D4.8. Report on social LCA novIGRain

Report on social LCA novIGRain	
Lead beneficiary:	**United Experts**
Main authors:	**Egor Moshkin, Dries Vanlommel, Astrid Croes, Lies Bamelis**
Issued Date:	**31/12/2025**
Due date:	**31/12/2025**

Version	Date	Contributors	Reviewers
1	31/12/2025	Egor Moshkin (United Experts)	Anna Tass (Babolna), Frederic Verwilghen (MAXILINE)

Dissemination Level	
X	PU = Public
	PP = Restricted to other programme participants (including the EC)
	RE = Restricted to a group specified by the consortium (including the EC)
	CO = Confidential, only for members of the consortium (including the EC)

This project has received funding from the European Union's Horizon 2020 research and innovation programme, under grant agreement No 101000663.

Table of Contents

Table of Contents 2
1 Introduction 3
2 Methodology 3
3 NovIGRain Case Study 4
3.1 Goal and Scope 4
3.2 Assessment Scenarios 6
3.3 Life Cycle Inventory 8
3.4 Social Risk Assessment 9
3.5 Life Cycle Impact Assessment 9
4 Results and Discussion 10
4.1 Comparative Analysis 10
4.1.1 Workers 10
4.1.2 Local Community 12
4.1.3 Society 13
4.1.4 Value Chain Actors 14
4.2 Hotspot Analysis 15
4.2.1 France 15
4.2.2 Hungary 15
4.2.3 Germany 16
4.2.4 Supply Chain Hotspots 16
5 Sensitivity Analysis 17
5.1 Grain Loss Uncertainty 17
5.2 Transport Scenario Variability 19
5.3 Alternative Methograin IGR 30 ULV Dosage 20
6 Discussion and Conclusions 21
7 References 24
8 Appendix 25

1 Introduction

The European Union has prioritized the enhancement of grain storage capacity for cereals, oilseeds, and protein crops to improve food security and supply chain resilience. However, storage infrastructure alone cannot fully address the broader sustainability challenges in grain management. In addition to environmental and economic considerations, the social dimensions of grain storage practices, including labour conditions, human health impacts, and stakeholder well-being are increasingly recognized as critical to long-term viability.

Post-harvest grain losses, often caused by pest infestations and inadequate handling, have not only economic and environmental costs but also social consequences. These include occupational hazards for workers, community exposure to chemical treatments, and regulatory pressures affecting employment and business practices. Moreover, the gradual phase-out of several chemical pesticides under EU regulation has created demand for safer, socially responsible pest control alternatives.

The NovIGRain project addresses these challenges by advancing a novel, integrated approach to grain protection. It focuses on three major innovations:

- A novel insect growth regulator (IGR) larvicide based on S-methoprene (referred to as Methograin IGR 30 ULV) utilising the insect growth regulator S-methoprene, which targets early insect development stages;
- An ultra-low volume (ULV) application technology (further referred as application technology) that enables more precise and efficient treatment;
- A digital decision-support tool to guide the implementation of integrated storage protection strategies across various operational contexts.

This deliverable focuses on a social Life Cycle Assessment (sLCA) of the NovIGRain innovations, particularly Methograin IGR 30 ULV and its application technology. The analysis includes direct input from product developers and partners involved in the production processes, providing insights into upstream social impacts. By evaluating these technologies across multiple countries and storage operation levels, this report supports a more holistic understanding of their potential social implications.

By including this assessment as part of the NovIGRain project, the report contributes to a sustainable by design development process. It helps ensure that social aspects of sustainability, often overlooked in new product development, are addressed from the start. The findings aim to support more informed and responsible decisions around the design, deployment, and broader adoption of grain protection technologies that are not only effective and safe but also socially responsible.

2 Methodology

This social Life Cycle Assessment (sLCA) was carried out using the PSILCA (Product Social Impact Life Cycle Assessment) database developed by GreenDelta GmbH within the openLCA software platform, an open-source tool. The version of PSILCA used in this study is v3.1.1, which is built on the Eora 2019 multiregional input–output (MRIO) database (Loubert et al., 2023). Eora 2019 includes global supply chain data covering approximately 15,000 economic sectors across 189 countries.

PSILCA provides social risk data across 74 indicators, grouped into 20 social subcategories aligned with the stakeholder categories proposed in the UNEP/SETAC Guidelines (UNEP/SETAC, 2009). These indicators are categorized according to their relevance to four stakeholder groups: Workers, Local Communities, Society, and Value Chain Actors (Maister et al., 2020).

Each indicator in the database is assigned a risk or opportunity level, ranging from "no risk" to "very high risk" for potential negative impacts, or from "no opportunity" to "high opportunity" for the few indicators reflecting positive outcomes, such as economic development contributions. These risk levels are based on a set of standardized criteria documented in the PSILCA v3.1.1 Manual (Maister et al., 2020).

A key feature of the PSILCA method is the use of activity variables, specifically worker hours, to quantify social impacts throughout the life cycle of a product or process. This approach follows the concept introduced by (Norris, 2006), where worker hours linked to a process are used to scale social risks. While this method is well-suited for indicators related to workers, it may be less accurate for other stakeholder categories, such as communities or society, where social risks are not always directly tied to labour inputs.

The assessment in this report was conducted using this framework, with data inputs based on the specific supply chains of Methograin IGR 30 ULV and the application technology as used in France, Germany, and Hungary, across Port, Trader, and Farm storage levels.

3 NovIGRain Case Study

3.1 Goal and Scope

The main objective of this report is to carry out a social Life Cycle Assessment (sLCA) of the NovIGRain innovations, specifically Methograin IGR 30 ULV and its application technology, across three EU countries: France, Germany, and Hungary, and at three levels of grain storage operation: Port, Trader, and Farm, as defined in (Croes & Bamelis, 2021).

This assessment focuses on:

- Identifying and evaluating social impacts linked to the production and use of Methograin IGR 30 ULV and the application technology, such as working conditions, health and safety of operators, and possible effects on local communities
- Exploring how these social impacts vary depending on the country, storage scale and grain supply chain scenarios, highlighting region-specific risks or opportunities
- Estimating the level of grain loss reduction needed for these innovations to balance or outweigh the social impacts introduced during their production and use

To meet the objectives of this study and to assess the social risks and opportunities associated with the production and use of Methograin IGR 30 ULV and its application technology, the assessment encompasses all critical stages of the grain supply chain, including storage and transportation.

As the social impacts of the new insecticide and its application technology are inherently linked to grain, the functional unit is defined as **1 tonne of grain dispatched to final**

customer. This unit was chosen to capture the social implications of grain losses and the resulting need for additional production and transport to compensate for these losses.

The system boundaries and product system are summarised in Figure 1.

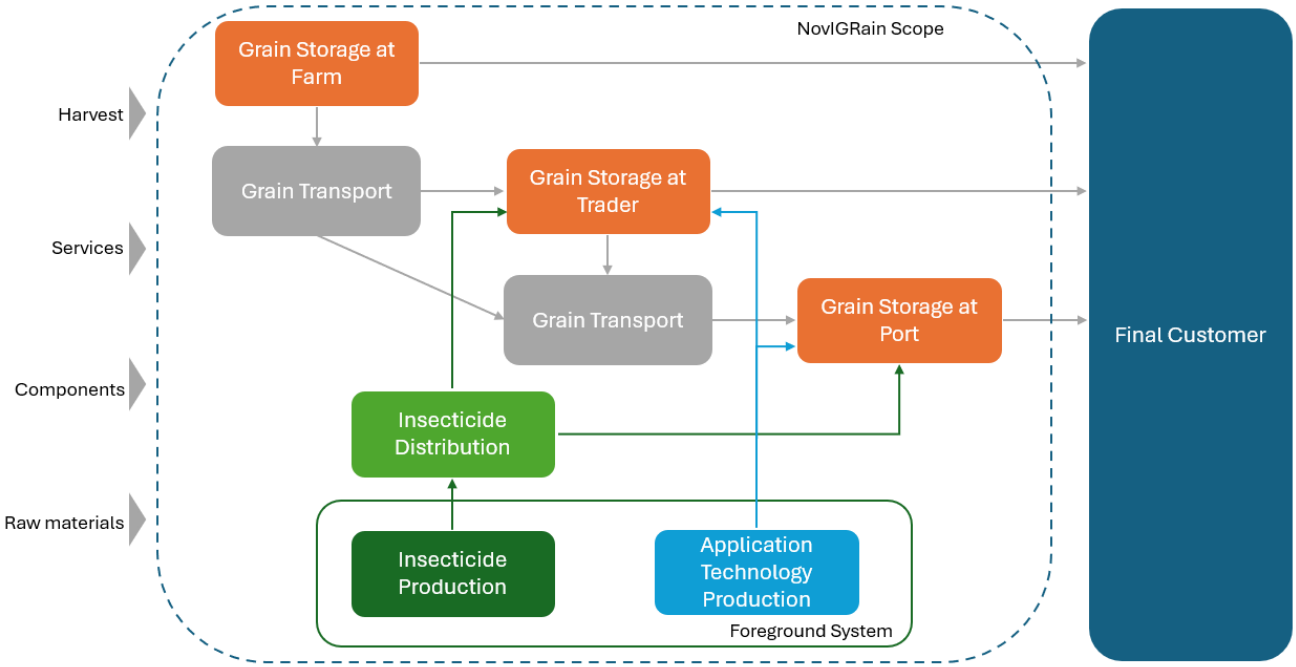


Figure 1. NovIGRain Grain Supply Chain System Boundaries

The system includes all essential processes involved in grain supply chain: grain storage at the farm, trader, and port, as well as grain transport between these stages. The system also accounts for alternative grain flows, including direct transport from the farm or trader to the final mode of transport, bypassing intermediate storage steps where applicable.

In addition, the production and distribution of the insecticide and the manufacture of the application technology are included as foreground processes with detailed data provided by producers of Methograin IGR 30 ULV and application technology, given their direct role in preventing grain losses as well as availability of the data within the consortium.

Elements outside the system boundary represent the background system, including upstream inputs such as raw materials, components, and services. These are shown in the diagram for illustration purposes only and are not exhaustive; however, all relevant background processes are included in the analysis.

The system boundary ends at the point where grain is dispatched via the final mode of transport, excluding downstream activities such as delivery to the final customer. Final delivery to the end customer is not included within the system boundaries of this study. This stage is excluded due to the high variability in how grain is distributed beyond the point of dispatch, including differences in transport modes, routes, and handling practices. In particular, international sea transport introduces additional complexity, with region-specific logistics chains and varying social conditions that cannot be consistently represented across scenarios. From a social LCA perspective, the lack of granular, context-specific data makes it infeasible to meaningfully assess the social impacts of this final stage within the scope of the current analysis.

3.2 Assessment Scenarios

To evaluate the social impacts of the NovIGRain innovations, three baseline scenarios were developed with one for each of the target countries: France, Germany, and Hungary. These scenarios reflect representative national conditions, operational practices, and storage configurations, and serve as the reference point for all subsequent comparisons within the social Life Cycle Assessment.

Each baseline scenario is defined by a set of parameters that describe how grain is handled, stored, treated, and transported within the supply chain, as well as how Methograin IGR 30 ULV and its application technology are used. These parameters cover three main aspects: (i) Methograin IGR 30 ULV use and treatment frequency, (ii) grain losses and flows, and (iii) transport modes, distances, and related costs. The parameters are summarised in table 1.

