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Introducing the Occupational Health and Safety Potential Midpoint Impact Indicator in Social Life Cycle Assessment

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Abstract: Occupational health and safety (OSH) is crucial for sustainable development, recognized by corporations, the European Union, and Sustainable Development Goals. This study introduces a characterization model for OSH in the social life cycle assessment (S-LCA) to support the quantification of OHS along product supply chains and sustainable decision making. The characterization model aims to provide a practical approach for assessing OHS at the product level with actual working hours or recommends a secondary approach with monetary data, when working hours are unavailable, to calculate the Occupational Health and Safety Potential (OHSP). The developed model was tested in a theoretical case study on shirt production in Europe and globally. The case study shows that the European shirt value chain resulted in higher OHSP values than the global shirt values chain. In addition, the model shows which life cycle stages and organizations highly contributed to the OHSP results. In both approaches, the shirt production stage contributed highly. Differences in results emerged based on the calculation approach, underscoring the model's versatility, because increasing the complexity of calculating the CFs with monetary values will affect the results based on sectorial monetary output. Additionally, the study mentions benefits to the operationalization of social impact assessment and limitations when the developed characterized model is employed. Last, this study aids in offering a tool for organizations to meet the demands of the new Corporate Sustainability Reporting Directive by quantifying and publicizing OHS data.

Keywords: worker; accident; reference scale; impact pathway; type III; SLCA; S-LCA; IP S-LCIA

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1. Introduction

The significance of occupational health and safety (OSH) as a component of sustainable development has been widely recognized in recent years because it directly impacts the well-being of workers. Previous research [1] and European legislative acts [2] have highlighted and recognized the importance of OSH in promoting social sustainability. However, there is still a need for further investigation into the intricate relationship between OSH and product system modeling using social life cycle assessment (S-LCA). This study developed a characterization model and applied it to a case study to further develop S-LCA and align it with the quantitative approach of life cycle sustainability assessment [3].

Worker health has become more important than ever since the COVID-19 pandemic [1,4]. However, even before and during the pandemic [5], OHS was linked with several Sustainable Development Goals and their targets, such as Targets 3.9, 8.8, and 16.6, and their consequent Goals [6]. Additionally, the European Union (EU) has mandated that organizations manage OSH risks, and OSH statistics are used to measure the level of protection at the macro level. Recently, the EU took a step forward towards corporate sustainability reporting, introduced the Non-Financial Reporting Directive [7], and put in force the Corporate Sustainability Reporting Directive [2], where OHS aspects are communicated for the workers of reporting organizations and suppliers. Eurostat [8], EU OSH Agency [9], and European Foundation [10] publish OSH statistics, which include indicators for serious and fatal accidents at work, as well as occupational diseases and sickness absence.

Social Life Cycle Assessment (S-LCA) is a methodology developed by the United Nations to assess the social performance of products throughout their life cycle [11]. The importance of S-LCA lies in its ability to provide a comprehensive understanding of the social impacts of products, which can contribute to sustainable development [12]. Research has shown that S-LCA is a valuable tool for identifying social hotspots and guiding product design and policy development [12,13]. The S-LCA follows the standardized framework for environmental LCA [14]; however, in contrast to LCA, it follows both a qualitative and quantitative approach to assess social impacts. S-LCA can be classified into three types: Type I, Type II, and Type III. The Type I approach is known as the Reference Scale Assessment. This approach focuses on evaluating past or current social performance related to the social performances of organizational activities through the calculation of reference points. Most S-LCA studies have employed this approach due to the complexity of social issues [15]. In contrast, the Type II approach, also called Impact Pathway assessment, assesses the potential consequences of the product system [16]. A few S-LCA studies have employed Impact Pathway assessment, because identifying and tracking the consequences of activities along an impact pathway, akin to environmental LCA impact assessment, is a challenging task. Moreover, it is difficult to establish a connection between the activities of a product system or organization and the potential social impacts that result from them using causal models [17]. Finally, Neugebauer [18] introduced the Type III approach, where the social impact assessment follows a different path from that of Types I and II. This approach links socioeconomic pathways to macroeconomic social impacts.

