44]	x	[1]
	Category: Economic consequences			
	Subcategories: What impact will the use of devices such as an autonomous laser weeder have on:			
	Good quality agricultural products that meet customers' needs?	[45,46]	x	[1]

	Farms' productivity per hectare?	[29,30,34,47]	x	[1]
	Demand for seasonal/temporary workers?	[48]	x	[1]
	Production costs	[49–53]	x	[1]
	Category: Risk for farms operation			
	Subcategories: What impact will the implementation/purchase/rental of devices such as an autonomous laser weeder have on:			
	Risks related to unexpected functional limitations of the device?	[37,38,54,56,57]	x	-
	Farmers' liability for damage to third party property caused by the device?	[37,57]	x	-
	Risk of theft or damaging the device?	-	x	-
Society	**Category: Quality of life and environment**			
	Subcategories: What impact will the use of devices such as an autonomous laser weeder have on values determining the quality of life due to limitation of methods used so far (including current weeding practices based on chemical plant protection products)?			
	Quality and safety of agricultural products?	[45,55,58]	x	[1]
	State of the environment	[44,59,61,63]	x	[3]
	Affordability of agricultural products for the society	[60,62]	x	[1]
	Category: Demographic consequences			
	Subcategories: What will be the impact of the availability of devices such as an autonomous laser weeder on the following demographic groups compared to the existing practice of weeding:			
	Young people interest in running a farm?	[64–67]	x	[4]
	Women's interest in working in agriculture?	[64,68–71,74]	x	[4]
	The demand for low-skilled labour?	[31,42,75]	x	[4]
	Category: Just agriculture transition			
	Subcategories: What impact will the widespread use of devices such as an autonomous laser weeder have on the following aspects of rural transformation in the long term perspective compared to the existing practice of weeding:			
	The agrarian structure of agriculture?	[71,76–78]	-	[4]
	Development of ecological (organic) farms?	[72,79]	x	[80]
	Economic diversification of rural areas?	[31,81,82]	x	[4]
Business	**Category: Profitability**			
	Subcategories: What impact will the widespread use of devices such as an autonomous laser weeder have on profits of the following branches in value chain compared to the existing practice of weeding:			
	Profits of companies producing the machines	[84]	-	-
	Profits of agri-food and food processing industry?	[83]	-	[1]
	Profits of agricultural producers/farmers/producers groups?	[83,85–87]	x	[1]
	Category: Business risks			
	Subcategories: What impact will the production of devices such as an autonomous laser weeder have on the following risks for the manufacturers with regard to the producers of alternative weeding machines			
	Manufacturer's responsibility for product's malfunctions (complaints, service)?	[88,92]	x	[89]

Manufacturer's responsibility for the damage to the user or third party property caused by the device?	[64]	x	[91]
Manufacturer's risk for the supply chain interruption in manufacturing processes?	[98,99]	-	-
Category: Environmental performance of companies			
Subcategories: What impact will the wide scale production of devices such as autonomous laser weeder have on the following environmental aspects with regards to alternative weeding machines?			
Demand for critical resources?	[97]	-	[90]
Manufacturer's responsibility for waste management of devices in its post-consumption phase?	[91]	-	[93]
Production pressure on the environment?	[95,96]	-	-
Category: Perspectives of business development			
Subcategories: What impact will the production and wide use of laser weeder have on perspectives of business development:			
Creation of new jobs?	[48,56]	X	[1]
New prospects for the companies development?	[48,61,94]	X	[1]
Strengthening competences of organisations, companies and workers?	[48,100]	-	[1]

Experts characterized the impacts in the particular categories/domains and subcategories/fields by providing their opinion on how WeLASER technology impact the societal aspects in particular fields and domains in comparison with the current situation. 5 scale of assessment was applied with the range of negative assessment, neutral to positive assessment

The results of the assessment were further discussed with the groups of experts representing each perspective during three workshops. During the workshop experts expressed their preferences according to Analytic Hierarchy Process (AHP) [23] .This method was applied as a tool in order to in the evaluation of the relative importance of each impact category and subcategory.

2.2. *Approach to Impact Assessment and Interpretation of Results*

Within the frames of the WeLASER project face-to-face surveys pertaining the introduction onto the market laser weed control system, i.e. antiweed system basing on application of laser technology, precise positioning, artificial intelligence and autonomously mobile platform. The goal of this study was to assess the impact of the launch of a new weed control tool on various fields and domains of life as assessed by experts representing three perspectives. In addition, the study aimed to determine the strength of experts' preferences between fields and domains, which was used in assessing the strength of the calculated impact. And using calculated weights, the effect of these preferences on the final impact assessment on fields and domains was carried out.