Table 1. Parameters for NovIGRain Scenarios

Category	Parameter	France	Hungary	Germany
Methograin IGR 30 ULV and Application Technology Use	Applied at farm	No	No	No
	Applied at port	Yes	Yes*	Yes
	Applied at trader	Yes	Yes	Yes
	Methograin dosage per 1 tonne of grain (ml)	40	40	40
	Methograin treatments per cycle**	1.16	1.08	1.16
Grain Losses	At farm (%)	5%	7%	5%
	At port (%)	1%	1%	1%
	At trader (%)	3%	3%	3%
Grain Flow Shares from Farm	Direct to final customer (%)	5%	5%	5%
	To port (%)	47.5%	0%	47.5%
	To trader (%)	27.5%	85%	27.5%
	To trader then port (%)	20%	10%	20%
Transport Mode Shares	Grain transported by truck (%)	95%	95%	95%
	Grain transported by rail (%)	47.5%	60%	95%
	Grain transported by water (%)	20%	10%	20%
Service & Transport Costs	Port handling cost (EUR/tonne)	3	3	3
	Trader handling cost (EUR/tonne)	15	15	15
	Rail transport cost (EUR/tonne/km)	0.04	0.04	0.04
	Truck transport cost (EUR/tonne/km)	0.04	0.04	0.04
	Water transport cost (EUR/tonne/km)	0.02	0.02	0.02
Transport Distances by Operator Country	Rail (km)	410 (French operator)	1200 (Hungarian operator), 600 (German operator)	590 (German operator)
	Truck (km)	190 (French operator)	445 (Hungarian operator), 60 (German operator)	115 (German operator)
	Water (km)	650 (French operator)	850 (Hungarian operator)	300 (German operator)
Insecticide Transport	Distance from production site (km)	1500 (Hungarian distributor)	150 (Hungarian distributor)	1200 (Hungarian distributor)

** German port*

*** Calculated from customer shares along each supply chain case adjusted for losses at trader and port.*

Grain is stored at farms, ports, and trader facilities in all cases, representing the complexity of a multi-level storage and accounting for the potential inputs needed to maintain quality and

manage logistics. Based on the feedback of the consortium as well as rare available reports such as (Vancrayenest et al., 2018), grain losses are assumed to be highest at the farm level with 5% assumed for French and German case and 7% for Hungarian due to lower level of scrutiny as pointed out in NovIGRain workshops. At the trader level, losses are assumed to be similar across all cases at around 3%, while ports are expected to have minimal losses of approximately 1%.

The flow of grain from farms also varies between countries: although a small share is delivered directly to final customers, most grain passes through traders and/or ports, depending on local market structures and supply chain configurations (Croes & Bamelis, 2021; Izinovations et al., 2024; Szilagyi et al., 2021). Since accurate data on grain losses is not available, this parameter will be tested in the sensitivity analysis.

Regarding transport modes, assumptions were made based on realistic routes used for grain transport in each scenario. Considering that 5% of the grain is assumed to be shipped directly from farm to customer this share is excluded from the analysis as grain delivered directly to the customer is out of scope of this analysis.

In all cases, trucks are used to some extent at least for the initial or final legs of delivery resulting in 95% of grain transported by trucks. Rail transport is also widely used, with 47.5% of grain transported by rail in the French scenario, compared to 60% in the Hungarian scenario and 95% in the German scenario. Based on consortium feedback, water transport is less commonly used, representing only 10–20% of total transport.

Rail and truck transport at €0.04/tonne/km, and water transport at €0.02/tonne/km, reflecting typical industry averages (CNR, 2021; Eurostat, 2025; IRG-rail, 2025). Transport distances vary according to the common scenarios how grain is traded in all three countries. The scenarios were developed using feedback from consortium members and information from (Szilagyi et al., 2021), which summarises the most commonly used transport modes and locations. The hypothetical routes used in the baseline scenarios are presented in Table 2. As with grain loss data, the variability of grain trade routes creates the uncertainty about the extent of the social effects caused by transport, therefore this parameter will also be tested in the sensitivity analysis.

Table 2. Summary of Baseline Grain Transport Routes

France

Route	Distances (km)	Grain Share Transported (%)
Farm (Beauvais) → Port (Rouen)	Truck: 140 / Barge: 0	47.5
Farm (Limoges) → Trader (Bordeaux)	Truck: 20 + 10 / Train: 210	27.5
Farm (Dijon) → Trader (Lyon) → Port (Rouen)	Truck: 20 / Train: 200 / Barge: 650	20

Germany

Route	Distances (km)	Grain Share Transported (%)
Farm (Brunswick) → Port (Hamburg)	Truck: 20 + 15 / Train: 160	47.5
Farm (Ulm) → Trader (Nuremberg)	Truck: 30 + 10 / Train: 150	27.5
Farm (Potsdam) → Trader (Berlin) → Port (Hamburg)	Truck: 40 / Train: 280 / Barge: 300	20

Hungary

Route	Distances (km)	Grain Share Transported (%)
Farm (Debrecen) → Trader (Budapest)	Truck: 230 / Train: 0	35
Farm (Debrecen) → Trader (Milan)	Truck: 15 + 10 / Train: 1,200	50
Farm (Debrecen) → Trader (Baja → Regensburg) → Port (Hamburg)	Truck: 200 + 50 / Barge: 850 / Train: 600	10

Finally, insecticide transport distances from production sites to distributors range from 150 km to 1,500 km, reflecting the potential supply chain for Methograin IGR 30 ULV given its production location in Hungary.

Together, these baseline scenarios provide a consistent and context-specific foundation for evaluating the social risks and potential benefits of NovIGRain innovations under varying operational conditions across the European grain supply chain.

3.3 Life Cycle Inventory

To model the Methograin IGR 30 ULV product system within PSILCA, all relevant inputs and outputs associated with each process in the foreground system were identified. For each material input, data on quantity, cost, and country of origin were collected. These inputs include, among others, raw materials for insecticide production, components for the application technology, and operational resources for grain storage and transport.

All cost data were converted to US dollars (USD) in accordance with the requirements of PSILCA v3.1.1, which is based on a 2015 USD baseline. The original cost values, reported in local currencies, were converted using the appropriate historical exchange rates.

Each input was then matched to the corresponding EORA sector in PSILCA to enable risk characterisation, as outlined in Table A2 in Appendix. Where specific matches were not available, the most representative sector based on input type and country was selected.

Primary data for foreground processes such as the production of Methograin IGR 30 ULV and its application technology, as well as application rates and energy use were obtained in full detail from the producers. It is important to note that the production process of Methograin IGR 30 ULV is considered commercially sensitive information. As such, the names and values of specific inputs and the detailed production steps have been redacted. In this report, the production process is presented in a summarised format, with the full version available upon request and at the discretion of the producer.

For other relevant processes within the system boundaries, information such as grain cost, storage costs, transport distances, and related parameters was sourced from a variety of references, as summarised in Table A2. These data points were verified with industry experts to ensure their accuracy and relevance.

To estimate worker hours associated with each activity in the foreground system, data were provided directly by the producers, based on their internal calculations. This approach ensured a precise allocation for assessing social risks across the selected indicators. For the background system, PSILCA's predefined worker hours per USD of output were used, based on the most representative industry sector for each corresponding process in the grain supply chain. The details are summarised in Table A2 in Appendix A.

3.4 Social Risk Assessment

The social risk assessment in this study was carried out using the PSILCA database (version 3.1.1), which includes a predefined set of up to 70 social indicators covering a broad range of impact categories and subcategories. These indicators form the core of the social Life Cycle Impact Assessment (sLCIA), providing risk levels for issues such as labour rights, health and safety, human rights, governance, and community well-being.

While PSILCA provides sector- and country-level risk characterisations for each indicator, these generalised values do not always reflect the specific conditions of a particular product or company. To address this limitation and improve the accuracy of the assessment, a two-step refinement process was applied.

First, a subset of eight indicators primarily those with a strong dependence on company-level practices, such as fair salary, health and safety, and working time regulations were assessed directly by the producer of the insecticide, based on internal company data and operational knowledge. This allowed for greater specificity in evaluating the social performance of the foreground processes most directly linked to the NovIGRain innovation.

Second, the remaining indicators were reviewed and validated using publicly available sectoral and national datasets, as well as relevant literature and expert feedback from the project consortium. This step was particularly important for indicators where national context or sectoral practices vary widely and could significantly influence the risk level (e.g., freedom of association, corruption, etc.).

This targeted risk assessment was applied exclusively to the foreground process of insecticide production, where company-specific data were available and meaningful differences from PSILCA's default values were expected. For all other parts of the system including storage, transport, and other upstream or downstream activities, PSILCA's default risk characterisations were used, as these processes fall within the background system. In the case of the application technology, no additional refinement was performed. Based on expert judgment and initial screening results, the expected social risk contribution of this component was very low, and further investigation was not considered proportionate or impactful in improving the robustness of the overall assessment. Table A1. in Appendix summarises the indicators used in the analysis along with the assigned level of risk and level of data.

3.5 Life Cycle Impact Assessment

The calculation of social risks and opportunities in this study was conducted using the Social Impacts Weighting Method implemented in PSILCA v3.1.1 within openLCA. This method expresses social risks in terms of medium risk hours, a unit that reflects the potential exposure of workers to social issues based on the average risk associated with generating 1 USD of output in a given sector (Maister et al., 2020).

Medium risk hours are calculated by scaling the risk level of each social indicator with the economic value of the inputs, the estimated worker hours per process, and the characterisation factors defined in PSILCA. These results are aggregated and reported by impact category as defined within the PSILCA framework.

4 Results and Discussion

The results of the social Life Cycle Assessment are presented in two main parts: a comparative analysis of the baseline scenarios for France, Germany, and Hungary, followed by a hotspot analysis identifying the most relevant processes and locations contributing to social risks.

The comparative analysis (Section 4.1) summarises the relative performance of each country scenario across four PSILCA impact categories: Workers, Local Community, Society, and Value Chain Actors. This breakdown follows the indicator groupings defined in PSILCA and enables the assessment to address risks at different societal levels. The results are expressed in medium risk hours per functional unit.

It is important to note that impact categories in sLCA cannot be compared directly with one another, as each is measured using different indicators and underlying units. To ensure comparability and provide contextual meaning, all results are normalised to a reference scenario: the country scenario with the highest impact in a given indicator is scaled to 100. The remaining country scenarios are then expressed relative to this maximum value. This scaling approach emphasizes differences between scenarios and avoids misinterpretation that could arise from presenting isolated figures, since single values do not provide sufficient context. For full details on each scenario refer to Table A3 in Appendix.

The hotspot analysis (Section 4.2) builds on these findings by exploring the country-specific contributions of individual processes within the grain supply chain. By focusing on France, Hungary, and Germany separately, this analysis highlights the sectors, stages, and supply chain actors where the greatest potential for social risk reduction exists. For more details refer to table A4-A6 in Appendix.

4.1 Comparative Analysis

4.1.1 Workers

The “Workers” category in PSILCA captures risks directly affecting employees in the grain supply chain and in the upstream production of Methograin IGR 30 ULV and its application technology. It includes a broad set of indicators covering labour rights, wages, health and safety, working conditions, and legal protections. The resulting relative scores “Workers” category are summarised in Figure 2.