In S-LCA studies, OHS belongs to the most considered stakeholder category [19] and is one of the most considered impact subcategories [20,21]. Recent S-LCA reviews about the agri-food [22], solid waste management [20], and biofuel [21] sectors found that most studies follow a mixed approach where quantitative and qualitative data are collected but organizations have difficulties in collecting OHS data [23]. Following the Type I approach results in selecting OHS indicators about (1) policy concerning health and safety; (2) general occupational safety measures; (3) preventive measures and emergency protocols for accidents and injuries; and (4) appropriate protective gear required, which are assessed with a 0–5 or 0–4 point index [24–26]. Alternatively, social databases are employed to quantify OHS with risk hours [27,28]. In contrast, a minority of S-LCA studies follow a more quantitative approach to present work-related injuries by sector or country, and/or effects on human health. For instance, Cooper et al. [29] used the accident rate per functional unit in their study to assess OHS, Iofrida et al. [30] highlighted the links between the amount of working hours and specific diseases, such as cardiovascular diseases, and Hofstetter and Norris [31] used sector-level data to compare the number of occupational injuries and illness in the steel and plastic sectors based on the sectorial monetary output. However, the limitation in the latter case regards volatile prices which may inflate the monetary outputs of sectors without affecting how the occupational time, the number of employees, or the physical output [32]. Therefore, S-LCA practitioners have assessed OHS with an index, used a social database to calculate OHS risk hours, or used an OHS indicator; however, no study has calculated OHS in a form that is clear and comparable with other product systems while accounting for working aspects that are crucial for OHS, such as time.

Despite the ongoing development of S-LCA, there is still a lack of the quantitative assessment of social impacts [17,33,34]. This study aims to contribute to the development of a quantitative social impact assessment model where time aspect is incorporated by exploring the opportunities associated with S-LCA implementation and lagging social indicators. This quantitative assessment can be classified as Type III because it couples socioeconomic pathways to the social impact of OHS. Therefore, the objective of this study is to provide a characterization model to assess the OHS of products and recommend databases where secondary data can be collected when primary data are unavailable. Finally, the developed characterization model was tested using a case study of shirt production.

2. Materials and Methods

2.1. Calculation of Occupational Health and Safety Midpoint Impact Subcategory

This study proposes a quantitative approach to calculate the occupational health and safety potential (OHSP) of products and services. Therefore, the impact model proposed follows the Type II approach, as defined in Introduction section, and includes the relevant factors of the final product and upstream products of the supply chain, which affect the OHSP. The possible linkages between the endpoint level and social Areas of Protection are beyond the scope of this study. In addition, databases consisting of secondary data for the OHS assessment are provided to guide practitioners in calculating national and sectorial OHS-related characterization factors (CF_{OHS}) and determining the OHSP for products/services along their life cycles. Last, an exemplary case study demonstrating the applicability of the developed characterization model is presented in Section 2.4.

2.2. Occupational Health and Safety Characterization

OHS is assessed using lagging and leading indicators. Leading indicators have predictive and qualitative natures. Examples of leading indicators include employee training completion rates, equipment inspection findings, and worker engagement in safety initiatives. In contrast, lagging indicators provide information about what has already occurred [35]. The objective of this study is to determine which product supply chain results in higher health and safety for workers, and does not provide information for steering and management purposes. Therefore, lagging indicators were used. Among lagging indicators, this study employs “Accidents at work” which is measured in hours lost because, since 2010, the lost worktime due to accidents is relatively stable in European countries (see Figures S1–S3). Thus, to determine the “Occupational Health and Safety”, the characterization model depends on two country/sector-specific parameters: (1) “Accidents at work by hours lost”, and (2) “Hours actually worked by the employees per year” or “Turnover or consumables cost” (expressed in EUR). It should be stressed that, to have a direct calculation and minimization of assumption in the characterization model, the preferred parameter is “Hours actually worked by the employees per year”, because the occurrence of an accidents is greatly affected by the amount of working time. For instance, in the extreme event of a working place with minimal safety equipment and policies, a negligible working time may result in a lower accidents rate than much safer working, where employees work an order of magnitude more. However, if data about “Hours actually worked by the employees per year” cannot be collected, then the practitioner is recommended to follow a secondary approach and use “Turnover” data.