The perspectives included in the paper are: farmers (P1), business (P2) and society (P3). In the study participated 15 experts, 5 representing each perspective.

The first perspective P1 included farmers working at the farm.

The second perspective P2 included: sales representative of companies; innovation broker at Agricultural Advisory Centre; representative of fruit and vegetable processing sector; representative of the company dealing with advice, research and development activities, trainings, support for farmers; and representative of the consulting company providing best agricultural practices.

The third perspective included coordinator of the program dedicated to organic food systems and representative of research organization; representative of NGO (network) and research organization; representative of Chamber of Agriculture (Management Board); member of the Board of the European organization acting in the field of organic food and farming; and representative of NGO.

Experts from these perspectives were interviewed on relevant to them themes. The themes were organized into fields, which represented specific questions and into domains, which constituted set of questions. Thus we have 3 level structure of analysis.

The farmer perspective (P1) consists of 3 domains (D11, D12, D13).

Domain D11. *Health and working conditions contains four following fields*: F111. *The farmer's working time*; F112. *Comfort of work*; F113. *Work safety and accidents*; F114. *Health conditions*.

Domain D12. *Economic consequences contains four following fields*: F121. *Good quality agricultural products that meet customers' needs*; F122. *Farms' productivity per hectare*; F123. *Demand on seasonal/temporary workers*; F124. *Production costs*.

Domain D13. *Risk for farms operations contains three following fields*: F131. R*isks related to unexpected functional limitations of the device*; F132. *Farmers' liability for damage to third party property caused by the device*; F133. *Risk of theft or damaging the device*.

The business perspective (P2) consist of 4 domains (D21, D22, D23, D24).

Domain D21. *Profitability contains three following fields*: F211. *Profits of companies producing the machines*; F212. *Profits of agri-food and food processing industry*; F213. Pr*ofits of agricultural producers/farmers/producers groups*.

Domain D22. *Business risks contains three following fields*: F221. *Manufacturer's responsibility for product's malfunctions (complaints, service)*; F222. *Manufacturer's responsibility for the damage to the user or third party property caused by the device*; F223. *Manufacturer's risk for the supply chain interruption in manufacturing processes*.

Domain D23. *Environmental performance of companies contains three following fields*: F231. *Demand on critical resources*; F232. *Manufacturer's responsibility for waste management of devices in its post-consumption phase*; F233. *Production's pressure on the environment*.

Domain D24. *Perspectives of business development contains three following fields*: F241. *Creation of new jobs*; F242. *New prospects for the companies development*; F243. *Strengthening competences of organizations, companies and workers*.

The society perspective (P2) consist of 3 domains (D31, D32, D33).

Domain D31. *Quality of life and environment contains three following fields*: F311. *Quality and safety of agricultural products*; F312. *State of the environment*; F313. *Affordability of agricultural products for the society*.

Domain D32. *Demographic consequences contains three following fields*: F321. Y*oung people interest in running a farm*; F322. *Women's interest in working in agriculture*; F323. *The demand for low-skilled labor*.

Domain D33. *Just agriculture transformation contains three following fields*: F331. *The agrarian structure of agriculture*; F332. *Development of ecological (organic) farms*; F333. *Economic diversification of rural areas*.

The experts were asked to assess the impact of the WeLASER technology on specific field and the impact was assessed in five-point ordinal scale. Starting from 1 point meaning very negative impact, 2 points meaning negative impact, 3 points meaning neutral impact, 4 points meaning positive impact; and ending with 5 points meaning very positive impact.

On the base of results of impact assessment from 5 experts, average impact on given field in a form of arithmetic mean $\bar{x}$ was calculated with formula:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (1)$$

where *n* is the number of individual assessments (n equals 5), x_i - impact evaluation of one of five experts.

Based on the average impact on given field, the average impact on a domain and finally the average impact for analyzed perspectives were calculated.

In evaluation of average impacts following ranges were used to classify obtained results: $1.0 < \bar{x} < 1.5$ means very negative impact; $1.5 <= \bar{x} < 2.5$ means negative impact; $2.5 <= \bar{x} < 3.5$ means neutral impact; $3.5 <= \bar{x} < 4.5$ means positive impact and $4.5 <= \bar{x} < 5.0$ means very positive impact.