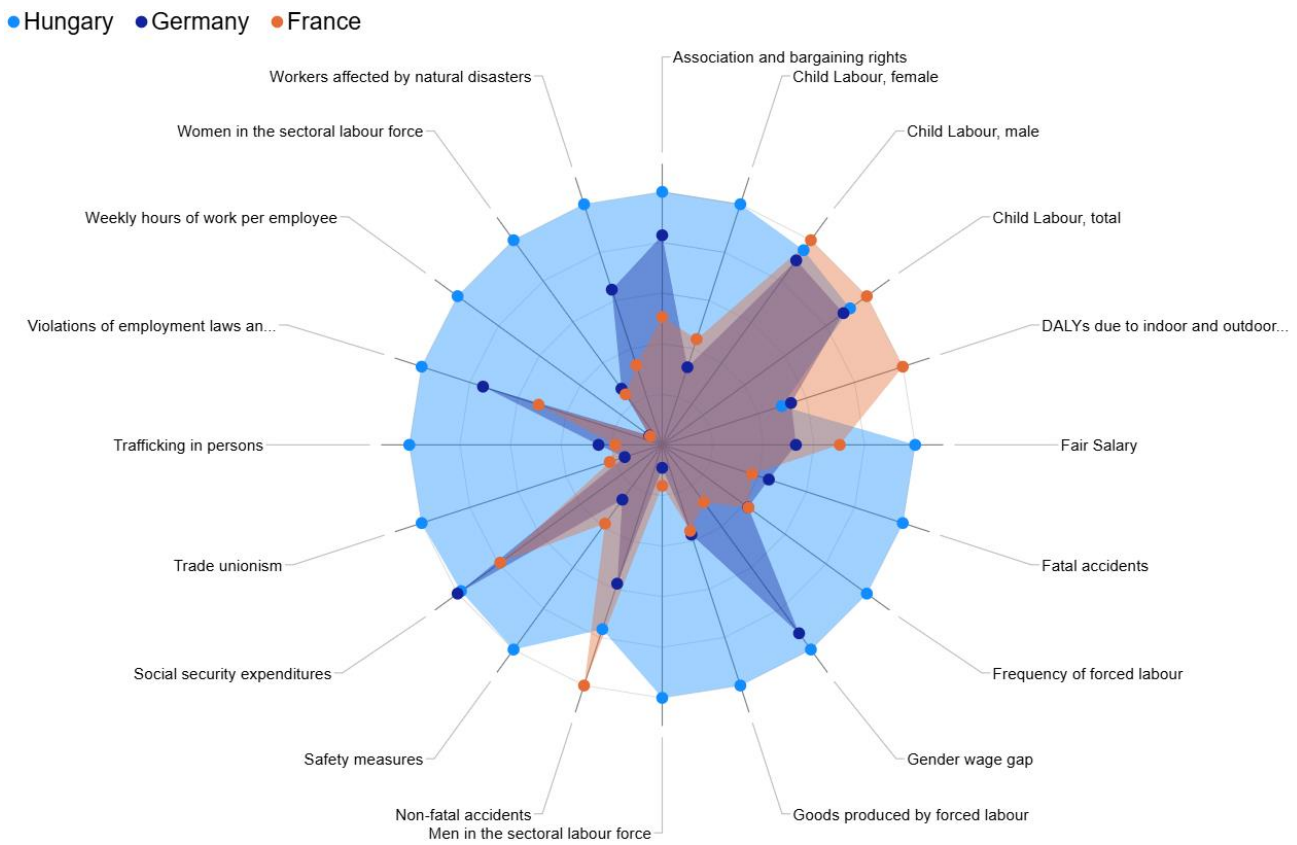


Figure 2. Results for Stakeholder Group of Workers

The results for the “Workers” stakeholder group show that the Hungarian case consistently demonstrates the highest risks, with most indicators at or close to 100%. French and German cases generally indicate more favourable results, though differences between the two are evident. For instance, risks of forced labour are notably lower in both France (42%) and Germany (42%) compared with Hungary (100%), and fatal accidents follow a similar pattern (37% in France, 44% in Germany, 100% in Hungary).

Several indicators highlight challenges specific to each country. French case demonstrates the highest relative risks for non-fatal accidents (100%, compared with 58% in Germany and 77% in Hungary) and child labour: total child labour is 100% in French case versus 88% in German and 91% in Hungarian, and female child labour is 43% in French case compared with 32% in German (Hungarian 100%). German case, on the other hand, records a much higher gender wage gap (92% versus 28% in France), but a better performance on fair salary (52% compared with 70% in France).

Other results show mixed outcomes. Workers affected by natural disasters are lower in France (33%) than in Germany (64%), while violations of employment laws are also more prevalent for German case (74%) compared with French (51%). In contrast, German case records lower risks than French case in some areas, such as safety measures (26% versus 38%) and child labour.

Overall, both French and German cases demonstrate lower risks for workers compared with Hungarian one, but neither is free of concern. French case performs worse on child labour and non-fatal accidents, while German case faces higher risks related to association and bargaining rights, violations of employment laws, and gender equality.

4.1.2 Local Community

Similarly to the stakeholder group of “Workers” the normalised results for the “Local Community” are summarised in Figure 3.

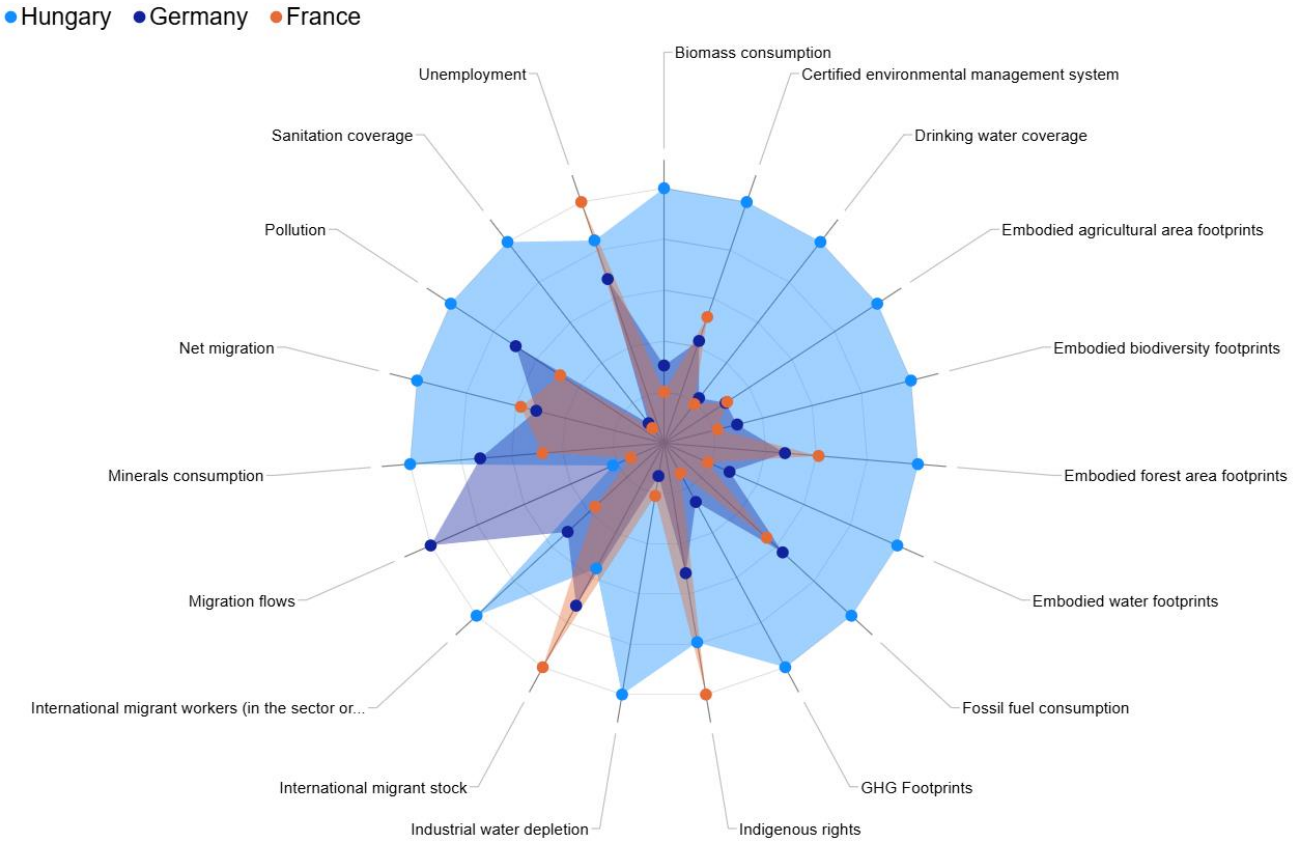


Figure 3. Results for Stakeholder Group of Local Community

The analysis of the “Local Community” stakeholder group shows that the Hungarian case generally faces the highest risks, with several indicators at or near 100%. This is especially apparent for industrial water depletion, drinking water and sanitation coverage as well as water and GHG footprints, where Hungarian case performed notably worse that French and German ones.

The French and German cases tend to perform better, though each exhibits specific areas of concern. For example, fossil fuel consumption is 54% in the French case and 63% in the German case, compared with 100% in the Hungarian case, while embodied forest area footprints are 60% and 47%, respectively.

Some indicators highlight contrasting challenges. The French case has elevated risks for unemployment (100%) and indigenous rights (100%), whereas the German case shows higher relative values for minerals consumption (72%), pollution (70%), and international migrant workers in the sector (51%). Migration flows are particularly pronounced in the German case (100%), while the French and Hungarian cases are considerably lower (14% and 22%).

Other differences are less pronounced: GHG footprints are lower in the French case (14%) than in the German case (26%), and access to drinking water and sanitation remains limited in both cases (19–22% and 7–10%, respectively). Overall, while the French and German

cases generally show lower risks than the Hungarian case, the data indicate that each has particular pressures that could affect local communities.

4.1.3 Society

Figure 4 summarises the results for “Society” stakeholder group.

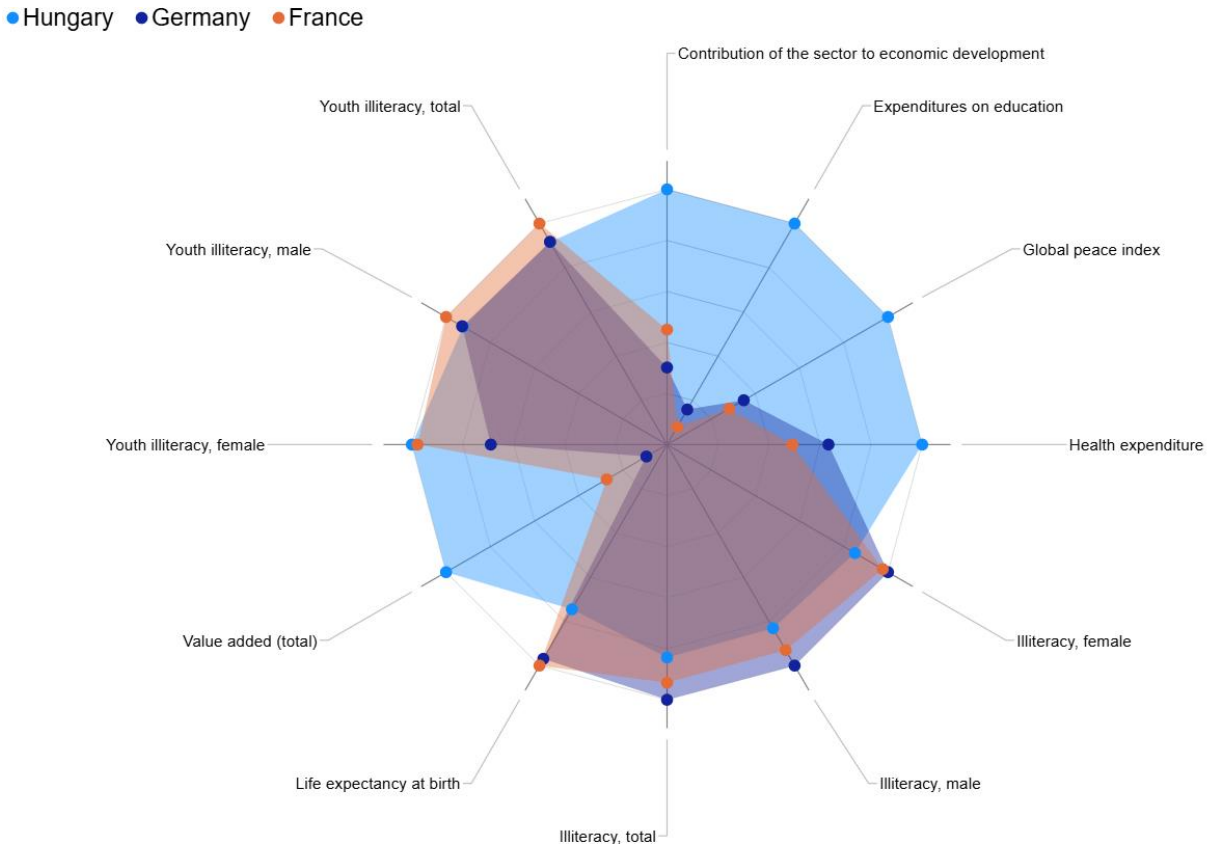


Figure 4. Results for Stakeholder Group of Society

In the “Society” stakeholder group, the Hungarian case again sets the reference point, with high relative risks across more indicators than for other scenarios. For instance, global peace index, expenditures on education and value added stand out the most in the negative way. The value-added indicator, which captures the risk of limited value creation in relation to one dollar of output, shows the Hungarian case with the highest risk (100%), while France (27%) and Germany (9%) present considerably lower values. Expenditures on education follow the same trend, with the Hungarian case again at 100% and France (8%) and Germany (16%) showing much smaller risks. The global peace index also indicates lower relative risks for the French (28%) and German (34%) cases compared with Hungary (100%).