To develop a characterization model, the characterization factors for these parameters need to be operationalized and included in a cause-and-effect relationship of the Type II approach. OHS aspects along a product’s life cycle (inventory data) will be converted into OHSP. Therefore, for each process of the product supply chain, the characterization factors are calculated according to a country’s and/or sector’s situation. The three identified parameters were operationalized as follows.

(1) **Accidents at work by hours lost**: Lost time due to accidents can be applied when accidents regard the respective situation in a certain country and sector. To determine OHSPs, this study mainly considered one source [36], which covers Europe-27 country situations, setting a basis for OHS characterization. The reasons for choosing this data source are described in more detail in Section 2.3.

(2) **Hours actually worked by employees per year**: To use the working time, actual working time needs to be considered because occupational accidents occur during paid or unpaid working hours. The potential data sources are presented in Section 2.3.

(3) **Turnover or consumables cost**: If working hours cannot be collected in the production lines of products, OHSPs will be determined by the purchase values of consumables.

However, in this case, the practitioner needs to collect purchase values per kg, L, or unit of consumable material and the actual purchased consumable material in kg, L, or unit to calculate total costs. The potential data sources are presented in Section 2.3.

Physical relationships are used to calculate the CFs in an environmental life cycle impact assessment (LCIA). However, such relationships are difficult to determine for social impacts. Nevertheless, by transferring an approach comparable to environmental LCIA to social LCIA with lagging indicators, relations between accidents occurring at work at the social life cycle inventory and the OHS of products at the midpoint level can be established. Therefore, Equations (1) and (2) present how OHSP and CFs are calculated when "Hours actually worked by the employees per year" or "Turnover or consumables cost" data are used. Equation (1a,1b) follow the "typical" characterization protocol of environmental LCIA as defined in ISO 14044 [14]: "Characterization models reflect the (social) mechanism by describing the relationship between the LCI results and category indicators". Equation (2a,2b) express the two proposed calculation procedures for determining the CF_{OHSF}. Information regarding the composition of the two equations is presented in the following lines:

$$OHSP_{n,a} = CF_{OHSP,n,a} \times WH_n \tag{1a}$$

$$OHSP_{n,b} = CF_{OHSP,n,b} \times Cost_n \tag{1b}$$

$$CF_{OHSP,n,b} = \frac{24 \times Accidents\ by\ days\ lost_n}{Hours\ actually\ worked\ by\ the\ employees\ per\ year} \tag{2a}$$

$$CF_{OHSP,n,a} = \frac{24 \times Accidents\ by\ days\ lost_n}{Turnover_n} \tag{2b}$$

where (a) and (b) represent different approaches for calculating the hours lost owing to accidents. (a) is the recommended approach based on hours worked by employees in a specific country and sector, but due to lack of data, an approach based on monetary flows in a specific country and sector can be followed as a secondary approach. $OHSP_{n,a\ or\ b}$ stands for Occupational Health and Safety Potential (expressed in hours), representing process n within a product's life cycle taking place at a defined location and sector. WH_n stands for the hours worked (expressed in hours) by a specific process n within a product's life cycle, occurring at a defined location and sector. $CF_{OHSP,n,a,\ or\ b}$ regards the characterization factor of a specific process n within a product's life cycle occurring at a defined location and sector, calculated based on worked hours within sector (a) or sector's turnover (b). Turnover or consumables cost (expressed in EUR 2020) is the total sales of a specific process n within a product's life cycle, occurring at a defined location and sector. Cost refers to the purchased costs (expressed in EUR) of a specific process n within a product's life cycle, occurring at a defined location and sector.