In evaluation of experts preferences expressed in weights, general approach of the analytical hierarchy process (AHP) [22–25] was applied (Figure 3).
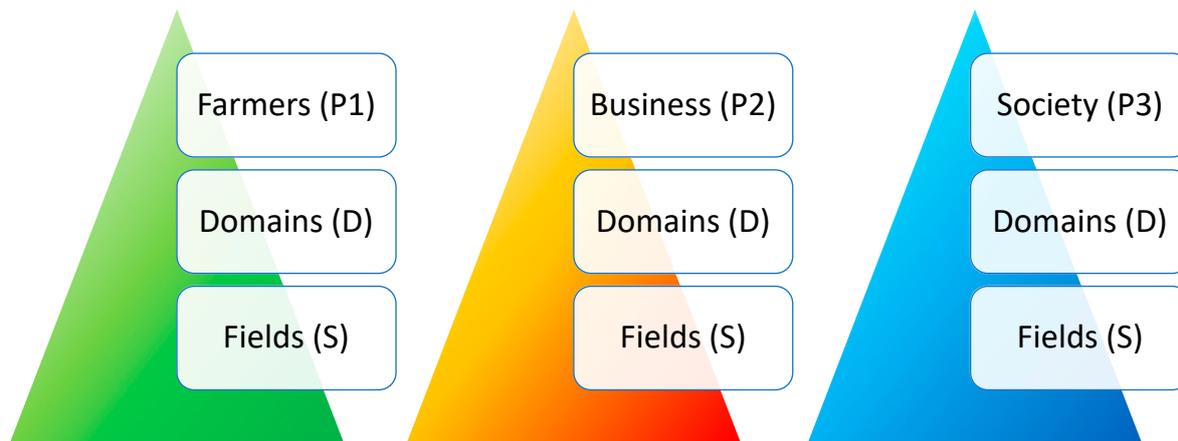
Figure 3. General scheme of the applied analytical hierarchy process.

For two levels of hierarchy, domains and fields, weights were calculated by use of pairwise comparisons. Narrowed and more detailed scale was used because it was assumed that irrelevant domains and fields were excluded before the survey was conducted. The scale of preferences and corresponding scores are presented below (Table 1).

Table 3. The assignment of numerical rates to the scale of preferences.

Numerical rate	Scale of preferences
1	**Equal preference**
1 1/2	Intermediate preferences
2	Equally to moderately preference
2 1/2	Intermediate preferences
3	**Moderately preference**
3 1/2	Intermediate preferences
4	Moderately to strong preference
4 1/2	Intermediate preferences
5	**Strong preference**

During the calculation of the weights, a consistency factor was also calculated to ensure the consistency of the resulting weights. Each expert had to express his or her preferences by comparing pairs of domains in a given perspective and fields in a given domain. The weights themselves were calculated automatically in Excel by a pre-prepared procedure. Thus importance of the field and domain for given expert was established. Calculated weights expressing importance of given field were averaged within domain while weights expressing importance of given domain were averaged within perspective. For averaging arithmetic mean was used (formula 1).

In evaluation of changes of weights, the calculated average weights were compared with values of initial weights w_i which were calculated according to the following formula:

$$w_i = \frac{1}{n} \tag{2}$$

where n is the number of fields (F) in a domain (D) or the number of domains (D) in given perspective (P).

The results of the changes in weights (expressing experts' preferences) were used to assess the strength of the assessed impacts, in other words, the strength of the experts' conviction in evaluating the impacts. In evaluation this strength 3 grade scale was used: strong, normal and weak. In assigning the strength of the impacts *R* following formula was used

$$R = \frac{D_w}{SD} \tag{4}$$

where D_w is percentage change in weight value in reference to initial weight value, SD standard deviation for sample representing all calculated for given perspective changes of weights values including domains and fields. The assumption was such that: if $R > 1$ and $D_w < 0$ it means weak evaluation; if $R > 1$ and $D_w > 0$ it means strong evaluation, otherwise it means normal strength of evaluation.

The averaged weights were used to check whether the introduction of preferences influence the assessed impacts. The weighted means of impacts ($\bar{x}$) were calculated by formula:

$$\bar{x} = \sum_{i=1}^{n} x_i w_i \tag{5}$$

where x_i score of assessed impact and w_i is calculated average weight for given domain or field. In this case n denotes the number of fields in domain or domains in given perspective.

3. Results

The results relate to the three main goals set. Because changes in weights were used to evaluate the strength of impact assessment the description of results begins with analysis of weights and their changes. Thus the first group of results relates to the average preferences (weights) of the three perspectives for each domain and field, which represent group of questions and individual questions.

3.1. Experts' Preferences between Domains and Fields in Three Perspectives

For the farmers' perspective, the most important domain is *Economic Consequences*. It gained about 20% of importance in comparison to initial state (Table 4). Problems related to *Health and working conditions* do not change much in importance (loss about 2%), and the least preferred domain in this perspective is *Risk to farm operations*. It lost about 18% in importance.