However, notably for this stakeholder group both German and French cases feature across several indicators with the highest level of social effect. The French and German cases still appear more favourable in general, but the picture is uneven. Education and literacy indicators illustrate this clearly: youth illiteracy is at 100% in the French case, compared with 91-92% in German and Hungarian. For total illiteracy, the French case also reaches 93–97% across male and female categories, while German case indicates 100% and Hungarian case somewhat lower (83–85%). These results suggest that literacy is a relatively equal concern across the analysed cases.

Health and wellbeing show slightly different patterns. Life expectancy at birth has the highest risks in the French case (100%), followed closely by Germany (97%), but lower in Hungary (75%). At the same time in terms of health expenditures, Hungarian case has the largest social impact (100%), Germany intermediate (63%), and France lowest (49%).

Economic and societal contributions are more mixed. Across the analysed scenarios among the analysed social indicators “Contribution to economic development” stands out as the only indicator measuring positive social effect. Considering that largest positive impact was in Hungarian case (100%), lower in French (45%) and smallest in Germany (30%).

Overall, the results “Society” stakeholder group show that Hungary carries the highest risks for most indicators, although the French and German cases also face notable issues. Hungary performs best in the contribution to economic development, life expectancy at birth and illiteracy, while showing the greatest risks in areas such as education spending and value added. France is most affected by youth illiteracy and life expectancy, while Germany shows higher risks in total illiteracy and health expenditure.

4.1.4 Value Chain Actors

Figure 5 summarises the results for “Value Chain Actors” stakeholder group.

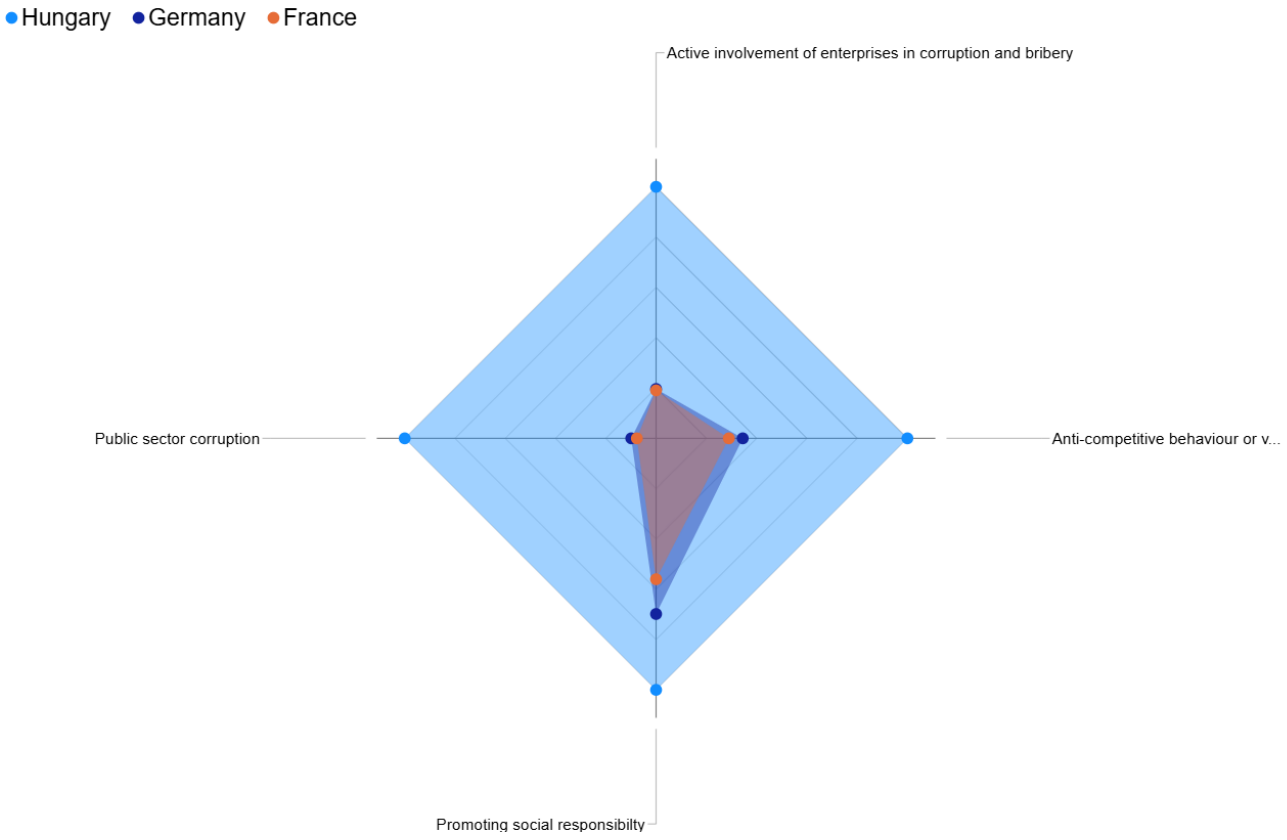


Figure 5. Results for Stakeholder Group of Value Chain Actors

The “Value Chain Actors” results show that the Hungarian case consistently carries the highest risks across all indicators. The French and German cases perform more favourably, with significantly smaller social effects. Risks of anti-competitive behaviour are considerably lower in France (29%) and Germany (34%) than in Hungary (100%), while active involvement in corruption and bribery is also reduced (19% in both cases compared with 100% in

Hungary). Public sector corruption is relatively minor in France (7%) and Germany (10%) yet remains a significant issue in Hungary (100%). For promoting social responsibility, France (56%) and Germany (69%) again show substantially lower risks than Hungary (100%).

4.2 Hotspot Analysis

To further analyse the social impacts, it is valuable to review the social hotspots on case-by-case basis to identify the regions responsible for the indicators with highest relative impact.

4.2.1 France

The data show that potential social risks in this case are mainly connected to agricultural supply chains. Indicators for child labour are particularly relevant, with higher contributions observed in Côte d'Ivoire, South Africa, and Cameroon. Since agriculture is identified as the sector with the greatest influence, these figures suggest that raw material sourcing from these regions may be associated with elevated risks of child labour within agricultural activities.

Health-related risks also appear linked to agricultural production, particularly in Côte d'Ivoire, Angola, and Cameroon, where the indicator for disability-adjusted life years (DALYs) due to air and water pollution is more pronounced. This highlights the possibility that agricultural processes contribute not only to labour-related impacts but also to broader community exposure to environmental stressors.

With regard to indigenous rights, the largest contribution is registered in France, with further notable levels in the United States, China, and Morocco. These values may be associated with land use and access to natural resources, where agricultural or industrial activities overlap with areas important to indigenous populations.

France also shows the highest values in relation to non-fatal accidents, primarily within the construction sector. Compared to other countries included in the dataset, this suggests that workplace safety in construction plays a relatively important role in the French context. Additionally, the indicator for international migrant stock is highest in France, pointing towards a significant presence of migrant workers in the labour force, which can be relevant when considering working conditions and integration.

4.2.2 Hungary

The Hungarian case shows the highest impacts across most indicators, with some areas performing notably worse than in the German and French cases. In particular, men in the sectoral labour force, weekly hours of work per employee, expenditures on education, sanitation coverage, and public sector corruption stand out as key hotspots.

Unlike the French case, where high impacts are largely linked to other countries in the supply chain, the Hungarian results are primarily driven by domestic industries. Nevertheless, external contributions are also visible, with Russia, China, India, and Slovakia appearing most frequently. These countries account for around 15–20% of the overall impact across the relevant indicators, showing that international supply chains still play a role, albeit a smaller one compared to domestic factors.

A closer look at the Hungarian industries highlights agricultural production and land transport as the sectors with the highest concentration of social impacts. These areas appear

consistently across multiple indicators, underlining their importance in shaping the overall risk profile of the Hungarian case.

4.2.3 Germany

The German case highlights several social risk indicators where impacts are more pronounced compared with the other cases examined. The two areas of greatest concern are migration flows and the gender wage gap, both of which show notably higher contributions in Germany.

Migration flows are by far the most significant, with Germany recording the highest value overall. Within this indicator, agriculture and hunting, wholesale trade, rail transport, and business services are among the sectors most strongly represented. This suggests that migration-related risks are closely tied to these areas of economic activity, shaping the country's overall profile.

The gender wage gap is another key hotspot for Germany, where the contribution is not higher than in Hungary but still is notably larger than in France. The main sectors associated with this indicator are wholesale trade, agriculture, business services, transport, food manufacturing, and banking. While South Africa, Austria, and Japan also contribute to this indicator, their relative values are considerably smaller, confirming the structure of German sectors itself as the main driver.

In addition, risks relating to association and bargaining rights are visible in the supply chain but are primarily connected to China rather than Germany itself. This highlights the importance of international linkages in the German case, where domestic risks are reinforced by external contributions.

4.2.4 Supply Chain Hotspots

To better understand the social impact within the system, it is useful to examine how the social impact is distributed across the different stages of the supply chain. Figure 6 shows the contribution of each stage to the social impacts in the three cases analysed. The values represent the average contribution of each stage across all indicators. While the results vary by individual indicator, the overall pattern of impact distribution remains consistent. For this reason, the results are presented as average values.