2.3. Databases for Calculating Occupational Health and Safety Potential

It is recommended that primary data are used to calculate the CFs on a process level. However, the collection of those data may be challenging, and data collection will occur for reference product systems. Therefore, the Eurostat database [37] is recommended to facilitate the practical implementation of the developed characterization model and enable a consistent calculation of OHSPs for different product life cycles and various locations. The Eurostat database provides reliable country- and sector-specific data that can be used for both primary and secondary approach in calculating CFs. The Eurostat database is viewed as the best secondary source of data regarding "Accidents at work by hours lost", "Hours actually worked by employees per year", and "Turnover". Alternatively, if the product system exists outside Europe or part of the supply chain is sourced outside Europe, then the practitioner is recommended to employ national datasets or global databases for employment and occupational accidents, such as ILOSTAT [38], EXIOBASE [39], and OECD [40].

2.4. Exemplary Case Study on Textiles

2.4.1. Goal and Scope Definition

The goal of the case study was to apply the developed characterization model to compare OHS. Therefore, a theoretical case study was developed for shirt production in Europe and globally. The functional unit was one shirt produced and distributed to retail stores. The designed product systems were gate-to-gate, and consisted of cotton production, shirt production, and shirt distribution to retail. Figure 1 shows the system boundaries of the theoretical shirt system adapted from [11].

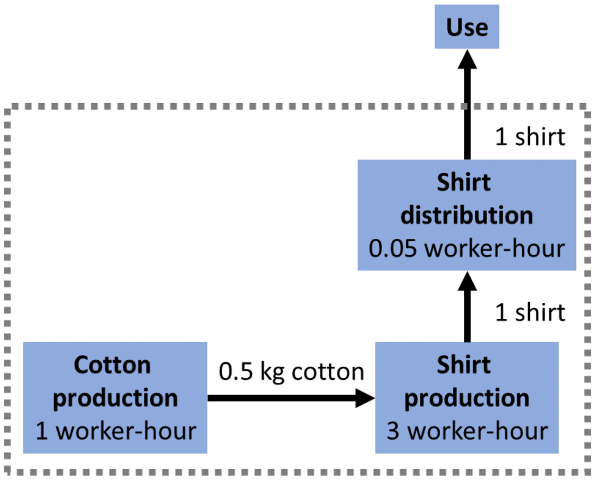

Figure 1. System boundaries with worker–hours of an exemplary case study, adapted from [11].

2.4.2. Inventory Analysis

Worker–hours data for the processes of the product system were collected from the S-LCA Guidelines [11] and EXIOBASE 3 database [39], and data on OHS, and employment indicators of sectors were collected from Eurostat [36,41,42] and national Input-Output Tables collected from the OECD database [40]. Table 1 presents the inventory data of both product systems, and Table 2 presents the calculated CFs based on Equations (1a) and (2a), where worked hours are used. The Supplementary Materials shows the CFs when costs are used instead of the working time.

Table 1. Inventory data of European and global shirt systems.

	Cotton Production	Shirt Production	Shirt Distribution
EU supply chain	Spain	Portugal	Portugal
Global supply chain	USA	Belgium	Belgium
Hours worked (h)	1	3	0.05
Quantity (kg or unit)	0.5	1	8.91667×10^{-8}

Table 2. Calculated characterization factors.

Locations	Cotton Production	Shirt Production	Shirt Distribution
		EU supply chain	
Spain	0.0011	-	-
Portugal	-	0.000189823	-
Portugal	-	-	0.00060508
		Global supply chain	
USA	0.00029	-	-
Belgium	-	0.000113364	-
Belgium	-	-	0.00053357

2.4.3. Assumptions

Eurostat does not collect data about the "Hours actually worked by the employees per year" for "Crop and animal production, hunting and related service activities" sector, and this is the relevant economic sector regarding cotton production process. Therefore, the working hours for crops were collected from the EXIOBASE database, where the working time is normalized to the production of one EUR of commodity. This value was multiplied by the total output in EUR of the agricultural sector in 2020.