In the first domain (D11), the most preferred field (problem) is *Work Safety and Accidents*. Its importance increased by 16%. *Health conditions* have gained in importance by 9.5% and is in the second place in this group. Interestingly, *Comfort of work* is perceived as the least important, having lost 13.7% in importance.

In the second domain (D12), the *Production costs* are viewed as the most important. After weighing it gained about 35% in importance, which is the highest rise in this perspective. The highest loss in importance 26.5% pertains *Farms' productivity per hectare* and it is also the highest loss in perspective P1.

In the last domain (D13) of this perspective, the highest increase in importance is for *Risks related to unexpected functional limitations of the device* (about 20%). The largest decrease in importance relates to *Farmers' liability for damage to third-party property caused by the device* (about 15%).

Table 4. Preferences from farmers' perspective (P1).

Code	Domains and fields	Initial W.	Weights	Change
D11	*Health and working conditions*	1/3	0.3257	-2.29%
D12	*Economic consequences*	1/3	0.4006	20.17%
D13	*Risk for farms operations*	1/3	0.2738	-17.87%
F111	*The farmer's working time*	1/4	0.2204	-11.83%
F112	*Comfort of work*	1/4	0.2157	-13.73%
F113	*Work safety and accidents*	1/4	0.2900	16.01%
F114	*Health conditions*	1/4	0.2739	9.55%
F121	*Good quality agricultural products that meet customers' needs*	1/4	0.2483	-0.66%

Code	Domains and fields	Initial W.	Weights	Change
F122	*Farms' productivity per hectare*	1/4	0.1838	-26.50%
F123	*Demand on seasonal/temporary workers*	1/4	0.2307	-7.74%
F124	*Production costs*	1/4	0.3373	34.90%
F131	*Risks related to unexpected functional limitations of the device*	1/3	0.4009	20.26%
F132	*Farmers' liability for damage to third party property caused by the device*	1/3	0.2816	-15.52%
F133	*Risk of theft or damaging the device*	1/3	0.3176	-4.73%

Source: Authors' calculation on the base of WeLASER project data.

The next table (below) presents initial weights, calculated weights, representing preferences from business' perspective (P2) and changes in percentages between initial and calculated weights (Table 5).

Table 5. Preferences from business' perspective (P2).

Code	Domains (D) and fields (F)	Initial W.	Weights	Change
D21	*Profitability*	1/4	0.2868	14.72%
D22	*Business risks*	1/4	0.1935	-22.60%
D23	*Environmental performance of companies*	1/4	0.1907	-23.72%
D24	*Perspectives of business development*	1/4	0.3290	31.60%
F211	*Profits of companies producing the machines*	1/3	0.4839	45.17%
F212	*Profits of agri-food and food processing industry*	1/3	0.1398	-58.06%
F213	*Profits of agricultural producers/farmers/producers groups*	1/3	0.3762	12.86%
F221	*Manufacturer's responsibility for product's malfunctions (complaints, service)*	1/3	0.4417	32.51%
F222	*Manufacturer's responsibility for the damage to the user or third party property caused by the device*	1/3	0.2995	-10.15%
F223	*Manufacturer's risk for the supply chain interruption in manufacturing processes*	1/3	0.2588	-22.36%
F231	*Demand on critical resources*	1/3	0.2992	-10.24%
F232	*Manufacturer's responsibility for waste management of devices in its post-consumption phase*	1/3	0.3597	7.91%
F233	*Production's pressure on the environment*	1/3	0.3412	2.36%
F241	*Creation of new jobs*	1/3	0.2115	-36.55%
F242	*New prospects for the companies development*	1/3	0.4684	40.52%
F243	*Strengthening competences of organizations, companies and workers*	1/3	0.3201	-3.97%

Source: Authors' calculation on the base of WeLASER project data.

In the business perspective, more favored domains are *Perspectives of business development* (about 32% increase in importance) and *Profitability* (about 15%), while less favored are *Business risks* (about 23% decrease) and *Environmental performance of companies* (24% decrease in importance).

Within the first domain (D21) the most important field (problem) is *Profits of companies producing the machines* (about 45% gain in importance) and the least important is *Profits of agri-food and food*

processing industry (decline in importance of 58%). This two values constitute the highest rise and highest list of field importance in the perspective P2.

In the second domain (D22) of this perspective it may be observed that the highest gain in importance pertains to *Manufacturer's responsibility for product's malfunctions (complaints, service)*. This field gained 32.5% in importance. On the other hand the highest decrease in importance pertain to *Manufacturer's risk for the supply chain interruption in manufacturing processes* (minus 22.4%).