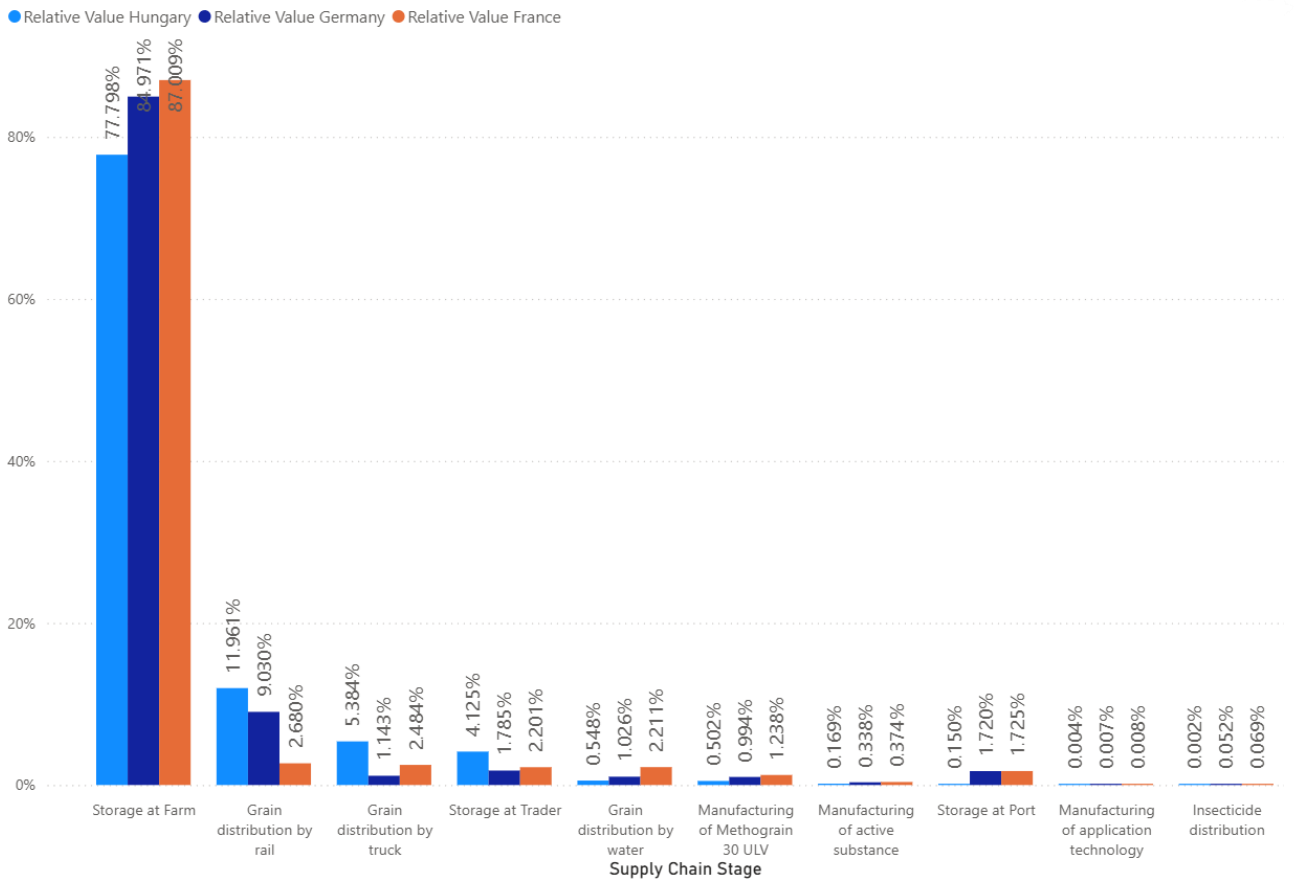


Figure 6. Average Contribution to Potential Social Impact by Supply Chain Stage

Since the stage 'Storage at Farm' also includes the impacts associated with grain production, the results highlight its dominant role in the supply chain. This stage contributes between 77% and 87% of the total social impact of the system. For individual indicators, its contribution ranges from 50% to 98%, but it consistently remains the leading contributor.

In the baseline transport scenarios, grain distribution by rail and truck also emerge as significant contributors. By contrast, the impact of the foreground system analysed in this study (namely the manufacturing of Methograin IGR 30 ULV and the active substance) is very small, averaging less than 1.7% of the total. The contribution of application technology is even lower, accounting for under 0.01% of the total system impact.

5 Sensitivity Analysis

5.1 Grain Loss Uncertainty

To assess the impact of changes in grain losses, the baseline input parameters can be adjusted. In this analysis, sensitivity testing will be carried out using discrete levels of change, ranging from major reductions to minor reductions, as well as minor increases to major increases in grain losses. Table 3 summarises the adjustment to the parameters.

Table 3. Scenario Adjustment for Sensitivity Analysis to Grain Losses

Parameter	Scenario	France	Hungary	Germany
Grain losses at farm (%)	Major Decrease	1%	2%	1%
	Minor Decrease	3%	5%	3%

	Baseline	5%	7%	5%
	Minor Increase	7%	10%	7%
	Major Increase	15%	20%	15%
Grain losses at port (%)	Major Decrease	0.1%	0.1%	0.1%
	Minor Decrease	0.7%	0.7%	0.7%
	Baseline	1%	1%	1%
	Minor Increase	1.5%	1.5%	1.5%
	Major Increase	3%	3%	3%
Grain losses at trader (%)	Major Decrease	1%	1%	1%
	Minor Decrease	2%	2%	2%
	Baseline	3%	3%	3%
	Minor Increase	4%	4%	4%
	Major Increase	5%	5%	5%

The resulting scenarios have been calculated across the same social indicators as the baseline scenarios for all analysed regions. To summarise the effect of the different scenarios results were calculated as potential social impact per 1 kg of grain. The impact is calculated as the average change across all social indicators to the baseline scenario. Table 4. summarises the results.

Table 4. Results of Sensitivity Analysis for Grain Losses

Baseline	Scenario	Needed Grain Production (kg)	Difference from Baseline (kg)	Average Impact Difference from Baseline	Impact per 1 kg	kg per 1% Impact
France	Major Decrease	1015	-54	-4.59%	0.0846%	12
	Minor Decrease	1042	-27	-2.30%	0.0842%	12
	Minor Increase	1098	+29	2.43%	0.0846%	12
	Major Increase	1208	+138	11.51%	0.0832%	12
Hungary	Major Decrease	1030	-76	-5.74%	0.0759%	13
	Minor Decrease	1073	-33	-2.53%	0.0767%	13
	Minor Increase	1152	+47	3.49%	0.0750%	13
	Major Increase	1303	+197	14.32%	0.0725%	14
Germany	Major Decrease	1015	-54	-4.47%	0.0823%	12
	Minor Decrease	1042	-27	-2.24%	0.0819%	12
	Minor Increase	1098	+29	2.37%	0.0823%	12
	Major Increase	1208	+138	11.17%	0.0807%	12

The results highlight that the impact associated with 1 kg of grain moving through the supply chain, including production, ranges from 0.0725% to 0.0846% across all analysed scenarios, which highlights a rather small difference across the scenarios. To express this in more meaningful terms, it is possible to calculate how many kilograms of grain must be saved to reduce the potential social impact (averaged across the 70 analysed indicators) throughout the entire supply chain. The findings suggest that, in the French and German cases, the saving of 12 kilograms of grain reduces the overall impact by 1%, while in the Hungarian case the equivalent figure is 13–14 kilograms.

5.2 Transport Scenario Variability

To illustrate the impact of transportation routes across the analysed scenarios, both shorter and longer route lengths were modelled. Reductions of 70% (major) and 20% (minor), as well as equivalent increases, were applied consistently across all transportation modes in the baseline scenarios. The resulting changes in potential social impacts are summarised in Table 5.

Table 5. Results of Sensitivity Analysis for Trasport Scenarios

Country	Scenario	% Distance Difference from Baseline	Change in km	Impact Difference from Baseline	Impact per 1% Distance Change	Impact Change per 100 km
France	Major Decrease	-70%	-875	-5.16%	0.0738%	0.5900%
	Minor Decrease	-20%	-250	-1.48%	0.0738%	0.5900%
	Minor Increase	+20%	+250	1.48%	0.0738%	0.5900%
	Major Increase	+70%	+875	5.16%	0.0738%	0.5900%
Hungary	Major Decrease	-70%	-2209	-12.46%	0.1780%	0.5641%
	Minor Decrease	-20%	-631	-3.56%	0.1779%	0.5638%
	Minor Increase	+20%	+631	3.56%	0.1779%	0.5638%
	Major Increase	+70%	+2209	12.45%	0.1778%	0.5636%
Germany	Major Decrease	-70%	-704	-7.76%	0.1109%	1.1037%
	Minor Decrease	-20%	-201	-2.22%	0.1109%	1.1030%
	Minor Increase	+20%	+201	2.22%	0.1109%	1.1030%
	Major Increase	+70%	+704	7.75%	0.1108%	1.1023%

The results suggest that an additional 100 km of transport has a similar effect in the French and Hungarian cases, increasing the average potential social impact by about 0.6% throughout the supply chain. In the German case, however, the relative effect is almost double, at around 1.1% per 100 km change.

It is important to note that these percentages represent the total potential social impact across the entire supply chain for each baseline scenario. Therefore, when comparing sensitivity analysis results across regions, the baseline values for each social indicator reported in Section 4.1 should also be taken into account.

5.3 Alternative Methograin IGR 30 ULV Dosage

Finally, to assess the potential social impact of Methograin IGR 30 ULV production, a sensitivity analysis was conducted on insecticide dosage. At the current stage of product development, the standard application rate is 40 ml of Methograin IGR 30 ULV per tonne of grain. To test system sensitivity, two additional scenarios were modelled across all regions: one with a dosage of 0 ml, effectively estimating the potential impact without Methograin IGR 30 ULV production or distribution, and another with 20 ml, simulating the effect of a half dose, which may still prove to have sufficient level of efficacy. Table 6 summarises the results.

Table 6. Results of Sensitivity Analysis for Application rate of Methograin IGR 30 ULV

Metric	France	Hungary	Germany
Average change (none → half dose)	0.87%	0.34%	0.70%
Average change (half → full dose)	0.86%	0.34%	0.69%
Average change (none → full dose)	1.75%	0.68%	1.41%

The results indicate clear regional differences in the potential social impact of Methograin IGR 30 ULV. France consistently shows the highest relative impact, followed by Germany, while Hungary records the lowest across all dosage scenarios.

Transitioning from no treatment to a full dose increases the average potential impact by around 1.75% in France, 1.41% in Germany, and 0.68% in Hungary. Halving the dose leads to Methograin IGR 30 ULV contributing to overall social impact approximately 0.87%, 0.70%, and 0.34% respectively.

It is important to note that while the average social impact figures appear relatively small, certain specific indicators showed a significantly larger change. In particular, indicators such as association and bargaining rights, mineral consumption, pollution, trafficking in persons, and violations of employment laws and regulations demonstrated increases in potential social impact ranging from approximately 4% to 10% for a full dose of Methograin IGR 30 ULV, depending on the scenario.

To place these results in context, the findings from Section 5.1 on grain losses and their associated potential social impacts can be applied. Based on these figures, it is possible to calculate the amount of grain that would need to be saved to offset the additional impact introduced by Methograin IGR 30 ULV production and distribution. Furthermore, these values can be expressed as a percentage of the total grain passing through the supply chain required to deliver one tonne to the final customer. The calculations are summarised in Table 7.

Table 7. Offset Methograin IGR 30 ULV Social Impact by Grain Loss Reduction

Metric	France	Hungary	Germany
Grain in total cycle (kg)	1069	1105	1069
Kg of grain causing 1% impact	12	14	12
Kg of grain saved to offset Methograin impact (half dose)	10.49	4.77	8.44

Kg of grain saved to offset Methograin impact (full dose)	20.99	9.54	16.88
% of grain relative to total cycle (half dose)	0.98%	0.43%	0.79%
% of grain relative to total cycle (full dose)	1.96%	0.86%	1.58%

For the full-dose scenario, the analysis shows the amount of grain that would need to be saved to offset the additional potential social impact of Methograin IGR 30 ULV. In France, this corresponds to 10.49 kg, in Hungary 4.77 kg, and in Germany 8.44 kg. Expressed relative to the total grain cycle, this represents between 0.43–0.98% of the grain.

For the half-dose scenario, the required grain savings increase, reflecting the higher potential social impact. The values rise to 20.99 kg in France, 9.54 kg in Hungary, and 16.88 kg in Germany, corresponding to approximately 0.86–1.96% of the grain.

It is notable that the required grain savings differ across regions, reflecting the relative contribution of Methograin IGR 30 ULV production and distribution in each scenario. In the Hungarian case, the overall impact of the background system (for example, grain production and distribution) is comparatively higher, which results in a lower amount of grain needing to be saved to offset the impact of the insecticide.

6 Discussion and Conclusions

This study performed a social life cycle assessment across three regions in Europe accounting for specificities of grain supply chain in each of the scenarios. Overall, the results highlight differences in social risks across France, Germany, and Hungary, with the Hungarian scenario consistently exhibiting the highest potential impacts across all stakeholder groups. Important to highlight that these differences are not exclusively due to worse social conditions of industries involved in the Hungarian case, but also due to the composition of the reference scenarios and the intensity of involvement of those industries (i.e. average value of grain produced, cost of transport). It is also worth noting that for the “contribution to economic development” (the only indicator measuring positive social impact), Hungary scores the highest.