2.4.4. Perturbation Analysis

Perturbation analysis was conducted to investigate the effect of parameter uncertainties on OHSP results. The perturbation analysis method [43] was applied which recommends calculating the sensitivity ratios to model parameter variations of +10%. For instance, if a parameter has a sensitivity ratio of 3, it implies that an increase by 10% of its value, will result in an increase in the final result by 30%. The sensitivity ratios were calculated for all input parameters using the equation below:

$$SR = \frac{\frac{\Delta_{result}}{initial\ result}}{\frac{\Delta_{parameter}}{initial\ parameter}} \tag{3}$$

3. Results

Figures 2 and 3 show that the European shirt (EU supply chain) results in approx. 2.5–7-times the OHSP score of the global shirt (global supply chain) with both approaches. When the working hours approach is used, the global shirt OHS score is 40% of that of the European shirt, and cotton production and shirt production processes are dominating the results of both systems. When the costs of the involved sectors are used, the global shirt OHS score is 15% of the score of the European shirt, and the EU shirt system is dominated by one process, i.e., shirt production in Spain. In contrast, the global shirt system is dominated by cotton and shirt production in USA and Belgium, respectively. Finally, the contribution of the shirt distribution is negligible for both systems and approaches.

Figure 2 shows that Spanish cotton production contributes highly to the OHSP of the European shirt, and USA cotton production and Belgian shirt production contribute highly to the global shirt industry. In contrast, Figure 3 shows that employing monetary flows to calculate the OHSP resulted in Portuguese shirt production contributing almost 100% to the OHSP of the European shirt, and USA cotton production and Belgian shirt production contributing highly to the global shirt industry, similarly to when working hours were used as activity variables.

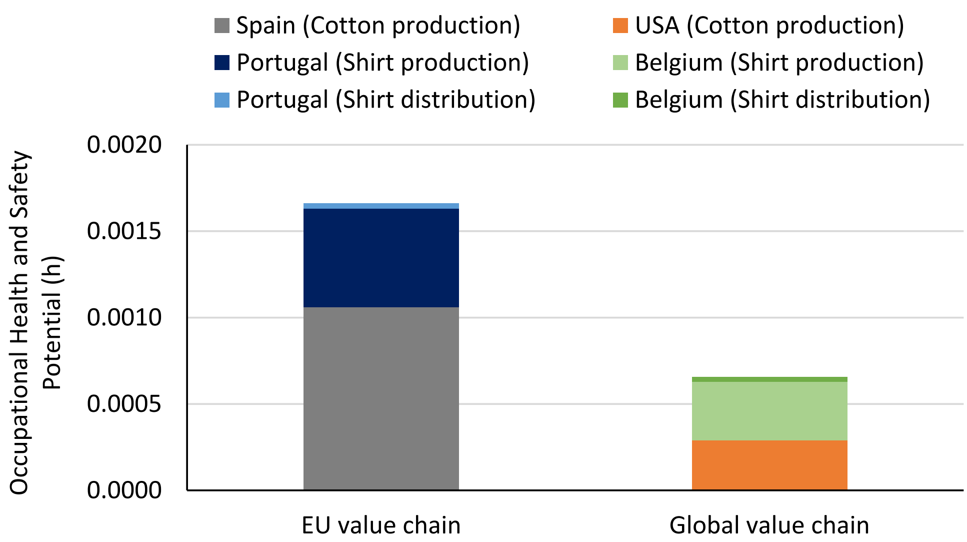

Figure 2. Occupational health and safety potential based on worked hours.