In the third domain (D23) the changes in importance are the smallest in this Perspective. The highest gain in importance, 7.9% is observed for *Manufacturer's responsibility for waste management of devices in its post-consumption phase*. The highest loss in importance (about 10%) refers to *Demand on critical resources*.

In the last domain (D24) of perspective P2, we observe also substantial changes in importance of particular fields (problems). We observe that, in this domain, the most important field is *New prospects for the companies development* (about 40.5% gain in importance) and the least important issue is *Creation of new jobs* (36.5% decrease in importance).

The third table (below) presents initial weights, calculated weights, representing preferences from perspective of society (P3) and changes in percentages between initial and calculated weights (Table 6).

Table 6. Preferences from society perspective (P3).

Code	Domains (D) and fields (F)	Initial W.	Weights	Change
D31	*Quality of life and environment*	1/3	0.4183	25.49%
D32	*Demographic consequences*	1/3	0.2254	-32.38%
D33	*Just agriculture transformation*	1/3	0.3563	6.89%
F311	*Quality and safety of agricultural products*	1/3	0.2922	-12.34%
F312	*State of the environment*	1/3	0.3639	9.17%
F313	*Affordability of agricultural products for the society*	1/3	0.3439	3.17%
F321	*Young people interest in running a farm*	1/3	0.4173	25.19%
F322	*Women's interest in working in agriculture*	1/3	0.3308	-0.76%
F323	*The demand for low-skilled labour*	1/3	0.2520	-24.40%
F331	*The agrarian structure of agriculture*	1/3	0.2550	-23.50%
F332	*Development of ecological (organic) farms*	1/3	0.4412	32.36%
F333	*Economic diversification of rural areas*	1/3	0.3038	-8.86%

Source: Authors' calculation on the base of WeLASER project data.

Within third, society perspective (P3) domain Quality of life and environment (D31) is assessed as the most important. It gained about 25.5% in importance The least important is domain Demographic consequences. It's importance decreased by about 32.4%.

Within the first domain (D31) the most important is State of the environment, it gained by about 9.2% in importance. The field (problem) of Quality and safety of agricultural products recorded the highest drop in importance in this domain, which amounted to 12%.

Within the second domain (D32) the most important issue (field) is Young people interest in running a farm expressed in a 25.2% increase of importance. The biggest drop in importance (by 24.4%) pertains The demand for low-skilled labor.

In the last, third domain (F33) of the Society perspective the biggest increase in importance (by 32.5%) was recorded for Development of ecological (organic) farms. The biggest drop in importance refers to The agrarian structure of agriculture (decrease by 23.4%).

The highest average change in importance within the perspectives, calculated on the basis of modal values of changes in the importance of domains and fields, relates to the Business perspective

and is 23.5%. The average change in preference within the Society perspective is 17.0%, and the smallest average change was calculated for the Farmers perspective (14.4%).

Among the domains, the highest average change in field preferences relates to the Profitability domain (D21) and is about 38.7%, while the second highest relates to Perspectives of business development (D24) and is 27%, both domains belong to Business' perspective.

3.2. Impact Assessment of the Lunch of the Laser Weed Control System (LWCS)

3.2.1. Farmers' Perspective on Impact of the LWCS Introduction on the Market

The score represents the average impact assessment based on the answers of 5 respondents. In this perspective, 11 questions were asked, divided into three sections.

The table contains average impact score, impact evaluation, and calculated on the base of change in weight values, result of evaluation of strength of given opinion expressed in given domain and field (Table 7).

Table 7. Farmers' perspective. Impact assessment and evaluation of opinion strength.

Code	Domains (D) and fields (F)	Impact scores	Impact evaluation	Evaluation strength
D11	*Health and working conditions (average)*	4.350	positive	normal
D12	*Economic consequences (average)*	4.375	positive	strong
D13	*Risk for farms operations (average)*	3.517	positive	weak
F111	*The farmer's working time*	4.200	positive	normal
F112	*Comfort of work*	4.600	very positive	normal
F113	*Work safety and accidents*	4.200	positive	normal
F114	*Health conditions*	4.400	positive	normal
F121	*Good quality agricultural products that meet customers' needs*	4.400	positive	normal
F122	*Farms' productivity per hectare*	4.500	positive	weak
F123	*Demand on seasonal/temporary workers*	5.000	very positive	normal
F124	*Production costs*	3.600	positive	strong
F131	*Risks related to unexpected functional limitations of the device*	3.750	positive	strong
F132	*Farmers' liability for damage to third party property caused by the device*	3.900	positive	normal
F133	*Risk of theft or damaging the device*	2.900	neutral	normal

Source: Authors' calculation on the base of WeLASER project data.