Country-specific hotspots demonstrate that risks arise from domestic or international supply chain dependencies: France’s risks are strongly linked to agricultural sourcing in West Africa, Hungary’s are largely domestic, and Germany’s are influenced by migration flows and gender inequality, with some contributions from international partners.

Still, regardless the country the elevated risks are largely driven by agricultural production and transport, suggesting that interventions targeting these sectors could yield the most significant reductions in social impact. This is supported by the supply chain analysis that further reveals that the majority of social risks originate from upstream agricultural production, which accounts for 77–87% of total impacts. Transport stages contribute significantly as well, particularly in Hungary, while the direct impact of the foreground system, namely Methograin IGR 30 ULV and its application technology production, remains relatively small.

This is particularly important in the context of applying the findings from this study. As the majority of the potential social impact is only indirectly linked to the innovations developed in NovIGRain, there are only limited opportunities to improve the system and generate positive social effects. Grain production and distribution remain the largest contributors to overall potential social impact, meaning that reducing losses should be the primary goal of the

industry. Minimising losses ensures that less grain is required to meet demand, thereby limiting social effects across the supply chain.

This study demonstrates the relationship between the potential social impact of grain production and distribution and that of Methograin IGR 30 ULV production and distribution, thereby outlining efficacy targets to maintain a socially neutral status for the innovations. The results suggest that to offset the application and distribution of a full dose of Methograin IGR 30 ULV, grain losses throughout the supply chain would need to be reduced by approximately 0.86–1.96%; for a half dose, reductions of 0.43–0.98% are required with lower end values representing the situation for grain originating from Hungary and higher values for the grain originating from France.

It should also be noted that with the emerging challenges of resistance to conventional grain protection methods, these targets indicate not only the reductions in grain losses needed but also the extent to which Methograin IGR 30 ULV must mitigate potential increases in losses in the coming years.

For social indicators with above average potential impacts, such as association and bargaining rights, mineral consumption, pollution, trafficking in persons and violations of employment laws and regulations, the heightened risk largely stems from sourcing a chemical material from China, which is used in the final production stage of Methograin IGR 30 ULV. Approximately 95% of the increase in potential social impact can be attributed to this factor. If this material input is replaced with input from other locations that demonstrate higher social performance across these indicators, the grain loss reduction target mentioned above could be further reduced by 30-40%.

Another area with potential to positively influence the overall social impact of the supply chain is the length and mode of transport. As shown in the results, reducing transport routes by 100 km lowers the potential social impact by 0.6–1.2% across the system, which is equivalent to saving an additional 7–14 kg of grain. However, unlike the efficacy targets outlined for Methograin IGR 30 ULV, it is unlikely that grain distribution routes can be managed with such flexibility. Unless more reliable grain storage facilities become available at farm level thus reducing the need to centralise the storage of grain, these potential gains will be difficult to realise.

Important to highlight that this study has a number of limitations which should be taken into account when considering the results. Firstly, this study does not account for the potential social effects caused by currently used grain protection methods such as fumigants or liquid insecticides. To perform an sLCA a detailed production data is needed which is not possible to obtain with the capabilities of the project. This means that the required grain saving to offset the usage of Methograin IGR 30 ULV will be smaller or potentially even negative (i.e. net positive social effect) if the other grain protection methods will be substituted by Methograin IGR 30 ULV. Future studies focusing on the comparisons of the social effects of Methograin IGR 30 ULV and other grain protection methods could be of great interest to the industry, however given the potential conflict of interests among the producers the data needed for such comparison is likely to be very difficult to obtain.

Another important consideration is the general limitations of LCA due to the data quality and compromises in translating specific inputs in the production process for both Methograin IGR

30 ULV an application technology to the industries available in PSILCA, therefore when comparing the results with other potential future studies on the topic, the setup of the current study summarised in methodology part as well as appendices should be carefully reviewed.

These considerations emphasise that while this study provides an overview of the potential social risks associated with the grain supply chain and the introduction of Methograin IGR 30 ULV, the results should be interpreted in light of data and methodological limitations. Nonetheless, the analysis offers a useful basis for understanding where the most significant social improvements can be achieved.

Ultimately, the findings suggest that innovations such as Methograin IGR 30 ULV can play a supportive role in mitigating social impacts, provided they contribute to measurable reductions in grain losses and resource use.

7 References

ADEME. (2020). AGRIBALYSE®: French agricultural and food LCI database, version 3.0. *[Database]. Agence de La Transition Écologique (ADEME)*. https://agribalyse.ademe.fr

CNR. (2021). *EUROPEAN STUDIES - The Belgian road freight transport 2021 study*.

Croes, A., & Bamelis, L. (2021). *D4.1 Report on the reference scenarios and alternatives selected per region/type of storage system June 2021 novIGRain Reference Scenarios and Alternatives*.

Eurostat. (2025). *Railway freight transport statistics - Statistics Explained*. https://ec.europa.eu/eurostat/statisticsexplained/

IRG-rail. (2025). *13th Annual Market Monitoring Report March 2025*. https://www.irg-rail.eu/irg/about-irg-rail/general-information/About-the-IRG-Rail.html

Izinovations, Ergen, V., & Szilagyi, J. (2024). *D4.3. Market Study - Step 2 October 2024 novIGRain*.

Loubert, M., Maister, K., Noi, C. Di, Radwan, L., Ciroth, A., & Srocka, M. (2023). *The PSILCA database v3.1*. *March*, 0–131.

Maister, K., Di Noi, C., Ciroth, A., & Srocka, M. (2020). PSILCA v.3. *PSILCA Documentation*.

Norris, G. A. (2006). Social impacts in product life cycles: Towards life cycle attribute assessment. *International Journal of Life Cycle Assessment*, *11*(SPEC. ISS. 1), 97–104. https://doi.org/10.1065/lca2006.04.017

Szilagyi, J., Rametti, L., Parquet, O., & Banse, R. (2021). *D4.2. NovIGRain Market study H2020 – step 1*.

UNEP/SETAC. (2009). UNEP-SETAC: GUIDELINES FOR SLCA of Product. In *Environment*.

Vancrayenest, L., Frérot, É., & Crépon, K. (2018). *Technical and economic analysis of pest management practices for stored wheat in 14 grain elevators in France*. *October*.

8 Appendix

Appendix added as the attachment to this report is separated into public and confidential versions. The confidential version should be requested from Babolna Bio and SOJAM.

Appendices

Table A1. Risk Assessment

Category	Indicator	Subcategory Indicator	Unit	Confirmed Risk Level	Assessment Level
Workers	Child labour	Children in employment, female	% of female children ages 5-17	no risk	O
		Children in employment, male	% of male children ages 5-17	no risk	O
		Children in employment, total	% of all children ages 5-17	no risk	O
	Working time	Weekly hours of work per employee	hours	low risk	O
	Health and safety	DALYs due to indoor and outdoor air and water pollution	DALY rate per 1,000 inhabitants in the country per year	very low risk	C
		Presence of sufficient safety measures	OSHA cases per 100,000 employees in the time frame (4 years)	no data	C
		Rate of fatal accidents at workplace	cases per 100,000 employees and year	very low risk	O
		Rate of non-fatal accidents at workplace	cases per 100,000 employees and year	medium risk	O
		Violations of mandatory health and safety standards	ratio number of cases/available labour force in reference year	no data	O
		Workers affected by natural disasters	% of population affected in the time frame (3 years)	very low risk	C
	Forced labour	Trafficking in persons	Tier placement	high risk	C
		Goods produced by forced labour	Number of goods in the sector (score for technical conformance from data mapping)	no data	S
		Frequency of forced labour	Cases per 1,000 inhabitants in the country	very low risk	C
	Fair Salary	Living wage, per month (AV)	USD	high risk	C
		Minimum wage, per month	USD	medium risk	C
		Sector average wage, per month	Ratio salary (sector wage)/living wage	medium risk	S
	Discrimination	Gender wage gap	% difference male and female wages in reference year	medium risk	S
		Men in the sectoral labour force	ratio men (% economic active female population) / women+men (% economic active total population) in reference year	very low risk	S
		Women in the sectoral labour force	ratio women (% economic active male population) / women+men (% economic	low risk	S

This project has received funding from the European Union's Horizon 2020 research and innovation programme, under grant agreement No 101000663.

			active total population) in reference year		
	Social benefits, legal issues	Evidence of violations of laws and employment regulations	cases per 10,000 employees in the time frame (7 years)	no risk	O
		Social security expenditures	% of GDP	low risk	C
	Freedom of association	Right of association	4 point scale (0-3)	no risk	S
		Right of collective bargaining	4 point scale (0-3)	no risk	S
		Right to strike	4 point scale (0-3)	low risk	S
		Trade union density	% of employees organised in trade unions in reference year	very high risk	C
Local community	Local employment	Unemployment rate in the country	% of population ages 15-64 in reference year	low risk	C
	Safe and healthy living conditions	Drinking water coverage	% of population	very low risk	C
		Pollution level of the country	Pollution Index in reference year	medium risk	C
		Sanitation coverage	% of population	high risk	C
	GHG footprints	Embodied CO2 footprint	t/$	no risk	S
		Embodied CO2-eq footprint	t/$	no risk	S
	Environmental footprints	Embodied forest area footprint	ha/$	no risk	S
		Embodied agricultural area footprint	ha/$	no risk	S
		Number of threatened species	# species/$	no data	S
		Embodied water footprint	Mm3/$	low risk	S
	Migration	Emigration rate	% (of total population)	low risk	C
		Immigration rate	% (of total population)	very low risk	C
		International migrant stock	% of population, in reference year	low risk	C
		International migrant workers in the sector	% of total employed population in the sector in reference year Ratio x (Int. migrants in sector / Int. migrants in country)	no data	S
		Net migration rate	% (per 1,000 persons) in reference year	very low risk	C
		Number of asylum seekers in relation to total population	Ratio asylum seekers and total population, in the time frame (2 years)	low risk	C
	Respect of indigenous rights	Presence of indigenous population	yes/no	no risk	C
		Indigenous people rights protection index	6 point scale (0-5)	no data	C
	Access to material resources	Extraction of biomass (related to area)	Annual t/km²	medium risk	C
		Extraction of biomass (related to population)	Annual t/cap	medium risk	C

		Extraction of fossil fuels	Annual t/cap	very low risk	C
		Extraction of industrial and construction minerals	Annual t/cap	medium risk	C
		Extraction of ores	Annual t/cap	very low risk	C
		Certified environmental management systems	# of CEMS (ISO 14001) per 10,000 employees in the time frame (5 years)	high risk	S
		Level of industrial water use (related to renewable water resources)	% of total actual renewable water resources per year	medium risk	C
		Level of industrial water use (related to total withdrawal)	% of total water withdrawal per year	very high risk	C
Society	Health and safety	Global peace index	index	low risk	C
		Health expenditure, domestic general government	% of total health expenditure in reference year	low risk	C
		Health expenditure, out-of-pocket	% of total health expenditure in reference year	medium risk	C
		Health expenditure, total	% of GDP	medium risk	C
		Health expenditure, external resources	% of GDP	very low risk	C
		Life expectancy at birth	years	very low risk	C
	Contribution to economic development	Contribution of the sector to economic development	% of GDP	medium opportunity	S
		Illiteracy rate, female	% of female population 15+ years	very low risk	C
		Illiteracy rate, male	% of male population 15+ years	very low risk	C
		Illiteracy rate, total	% of total population 15+ years	very low risk	C
		Embodied value added total	$/$	very high risk	S
		Public expenditure on education	% of GDP	high risk	C
		Youth illiteracy rate, female	% of female population 15-24 years	low risk	C
		Youth illiteracy rate, male	% of male population 15-24 years	low risk	C
		Youth illiteracy rate, total	% of total population 15-24 years	low risk	C
Value chain actors	Promoting social responsibility	Membership in an initiative that promotes social responsibility along the supply chain	Number of companies in the sector	no data	S
	Fair competition	Presence of anti-competitive behaviour or violation of anti-trust and monopoly legislation	Cases per 10,000 employees in the time frame (5 years)	low risk	S
	Corruption	Public sector corruption	index score	very high risk	C