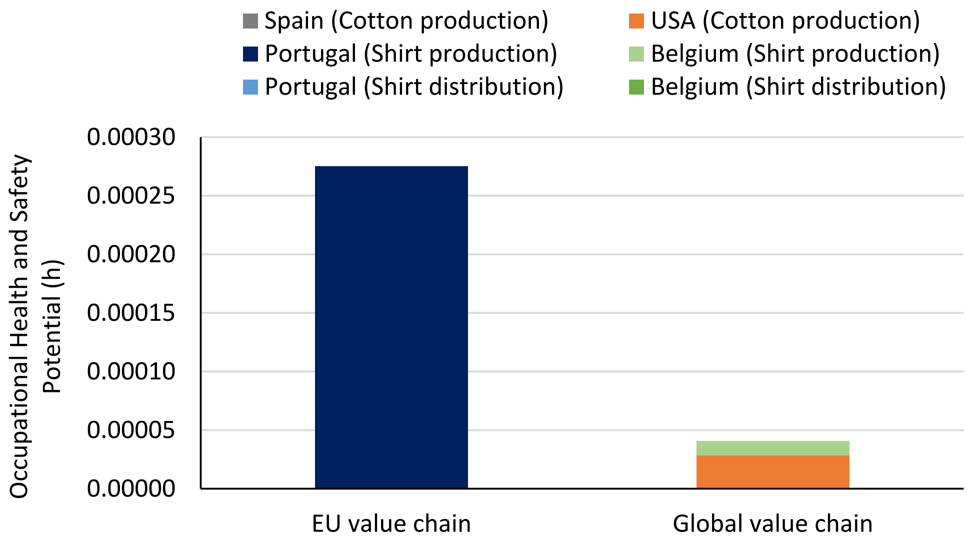

Figure 3. Occupational health and safety potential based on costs and worked hours.

The contribution analysis of the EU shirt system shows that when working hours are used to calculate CFs, Spanish cotton production, Portuguese shirt production, and Portuguese shirt distribution contribute approx. 63.9%, 34.3%, and 1.8%, respectively, to the OHSP. However, when the costs are used to calculate CFs, Spanish cotton production, Portuguese shirt production, and Portuguese shirt distribution contribute approx. 0.003%, 99.997%, and 0.0000003% to the OHSP, respectively. Additionally, the contribution analysis of the global shirt system shows that, when working hours are used to calculate CFs, USA cotton production, Belgian shirt production, and Belgian shirt distribution contribute approx. 44.1%, 51.8%, and 4.1% to the OHSP, respectively. When costs are used to calculate CFs, USA cotton production, Belgian shirt production, and Belgian shirt distribution contribute approx. 70.2%, 29.8%, and 0.000005%, respectively, to the OHSP.

4. Discussion

The purpose of the case study is to show that the developed characterization model can be applied in S-LCA studies as long as practitioners have data on working hours or costs per unit process. The primary approach that employs working hours results in the characterization model having a direct relation to the functional unit because longer working hours result in more occupational accidents. In contrast, the secondary approach results in the characterization model not correlating to the functional unit because higher costs can be associated with market trends and not necessarily with the employment of more hazardous materials or an extended working time.

The designed shirt systems consist of three processes, represented by three sectors. The cotton production process represented by the "Crop and animal production, hunting and related service activities" sectors (in Spain and the USA) had an order of magnitude higher lost worktime due to accidents than the road distribution process represented by the "Land transport and transport via pipelines" sector (in Portugal and Belgium), and two orders of magnitude higher than the shirt production process represented by the "Manufacture of wearing apparel" sector (in Portugal and Belgium). However, for shirt production and road distribution processes, the actual working time was an order of magnitude higher in Belgium than in Portugal. Therefore, the calculated CFs with the working time for both systems were higher for cotton production than for shirt production and distribution. In contrast, the use of costs and assumptions derived for calculating CFs for sectors (such as "Agriculture, forestry and fishing") that do not publish OHS indicators, resulted in a low calculated CF for cotton production (in Spain).

The CFs based on working time attribute absolute and relative impact to the "Cotton production" process equally or more than the secondary approach with CFs calculated with costs. This happens because using the working time to calculate CFs does not consider monetary sectorial output, which can greatly affect results, especially when prices surge due to unexpected events (such as wars or pandemics) and not due to national inflation. Furthermore, employing monetary sectorial outputs and purchasing costs result in greatly decreasing the absolute OHSP values of each process in the life cycle. In contrast, the relative contribution of "Cotton production" greatly diminishes when the secondary approach is used because its sectorial output is an order of magnitude larger than the sectorial output of the "Manufacture of wearing apparel" sector.