Looking at the Table 7, it can be observed that farmers positively evaluate the impact of the laser weed control system on *Economic consequences* (D12) and *Health and working conditions* (D11). The average ratings for these two factors are 4.375 and 4.35, respectively. In terms of *Risk to farming operations*, farmers rate the impact of LWCS as something between positive and neutral (3.52), with a slight indication in favor of positive (Table 7).

We may see that generally respondents from this perspective consistently evaluate the impact of the lunching LWCS on the market as positive. Two fields scored very positive: *Comfort of work* (4.6) and *Demand on seasonal/temporary workers* (5.0) and the strength of evaluation in both cases is normal. Out of 11 fields, 2 were evaluated as positive and strong, namely *Production costs* (3.6) and Ris*ks related to unexpected functional limitations of the device* (3.7). The only field scored neutral is *Risk of theft or*

damaging the device (2.9). Interestingly, *Farms' productivity per hectare*, which received a score of 4.5, meaning something between a positive and very positive impact, at the same time is rated in terms of evaluation strength as weak. This means that experts expect a strong positive impact of WeLASER on this field, but this it seems to be rather unimportant to them.

3.2.2. Business' Perspective on Impact of the LWCS Introduction on the Market

In the case of this perspective the score represents the average impact assessment based on the responses of 5 respondents on opinion on 12 fields divided into four domains (each domain contain 3 fields) (Table 8). Experts from Business perspective expect positive impact of the WeLASER on *Profitability* (score 4,03) and *Perspectives of business development* (score 3.93). On the other hand they expect negative impact on *Business risk* (2.0). Impact of WeLASER on the *Environmental performance of companies* is assessed as neutral (score 2.7).

Table 8. Business' perspective. Impact assessment and opinion evaluation strength.

Code	Domains (D) and fields (F)	Impact scores	Impact evaluation	Evaluation strength
D21	*Profitability (average)*	4.033	positive	normal
D22	*Business risks (average)*	2.000	negative	normal
D23	*Environmental performance of companies (average)*	2.700	neutral	normal
D34	*Perspectives of business development (average)*	3.933	positive	strong
F211	*Profits of companies producing the machines*	4.700	very positive	strong
F212	*Profits of agri-food and food processing industry*	3.500	neutral	weak
F213	*Profits of agricultural producers/farmers/producers groups*	3.900	positive	normal
F221	*Manufacturer's responsibility for product's malfunctions (complaints, service)*	1.800	negative	strong
F222	*Manufacturer's responsibility for the damage to the user or third party property caused by the device*	2.000	negative	normal
F223	*Manufacturer's risk for the supply chain interruption in manufacturing processes*	2.200	negative	normal
F231	*Demand on critical resources*	2.400	negative	normal
F232	*Manufacturer's responsibility for waste management of devices in its post-consumption phase*	2.800	neutral	normal
F233	*Production's pressure on the environment*	2.900	neutral	normal
F241	*Creation of new jobs*	3.800	positive	weak
F242	*New prospects for the companies development*	4.000	positive	strong
F243	*Strengthening competences of organizations, companies and workers*	4.000	positive	normal

Source: Authors' calculation on the base of WeLASER project data.

Analyzing the Table 8 we see that in Business' perspective, the only very positive impact of WeLASER is assessed for *Profits of companies producing the machines* (F211). The opinion for this field was evaluated as strong, which means that experts from business' perspective are strongly convinced that this field will be very positively impacted by WeLASER technology.

All fields of *Perspectives of business development* were assessed as being positively impacted. Out of them only impact assessment on *New prospects for the companies development* which scored 4.0 was evaluated by experts with strong conviction.

Also the experts of this perspective (P2) are strongly convinced that WeLASER will have negative impact on *Manufacturer's responsibility for product's malfunctions (complaints, service)*, it scored 1.8.

3.2.3. Society Perspective on Impact of the LWCS Introduction on the Market

In case of the society perspective the score represents the average impact assessment based on the responses of 5 experts on opinion on WeLASER impact on 9 fields divided into three domains (Table 9). Experts representing Society perspective expects positive impact of the laser weed control system on *Quality of life and environment, Demographic consequences* (scores 3.93 and 3.67 respectively) and neutral impact on *Just agriculture transformation* (3.47).

Table 9. Society perspective. Impact assessment and evaluation of opinion strength.