		Active involvement of enterprises in corruption and bribery	% of sector-related cases out of all registered foreign bribery cases in the time frame (15 years)	medium risk	S

Table A2. NovIGRain Social Life Cycle Inventory

Process	Input	France (USD)	Hungary (USD)	Germany (USD)	Country Provider	PSILCA Sector	Calculation	Details
Storage at Farm – 1 tonne of grain	Grain from French farms	278			France	Products of agriculture, hunting and related services - FR	Price per tonne x USD/EUR exchange rate	Market data for wheat/barley/maize in average proportions as traded in the corresponding country (based on (Croes & Bamelis, 2021; Szilagyi et al., 2021)+ (European Commission, 2025)
	Grain from Hungarian farms		281		Hungary	Products of agriculture, hunting and related services - HU		
	Grain from German farms			275	Germany	Agriculture and hunting - DE		
Storage at Trader – 1 tonne of grain	Electricity usage for ULV application at trader in France	0.78			France	Electrical energy, gas, steam and hot water - FR	Average Energy use for grain handling + (Energy demand of application technology/hour) × (Price/kWh) / 30 x USD/EUR exchange rate	Average energy use for grain handling (ADEME, 2020) Assuming 40 T/h grain flow, based on application technology producer data, corresponding country electricity price for industry (GlobalPetrolPrices, 2025)
	Electricity usage for handling grain at trader in Hungary		0.82		Hungary	Electrical energy, gas, steam and hot water - HU		
	Electricity usage for handling grain at trader in Germany			1.19	Germany	Electricity and district heat - DE		
	Trader activities in France	16.66			France	Wholesale trade and commission trade - FR	Price per tonne x USD/EUR exchange rate	Consortium feedback
	Trader activities in Hungary		16.66		Hungary	Wholesale trade and commission trade - HU		
	Trader activities in Germany			16.66	Germany	Wholesale Trade - DE		
Storage at Port – 1 tonne of grain	Electricity usage for handling grain at port in France	0.78			France	Electrical energy, gas, steam and hot water - FR	Average Energy use for grain handling + (Energy demand of application technology/hour) × (Price/kWh) / 60	Average energy use for grain handling (ADEME, 2020) Assuming 400 T/h average grain flow, based on application technology producer data, corresponding country electricity price for industry (GlobalPetrolPrices, 2025)
	Electricity usage for handling grain at port in Germany			1.19	Germany	Electricity and district heat - DE		
	Port Service in France	3.33			France	Water transport - FR	Price per tonne x USD/EUR exchange rate	Port handling tariffs are around 2-4 EUR per tonne based on consortium feedback. For analysis 3 EUR per tonne taken as average.
	Port Service in Germany			3.33	Germany	Shipping - DE		
Grain Distribution by Rail **– 1 tonne of grain**	Grain Transport by French Rail operators	18.21			France	Land transport; transport via pipelines - FR	Cost per tonne-distance × Distance defined by scenario x USD/EUR exchange rate	(Croes & Bamelis, 2021; Szilagyi et al., 2021), Consortium feedback, web resources (news and databases)
	Grain Transport by Hungarian Rail operators		53.31		Hungary	Land transport; transport via pipelines - HU		
	Grain Transport by German Rail operators		26.65	26.21	Germany	Rail transport - DE		
Grain Distribution by Truck **– 1 tonne of grain**	Grain Transport by French Truck operators	8.44			France	Land transport; transport via pipelines - FR		
	Grain Transport by Hungarian Truck operators		19.77		Hungary	Land transport; transport via pipelines - HU		
	Grain Transport by German Truck operators		2.67	5.11	Germany	Road and pipeline transport - DE		
Grain Distribution by Water – 1 tonne of grain	Grain Transport by French Barge operators	14.44			France	Water transport - FR	Cost per tonne-distance × Distance defined by scenario x USD/EUR exchange rate	(Croes & Bamelis, 2021; Szilagyi et al., 2021), Consortium feedback, web resources (news and databases)
	Grain Transport by Hungarian Barge operators		18.88		Hungary	Water transport - HU		
	Grain Transport by German Barge operators			6.66	Germany	Shipping - DE		

This project has received funding from the European Union's Horizon 2020 research and innovation programme, under grant agreement No 101000663.

Insecticide Distribution – 1ml of Methograin	Insecticide Delivery by Hungarian operator	0.0017	0.00017	0.0013	Hungary	Land transport; transport via pipelines - HU	Distribution cost per Liter per km x Distance transported / 1000 x USD/EUR exchange rate	Estimation based on web resources (news and databases)
Production of Active Substance – 1kg of active substance	Nitrogen Gas for packaging	XXX			Hungary	Chemicals, chemical products and man-made fibres - HU	Provided Data by Producer	-
	Materials 5, 7.1, 8, 11, 12, 17	XXX			Hungary	Chemicals, chemical products and man-made fibres - HU		
	Material 13	XXX			Italy	Chemicals, chemical products and man-made fibres - IT		
	Material 14.2	XXX			Netherlands	Chemicals, chemical products and man-made fibres - NL		
	Material 1	XXX			Poland	Chemicals, chemical products and man-made fibres - PL		
	Electricity	XXX			Hungary	Electrical energy, gas, steam and hot water - HU	Electricity demand per kg × cost of electricity	
	Gas	XXX			Hungary	Electrical energy, gas, steam and hot water - HU	Gas demand per kg × cost of gas	
	Materials 9, 15	XXX			India	Inorganic heavy chemicals - IN	Provided Data by Producer	
	Material 6.1	XXX			Venezuela	Manufacture of basic chemicals, except fertilizers and nitrogen compounds - VE		
	Material 3, 4, 7.2	XXX			Germany	Manufacture of chemical products - DE		
	Material 14.1	XXX			Spain	Manufacture of other chemical products - ES		
	Material 16	XXX			United States	Manufacture of other inorganic basic chemicals - US		
	Plastic barrel 1 piece (60 l)	XXX			Hungary	Manufacture of rubber and plastic products - HU		
	Material 18	XXX			Japan	Other industrial inorganic chemicals - JP		
	Material 2, 6.3	XXX			Saudi Arabia	Petroleum, Chemical and Non-Metallic Mineral Products - SA		
	Material 6.2	XXX			Trinidad and Tobago	Petroleum, Chemical and Non-Metallic Mineral Products - TT		
	Waste of solvent	XXX			Hungary	Sewage and refuse disposal, sanitation and similar activities - HU		
Production of Methograin – 1l of Methograin	Material 19	XXX			China	Chemical Fibres - CN		
	Input	XXX			Hungary	Coke, refined petroleum products and nuclear fuel - HU		
	Electricity	XXX			Hungary	Electrical energy, gas, steam and hot water - HU		
Production of Application Technology – 1 unit of application technology	Input 1	XXX			India	Electrical appliances - IN	Provided by Producer	
	Input 2	XXX			China	Electronic element and device - CN		
	Input 3	XXX			France	Machinery and equipment n.e.c. - FR		
	Input 4	XXX			Italy	Machinery and equipment n.e.c. - IT		

	Input 5	XXX	Germany	Machines - DE		
	Input 6	XXX	Czech Republic	Manufacture of electrical machinery and apparatus n.e.c. - CZ		
	Input 7	XXX	Italy	Manufacture of electrical machinery and apparatus n.e.c. - IT		
	Input 8	XXX	Morocco	Manufacture of electrical machinery and equipment - MA		
	Input 9	XXX	Tunisia	Manufacture of electrical machinery and equipment - TN		
	Input 10	XXX	Israel	Manufacture of electricity distribution and control apparatus - IL		
	Input 11	XXX	Israel	Manufacture of electronic components and of semi-conductors - IL		
	Input 12	XXX	United Kingdom	Manufacture of electronic valves and tubes and other electronic components - GB		
	Input 13	XXX	Germany	Manufacture of fabricated metal products - DE		
	Input 14	XXX	France	Manufacture of fabricated metal products, except machinery and equipment - FR		
	Input 15	XXX	Italy	Manufacture of fabricated metal products, except machinery and equipment - IT		
	Input 16	XXX	Poland	Manufacture of fabricated metal products, except machinery and equipment - PL		
	Input 17	XXX	Turkey	Manufacture of fabricated metal products, except machinery and equipment - TR		
	Input 18	XXX	Indonesia	Manufacture of general-purpose machinery - ID		
	Input 19	XXX	Japan	Manufacture of instruments for measuring, testing and navigating - JP		
	Input 20	XXX	Germany	Manufacture of paper and paper products - DE		
	Input 21	XXX	Spain	Metal Products - ES		
	Input 22	XXX	China	Other general industrial machinery - CN		

Table A3. Detailed Comparative Analysis

Stakeholder Group	Category	Impact category	Unit	France		Hungary		Germany	
				Absolute	Normalised	Absolute	Normalised	Absolute	Normalised
		Biomass consumption	BM med risk hours	92.57	20%	454.66	100%	139.43	31%

Local community	Access to material resources	Certified environmental management system	CMS med risk hours	124.97	53%	235.26	100%	101.10	43%
		Fossil fuel consumption	FF med risk hours	0.37	55%	0.68	100%	0.43	64%
		Industrial water depletion	WU med risk hours	775.34	21%	3680.78	100%	484.08	13%
		Minerals consumption	MC med risk hours	71.48	48%	149.15	100%	108.17	73%
	Environmental footprints	Embodied agricultural area footprints	EAF med risk hours	2.97	30%	10.03	100%	2.90	29%
		Embodied biodiversity footprints	EBF med risk hours	42.39	22%	194.33	100%	57.91	30%
		Embodied forest area footprints	EFA med risk hours	0.41	62%	0.67	100%	0.32	48%
		Embodied water footprints	EWF med risk hours	20.22	19%	107.90	100%	30.20	28%
	GHG Footprints	GHG Footprints	GHGF med risk hours	30.71	14%	226.07	100%	59.49	26%
	Local employment	Unemployment	U med risk hours	11.17	100%	9.35	84%	7.60	68%
	Migration	International migrant stock	IMS med risk hours	82.69	100%	45.73	55%	59.92	72%
		International migrant workers (in the sector or site)	IMW med risk hours	5.28	37%	14.24	100%	7.35	52%
		Migration flows	MF med risk hours	97.05	14%	144.61	21%	678.76	100%
		Net migration	NM med risk hours	0.65	59%	1.11	100%	0.57	52%
	Respect of indigenous rights	Indigenous rights	IR med risk hours	20.00	100%	15.74	79%	10.35	52%
	Safe and healthy living conditions	Drinking water coverage	DW med risk hours	104.66	20%	534.05	100%	120.53	23%
		Pollution	P med risk hours	84.99	49%	174.22	100%	121.43	70%
		Sanitation coverage	SC med risk hours	281.58	8%	3749.10	100%	372.18	10%
Society	Contribution to economic development	Contribution of the sector to economic development	CE med risk hours	29.78	45%	65.51	100%	19.93	30%
		Expenditures on education	EE med risk hours	30.13	8%	371.47	100%	59.04	16%
		Illiteracy, female	I med risk hours	101.95	98%	88.16	84%	104.35	100%
		Illiteracy, male	I med risk hours	87.76	93%	77.76	83%	94.22	100%
		Illiteracy, total	I med risk hours	88.80	93%	78.73	83%	95.00	100%
		Value added (total)	VAT med risk hours	489.36	27%	1790.74	100%	168.55	9%
		Youth illiteracy, female	YI med risk hours	7.39	99%	7.47	100%	5.19	69%
		Youth illiteracy, male	YI med risk hours	16.98	100%	15.52	91%	15.70	92%
		Youth illiteracy, total	YI med risk hours	17.62	100%	15.98	91%	16.12	91%
	Health and safety	Global peace index	GPI med risk hours	51.05	29%	179.06	100%	62.79	35%