Furthermore, we find that employing the working time to calculate the OHSP results in the shirt distribution process affecting the results (even to a small extent) because distribution (on land) results in a considerable number of accidents per year. In contrast, calculating CFs based on cost values significantly reduced the contribution of the shirt distribution process to the OHSP due to the transportation of bulk quantities, which greatly reduced the cost per item.

Figures 4 and 5 show the results of perturbation analysis when all input parameters were increased by 10%. Perturbation analysis shows that employing the working time resulted in all processes contributing (even to a small extent) to the OHSP results for both shirt systems. In contrast, the perturbation analysis of calculated OHSP with monetary values resulted in distribution negligibly affecting the results for both systems, and the "Cotton production" process contributing negligibly in the case of the EU shirt system.

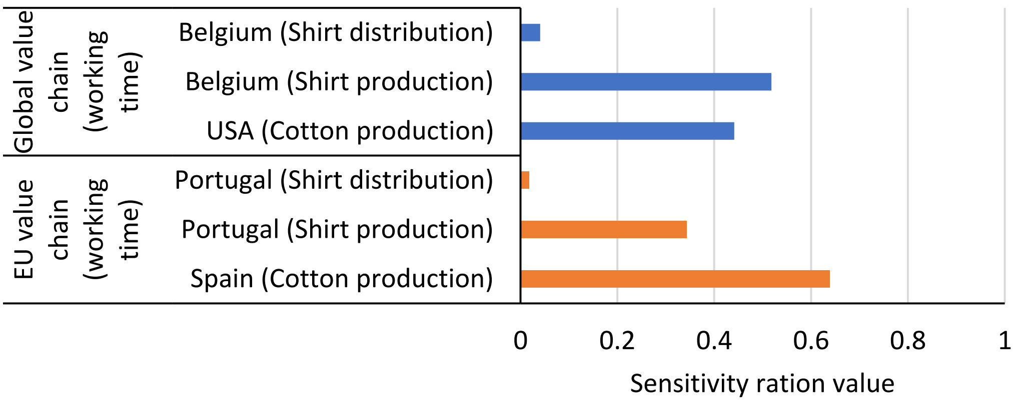

Figure 4. Perturbation analysis results based on the working time.

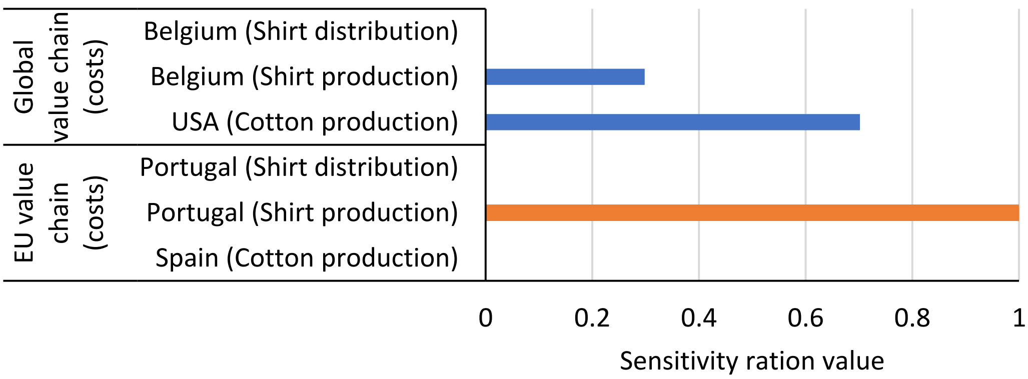

Figure 5. Perturbation analysis results based on cost values.