Code	Domains (D) and fields (F)	Impact scores	Impact evaluation	Evaluation strength
D31	*Quality of life and environment (averages)*	3.933	positive	strong
D32	*Demographic consequences (averages)*	3.667	positive	weak
D33	*Just agriculture transformation (averages)*	3.467	neutral	normal
F311	*Quality and safety of agricultural products*	4.000	positive	normal
F312	*State of the environment*	4.800	very positive	normal
F313	*Affordability of agricultural products for the society*	3.000	neutral	normal
F321	*Young people interest in running a farm*	3.800	positive	strong
F322	*Women's interest in working in agriculture*	4.000	positive	normal
F323	*The demand for low-skilled labour*	3.200	neutral	weak
F331	*The agrarian structure of agriculture*	3.200	neutral	weak
F332	*Development of ecological (organic) farms*	4.000	positive	strong
F333	*Economic diversification of rural areas*	3.200	neutral	normal

Source: Authors' calculation on the base of WeLASER project data.

In the Perspective P3 only impact of WeLASER on field *State of the environment* was assessed as very positive (score 4.8). There are no negative assessments within society perspective. We observe also strong experts' opinion on positive impact of WeLASER on *Young people interest in running a farm* and *Development of ecological (organic) farms*, which scored 3.8 and 4.0 respectively. It is worth to note that expert believe that WeLASER will have also positive impact on *Women's interest in working in agriculture* (score 4.0). Interestingly, the launch of the WeLASER, according to the experts' assessment, will have a neutral impact on *The demand for low-skilled labor*, (score 3.2) and at the same time, for the experts, the importance of this field is not very high.

3.3. Changes in Impact Assessment after Applying Experts' Preferences

3.3.1. Farmers' Perspective. New Impact Assessment after Application of Weights

The average score for the impact assessment of the laser weed control system for this perspective based on results for domains is 4.08. It means that from the farmers' perspective, the impact is rated as positive (Table 8).

In case of the perspective P1 application of calculated weights introduces no changes in respect to impact evaluation (compare Table 7 with Table 10). There are some changes in respect to obtained

impact scores. Score of *Health and working conditions* slightly decreased from 4.350 to 4.341, score of *Economic consequences* also slightly decreased, from 4.375 to 4.287 (drop by 1.8%), while score of *Risk for farms operations* increased from 3.517 to 3.522. Total score for this perspective calculated with application of two level of weights increased slightly from 4.08 to 4.10 (0.4%).

Table 10. Farmers' perspective. New impact assessment based on weighted means.

Code	Domains	Arithmetic mean	Weighted mean	New evaluation
D11	*Health and working conditions*	4.350	4.341	positive
D12	*Economic consequences*	4.375	4.287	positive
D13	*Risk for farms operations*	3.517	3.522	positive
P1	*Farmers perspective*	4.081	4.095	positive

Source: Authors' calculation on the base of WeLASER project data.

3.3.2. Business' perspective. New impact assessment after application of weights

The average rating for the impact of the laser weed control system for business perspective based on results for domains is 3.17. It means that from the business perspective, the impact is assessed as neutral (Table 11).

Table 11. Business' perspective. New impact assessment based on weighted means.

Code	Domains	Arithmetic mean	Weighted mean	New evaluation
D21	*Profitability*	4.033	4.231	positive
D22	*Business risks*	2.000	1.963	negative
D23	*Environmental performance of companies*	2.700	2.714	neutral
D34	*Perspectives of business development*	3.933	3.958	positive
P2	*Business' perspective*	3.167	3.413	neutral

Source: Authors' calculation on the base of WeLASER project data.

In case of the perspective P2 application of calculated weights introduces no changes in respect to impact evaluation (compare Table 8 with Table 11). Due to applied 2-level weights we observe increase value of impact assessment for whole Business perspective. The score rose by 0.246, which constitute 7.8% rise in comparison to initial value. We may observe changes in calculated means. Score of *Profitability* increased from 4.033 to 4.231 (circa 5% rise), score of *Environmental performance of companies* and *Perspectives of business development* also increased from 2.700 to 2.714 and from 3.933 to 3.958 respectively, while score of Business risks decreased from 2.000 to 1.963 (1.8%).

3.3.3. Society perspective. New impact assessment after application of weights

The average score of impact assessment of the laser weed control system for society perspective (P3) based on results for domains is 3.69. It means that from perspective P3, the impact is assessed as positive.

Analyzing the table above, we may observe that in all cases the weighted means are greater than arithmetic means. Introducing weights into the evaluation results in a slight change in the calculated domain impacts. Average change in score is 0.049, which constitute 1.4%. However, this was enough to change impact evaluation on *Just's agricultural transformation* from neutral to positive; the score rose from 3.467 to 3.553, exceeding the threshold for positive rating. The impact assessment for perspective P3 in terms of obtained scores slightly increased from 3.689 to 3.754, and in terms of impact assessment, the evaluation remained the same (Table 12).

Table 12. Society perspective. New impact assessment based on weighted means.