		Health expenditure	HE med risk hours	114.07	50%	229.75	100%	146.33	64%
		Life expectancy at birth	LE med risk hours	11.99	100%	8.83	74%	11.56	96%
Value chain actors	Corruption	Active involvement of enterprises in corruption and bribery	AI med risk hours	33.72	19%	174.74	100%	34.84	20%
		Public sector corruption	C med risk hours	288.30	8%	3747.59	100%	371.23	10%
	Fair competition	Anti-competitive behaviour or violation of anti-trust and monopoly legislation	AC med risk hours	28.79	29%	98.49	100%	34.31	35%
	Promoting social responsibilty	Promoting social responsibilty	PSR med risk hours	173.49	57%	306.16	100%	214.46	70%
Workers	Child labour	Child Labour, female	CL med risk hours	0.80	45%	1.79	100%	0.59	33%
		Child Labour, male	CL med risk hours	1.54	100%	1.46	94%	1.39	90%
		Child Labour, total	CL med risk hours	1.42	100%	1.29	91%	1.26	88%
	Discrimination	Gender wage gap	GW med risk hours	23.96	28%	84.76	100%	78.30	92%
		Men in the sectoral labour force	M med risk hours	0.76	16%	4.66	100%	0.42	9%
		Women in the sectoral labour force	W med risk hours	18.50	25%	74.48	100%	20.46	27%
	Fair salary	Fair Salary	FS med risk hours	883.33	71%	1252.24	100%	664.30	53%
	Forced labour	Frequency of forced labour	FL med risk hours	0.32	43%	0.76	100%	0.32	42%
		Goods produced by forced labour	GFL med risk hours	1.86	36%	5.17	100%	1.94	37%
		Trafficking in persons	TP med risk hours	107.48	19%	577.20	100%	145.12	25%
	Freedom of association and collective bargaining	Association and bargaining rights	ACB med risk hours	64.46	51%	127.42	100%	105.91	83%
		Trade unionism	TU med risk hours	780.06	22%	3565.05	100%	558.04	16%
	Health and safety	DALYs due to indoor and outdoor air and water pollution	DALY med risk hours	7.89	100%	3.87	49%	4.19	53%
		Fatal accidents	FA med risk hours	0.36	38%	0.96	100%	0.43	44%
		Non-fatal accidents	NFA med risk hours	32.82	100%	25.18	77%	18.87	57%
		Safety measures	SM med risk hours	42.84	39%	110.90	100%	29.73	27%
		Workers affected by natural disasters	ND med risk hours	13.84	33%	41.50	100%	26.83	65%
	Social benefits, legal issues	Social security expenditures	SS med risk hours	92.47	79%	113.66	98%	116.41	100%
		Violations of employment laws and regulations	VL med risk hours	97.36	52%	188.49	100%	140.70	75%
	Working time	Weekly hours of work per employee	WH med risk hours	20.04	6%	337.66	100%	21.26	6%

Table A4. Hotspots French Case

Location	Amount	Unit
Child Labour, total		
Côte d'Ivoire - CI	0.31914	CL med risk hours
South Africa - ZA	0.23615	CL med risk hours
Cameroon - CM	0.13373	CL med risk hours
Madagascar - MG	0.08068	CL med risk hours
Morocco - MA	0.06867	CL med risk hours
Algeria - DZ	0.06565	CL med risk hours
France - FR	0.06012	CL med risk hours
Ethiopia - ET	0.05126	CL med risk hours
Peru - PE	0.03961	CL med risk hours
Indigenous rights		
France - FR	12.02347	IR med risk hours
United States - US	1.3899	IR med risk hours
China - CN	1.17276	IR med risk hours
Morocco - MA	0.95013	IR med risk hours
India - IN	0.65778	IR med risk hours
Russian Federation - RU	0.56602	IR med risk hours
Argentina - AR	0.42933	IR med risk hours
DALYs due to indoor and outdoor air and water pollution		
Côte d'Ivoire - CI	2.78983	DALY med risk hours
Angola - AO	1.52207	DALY med risk hours
Cameroon - CM	1.3153	DALY med risk hours
India - IN	0.59798	DALY med risk hours
Ethiopia - ET	0.33095	DALY med risk hours
Madagascar - MG	0.27787	DALY med risk hours
Congo - CG	0.19544	DALY med risk hours
Non-fatal accidents	Construction in France	
France - FR	21.25286	NFA med risk hours

Argentina - AR	6.67721	NFA med risk hours
Spain - ES	2.37077	NFA med risk hours
Turkey - TR	0.76519	NFA med risk hours
International migrant stock		
France - FR	60.11734	IMS med risk hours
Switzerland - CH	5.46707	IMS med risk hours
Kazakhstan - KZ	2.07564	IMS med risk hours
Saudi Arabia - SA	1.97385	IMS med risk hours
Israel - IL	1.45173	IMS med risk hours
United States - US	1.3899	IMS med risk hours
Spain - ES	1.18631	IMS med risk hours
United Kingdom - GB	1.14808	IMS med risk hours

Table A5. Hotspots Hungarian Case

Location/Industry	**Amount**	**Unit**
Men in the sectoral labour force		
Hungary - HU	4.29026	M med risk hours
Health and social work - HU	1.83276	M med risk hours
Health and social work - HU	1.82493	M med risk hours
Education - HU	0.08783	M med risk hours
Agriculture, hunting and related service activities - HU	0.08577	M med risk hours
Products of agriculture, hunting and related services - HU	0.08112	M med risk hours
Other business services - HU	0.07646	M med risk hours
Other business services - HU	0.07352	M med risk hours
Weekly hours of work per employee		
Hungary - HU	305.01023	WH med risk hours
Agriculture, hunting and related service activities - HU	85.76569	WH med risk hours
Products of agriculture, hunting and related services - HU	81.11898	WH med risk hours
Land transport; transport via pipelines - HU	21.89088	WH med risk hours

Land transport; transport via pipelines - HU	20.44906	WH med risk hours
Wholesale trade and commission trade, except of motor vehicles and motorcycles - HU	8.93257	WH med risk hours
Manufacture of food products and beverages - HU	8.82355	WH med risk hours
Wholesale trade and commission trade, except of motor vehicles and motorcycles - HU	8.55852	WH med risk hours
Other business services - HU	7.64566	WH med risk hours
Other business services - HU	7.35166	WH med risk hours
Manufacture of food products and beverages - HU	7.20442	WH med risk hours
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods - HU	3.34008	WH med risk hours
Russian Federation - RU	12.72768	WH med risk hours
India - IN	6.45572	WH med risk hours
Expenditures on education		
Hungary - HU	318.49484	EE med risk hours
Agriculture, hunting and related service activities - HU	85.76569	EE med risk hours
Products of agriculture, hunting and related services - HU	81.11898	EE med risk hours
Land transport; transport via pipelines - HU	21.89088	EE med risk hours
Land transport; transport via pipelines - HU	20.44906	EE med risk hours
Wholesale trade and commission trade, except of motor vehicles and motorcycles - HU	8.93257	EE med risk hours
Manufacture of food products and beverages - HU	8.82355	EE med risk hours
Wholesale trade and commission trade, except of motor vehicles and motorcycles - HU	8.55852	EE med risk hours
Other business services - HU	7.64566	EE med risk hours
Other business services - HU	7.35166	EE med risk hours
Manufacture of food products and beverages - HU	7.20442	EE med risk hours
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods - HU	3.34008	EE med risk hours
Russian Federation - RU	13.75607	EE med risk hours
India - IN	6.45572	EE med risk hours
Slovakia - SK	6.22936	EE med risk hours
Germany - DE	4.91359	EE med risk hours
Sanitation coverage		
Hungary - HU	3184.94842	SC med risk hours
Agriculture, hunting and related service activities - HU	857.6569	SC med risk hours
Products of agriculture, hunting and related services - HU	811.18984	SC med risk hours

Land transport; transport via pipelines - HU	218.90883	SC med risk hours
Land transport; transport via pipelines - HU	204.49059	SC med risk hours
Wholesale trade and commission trade, except of motor vehicles and motorcycles - HU	89.32567	SC med risk hours
Manufacture of food products and beverages - HU	88.23548	SC med risk hours
Wholesale trade and commission trade, except of motor vehicles and motorcycles - HU	85.58523	SC med risk hours
Other business services - HU	76.45664	SC med risk hours
Other business services - HU	73.51656	SC med risk hours
Manufacture of food products and beverages - HU	72.04419	SC med risk hours
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods - HU	33.40079	SC med risk hours
Russian Federation - RU	137.56074	SC med risk hours
China - CN	106.86021	SC med risk hours
India - IN	64.55723	SC med risk hours
Slovakia - SK	62.29355	SC med risk hours
Public sector corruption		
Hungary - HU	3184.94842	C med risk hours
Agriculture, hunting and related service activities - HU	857.6569	C med risk hours
Products of agriculture, hunting and related services - HU	811.18984	C med risk hours
Land transport; transport via pipelines - HU	218.90883	C med risk hours
Land transport; transport via pipelines - HU	204.49059	C med risk hours
Wholesale trade and commission trade, except of motor vehicles and motorcycles - HU	89.32567	C med risk hours
Manufacture of food products and beverages - HU	88.23548	C med risk hours
Wholesale trade and commission trade, except of motor vehicles and motorcycles - HU	85.58523	C med risk hours
Other business services - HU	76.45664	C med risk hours
Other business services - HU	73.51656	C med risk hours
Manufacture of food products and beverages - HU	72.04419	C med risk hours
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods - HU	33.40079	C med risk hours
Russian Federation - RU	137.56074	C med risk hours
China - CN	106.86021	C med risk hours
India - IN	64.55723	C med risk hours
Slovakia - SK	62.29355	C med risk hours

Table A6. Hotspots German Case

Location	Amount	Unit
Migration flows		
Germany - DE	659.86156	MF med risk hours
Agriculture and hunting - DE	306.52578	MF med risk hours
Wholesale Trade - DE	58.76296	MF med risk hours
Rail transport - DE	44.44893	MF med risk hours
Business services - DE	44.17893	MF med risk hours
Road and pipeline transport - DE	25.97955	MF med risk hours
Manufacture of food products - DE	22.30487	MF med risk hours
Services to transport - DE	20.72185	MF med risk hours
Banking - DE	17.71565	MF med risk hours
Gender wage gap		
Germany - DE	53.88532	GW med risk hours
Wholesale Trade - DE	27.98236	GW med risk hours
Agriculture and hunting - DE	14.59647	GW med risk hours
Business services - DE	2.10376	GW med risk hours
Road and pipeline transport - DE	1.23712	GW med risk hours
Manufacture of food products - DE	1.06214	GW med risk hours
Banking - DE	0.8436	GW med risk hours
Health and veterinary services - DE	0.62613	GW med risk hours
Electricity and district heat - DE	0.58297	GW med risk hours
South Africa - ZA	4.45333	GW med risk hours
Austria - AT	3.85704	GW med risk hours
Japan - JP	1.83214	GW med risk hours
Association and bargaining rights		
China - CN	103.5633	ACB med risk hours
Crop cultivation - CN	11.08354	ACB med risk hours
Non-metal minerals and other mining - CN	9.41195	ACB med risk hours
Wholesale and retail trade - CN	7.76574	ACB med risk hours

Coal mining and processing - CN	3.27089	ACB med risk hours
Railway freight transport - CN	3.18852	ACB med risk hours
Finance - CN	3.13458	ACB med risk hours