5. Benefits of the Developed Characterization Model

There are two main benefits of the developed characterization model: the potential exclusion of economic parameters that are directly linked with inventory data, and the omission of several assumptions of structural equation modeling that might not be met in practice. The former is apparent in social databases, such as the Social Hotspot Database [44] and the Product Social Impact Life Cycle Assessment database [45], which normalize process inventories to monetary outflows (prices). However, this approach by social databases inserts an error in the results when commodity prices increase to a greater extent than national inflation due to high demand. Additionally, structural equation modeling assumes linear path modeling, which may not be suitable for complex relationships [16]. Finally, the OSHP results calculated with the developed characterization model can be reported in corporate sustainability reporting, because they are understandable by everyone, and they are directly related to the functional units in S-LCA studies.

6. Limitations of the Developed Characterization Model

The main limitations of the developed characterization model are the use of lagging indicators and national economic sector-level data. Lagging indicators represent the past, which means that the calculated results represent the product system at the time when these indicators were calculated. However, Figures S1–S3 show that the lost time due to accidents has been relatively constant by country and sector since 2010 and many European countries have strict regulations which result in uniformity among companies within sectors [46]. Furthermore, the new Corporate Social Responsibility Directive [2], enforced in 2025, will provide OHS data at the company level in Europe. Therefore, the OHSP for European product supply chains will be calculated starting in 2026.

Additionally, OHS is more complicated than the calculated 'Accidents at work by hours lost', normalized with 'Hours actually worked by employees per year'. Biological, physical, and chemical agents can deteriorate the OHS of workers. Furthermore, the type of work, the equipment used, corporate policies, and emergency protocols affect OHS.

In addition, employing turnover to calculate CFs and OHSP results in processes (and consequently organizations) downstream the supply chain having a higher probability of higher CFs, unless there is a subsidy that keeps costs low, and consequently, turnover lower than without the subsidy. Similarly, the volatility of prices without being affected by inflation may result in increasing uncertainty and incomparability among organizations in the different countries of compared product systems. Therefore, this study recommends the use of working time when possible, with the provision of recommended databases.

7. Conclusions

There is still a lack of quantitative social impact models because it is challenging to develop causal links between processes and socioeconomic impacts. This study is the first to develop a characterization model to consistently determine the impact of OHS on a product's lifecycle. In addition, the calculated OHS results could be directly related to the functional units selected in future studies.

The characterization model uses, for calculating OHS, the working hours of processes or economic sectors because the longer the workers stay in the working environment, the higher the risk of an occupational accident to happen. Alternatively, if working hours are unavailable, the study recommends collecting monetary data from national Input-Output Tables and costs of consumables.

A theoretical case study was conducted to test the characterization model. The case study considered shirt production both globally and in Europe. The application of the developed characterization model shows which product system is better in terms of OHSP and what processes are the main contributors to OHSP. The midpoint subcategory OHS and the associated characterization model support the operationalization of social impact assessment and provide organizations with a practical approach to quantify OHS at the product level and generate public data requested by the new Corporate Sustainability Reporting Directive.

The updated Corporate Sustainability Reporting Directive will result in the production and publication of OHS data at the organizational level. Thus, we expect the developed model to support product comparison in a fair and clear manner and produce results that can be combined with environmental LCA and Life Cycle Costing to promote Life Cycle

Sustainability Assessment studies, and support the corporate and national reporting of Sustainable Development Goals 3 and 8.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16093844/s1, The supplementary material presents Figures about Calculated characterization factors when the secondary approach (based on costs) is employed and "Accidents at work by days lost and NACE" of "Crop and animal production, hunting and related service activities", "Manufacture of textiles", and "Land transport and transport via pipelines" sectors across Europe. Figure S1: "Accidents at work by days lost and NACE" of "Crop and animal production, hunting and related service activities" sector across Europe; Figure S2: "Accidents at work by days lost and NACE" of "Manufacture of textiles" sector across Europe; Figure S3: "Accidents at work by days lost and NACE" of "Land transport and transport via pipelines" sector across Europe; Table S1: Calculated characterization factors with the secondary approach (based on costs).

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