Code	Domains	Arithmetic mean	Weighted mean	New evaluation
D31	*Quality of life and environment*	3.933	3.947	positive
D32	*Demographic consequences*	3.667	3.715	positive
D33	*Just agriculture transformation*	3.467	3.553	positive
P3	*Society perspective*	3.689	3.754	positive

Source: Authors' calculation on the base of WeLASER project data.

4. Discussion and Conclusions

The results of S-LCA assessment for wide implementation of the LWCS in practice in Europe are in overall positive. It is in agreement with views showing benefits of Precision agriculture [29,31,48]. WeLASER technique has specific features related to laser application including risks, operational requirements, life cycle specifics, skills and competences.

When comparing the results of assessment of LWCS wide adoption in agriculture in the three perspectives the assessment in Farmer's perspective is the most positive. The least positive assessment was observed in the business perspective.

In farmers' perspective impacts in all analyzed sections were assessed positive. farmers positively evaluated the impact of the laser weed control system on in the category of Economic consequences and Health and working conditions. Regarding the Risk to farming operations, farmers rate the impact of LWCS as something between positive and neutral, with a slight indication in favor of being positive. It shows that potential risks can be manageable depending on specific farming conditions.

Experts very positively assessed especially the impact of the LWCS implementation on health conditions and safety of the farmer's work and to a lesser degree comfort of work. According to them, due to the elimination chemicals use, the impact on health will be very positive. However, it should be emphasized that according to literature the laser used in the technology may pose certain risks related to health. An important aspect is the replacement of human work by a robot, especially that which is performed by seasonal/temporary workers meaning that it can solve the problem of labor shortages. From farmers perspective production costs are expected to be impacted in a positive way. The experts evaluated the effect in a long time perspective expecting future decrease of the investment costs. It is also seen that LWCS application will not raise the risks related to unexpected functional limitations of agricultural machinery. Risk of theft or damaging the device is assessed as neutral.

In Society perspective there is expected positive impact of the laser weed control system on Quality of life and the domain Environment. In this section evaluation of LWCS' very positive impact is assigned to the State of the environment. In experts opinion in the long term, there will be significant improvement in environmental conditions in agriculture and biodiversity. Moreover, according to experts, the implementation of innovative weed control technology will improve the quality and safety of agricultural products due to the elimination of chemical residues in agricultural produce. Impact on Affordability of agricultural products for the society is viewed as neutral.

In the section Demographic consequences there is observed positive impact of LWCS on Young people interest in running farms and on Women's interest in working in agriculture. The LWCS will have a neutral effect on demand for low-skilled labor, meaning that it will neither simulate nor dissimulate demand for this type of labor. Considering this there will not be an essential unemployment effect due to the changes.

In the section Just agriculture transformation for the society, we may observe that introduction on the market of LWCS can also significantly contribute to the development of organic agriculture. Impact on the agrarian structure of agriculture and Economic diversification of rural areas is assessed

as neutral. It can be interpreted that use of this advanced technique will not favor large farms giving them essential competitive edge.

Overall score in the business perspective of the LWCS is regarded as having generally neutral impact on market of four analyzed sections.

In Business perspective there is expected positive impact of the LWCS wide introduction on the market in the section Profitability.

Impact on Profits of companies producing the machines was evaluated as being very strongly impacted in positive terms and evaluation of this opinion is strong. On the other hand it is believed that introduction of the laser weed control system will have negative impact on business risk and especially on risk pertaining Manufacturer's responsibility for product's malfunctions as well as responsibility for servicing of the machinery It was also viewed that farmers and agricultural producers will positively benefit from LWCS implementation.

The technology should bring profits to the LWCS producers and have a positive impact on the economy. Due to the introduction of the LWCS to the market, it is expected that new jobs will appear and an increase in the competences of employees involved in the production process, service, advisors, consulting companies, sales representatives and users was indicated.

Although, the impact of the device's production stage on the environment, according to experts, may be higher compared to the production of currently used mechanical cultivators, but in the overall assessment it is viewed as neutral. In addition, the demand for rare earth metals will increase. Experts are concerned about the potentially high investment cost of the device, which is why they indicated the need to provide financial support and consider the introduction of new business models.. Waste management for   manufacturers and pressure on environment were assessed as neutral but at the same time indicated as important factors of   business activities related to LWCS.

Evaluation of importance of selected factors by the experts allowed to weight and revise experts' impacts assessment. From farmers' perspective the most preferred factor influencing the wide implementation of WeLASER technology are economic consequences of which the most important are production costs related to implementation of new technology. According to experts representing business the perspective of business development with particular emphasis on new prospects for the companies and development is the most important factor. Quality of life and environment is the most valuated in the society' perspective.

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