Report on the Environmental & Social Life Cycle Assessment & Social Impact Assessment



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Technical References

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[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

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Summary

This document summarises the work completed for life cycle assessment, including social impact assessment, as well as reflections on a workshop conducted with living labs. It includes 4 chapters:

Chapter 1: Environmental and Social LCA results discussion
Chapter 2: Methodology report for LCA and MAGNET prospective analysis
Chapter 3: Report on social impact assessment of living labs
Chapter 4: Reflection of workshop on future farming scenarios

The results from the LCA work are viewable in the ECOREADY Observatory, where social and environmental impact for 10 baseline LCAs + scenario analysis for 2030 and 2050 for a green, middle, and rocky road scenario. Full results are also available on request, please contact the authors: *Branwen Ap Dafydd Tomos (branwen.tomos@wur.nl) or Annabel Oosterwijk (annabel.oosterwijk@wur.nl)*

Disclaimer

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Chapter 1: Environmental and social LCA results discussion



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1. Introduction

The results presented in this section are the findings from the baseline Life Cycle Assessments (LCAs) conducted for the 10 living labs. LCA is a standardized methodology that quantifies the environmental impacts of a product or process across its full life cycle, covering categories such as climate change, resource use, and land use. Social Life Cycle Assessment (S-LCA) complements this by assessing social impacts on stakeholders like workers and local communities, for topics such as working conditions and health and safety. Analysed were: two case studies of industrially produced tomatoes (Greece and Italy), two case studies of vertical farming systems (Hungary and Sweden), three case studies of barley production (Poland, Demark, and Germany), two case studies of wheat production (Spain and Czech Republic), and one case study of mushroom cultivation (France). All systems but one were based on conventional production; the Czech Wheat case study is based on organic production. The LCA inventories are based on primary data collected during the ECOREADY project; more details on the inventories and the methodology applied are available in the Annex 4 (LCA Methodology report).

Data from different years were used in this study. While the aim was to collect harmonised data for 2023 and 2024, this was not always possible. For instance, the Swedish leafy greens LCA is based on a previous study from 2020, and for the Greek case study, no suitable data for 2023 or 2024 was available, so more recent data from 2026 was used. In the environmental LCA, this variation in reference years is not expected to materially affect the results. In the social LCA, however, it has a stronger influence, as material inputs are converted into USD values that are tied to the specific year of the underlying LCI data. In this study, each input was therefore matched with price data from the corresponding year (for example, 2020 inputs with 2020 prices). While this improves internal consistency within each system, it also means that comparisons across living labs are not fully harmonised, since differences in year, market conditions, and price structures remain. As a result, cross-country comparisons should be interpreted with caution. The analysis is therefore most robust when focusing on each product–country system individually rather than relying too heavily on absolute differences between systems.

This results discussion is structured in the following way: first the environmental and social baseline results are discussed, grouped by product clusters. This clustering is done to provide insights into how the results differ across similar products in different countries, and to highlight any trends or differences observed across different locations, and practices. Second, the results from the MAGNET scenario analysis are discussed. These results are based on prospective analysis that was conducted based on outputs of the MAGNET model (see Deliverable1.5), to assess how projected changes in the economy could influence the environmental and social impacts of food production. Baseline LCA results by product cluster

2.1 Wheat – Czech Republic and Spain

Environmental impact

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The Czech and Spanish case studies showcase two different production systems for growing wheat. The data is based on the years 2023 (Czech Republic) and 2024 (Spain). The Czech system is an organic one, where green manure (alfalfa) is used for fertilizer input, no pesticides are used, and no inorganic fertilizers. The Spanish case study is for conventional production, where urea fertilizer is used, along with animal manure, and various pesticides. The yields achieved for the Czech and Spanish case studies are 3500kg and 5042kg per hectare. There are several reasons why the Spanish system has a higher yield, for example, due to a more extensive production method that uses chemical fertilizers and pesticides, environmental conditions of the growing site such as soil quality, and weather conditions during the growing year. The Spanish system also harvests and sells wheat straw, meaning that economic allocation is applied to the system outputs, with 87% of impacts allocated to wheat, and 13% to straw. In comparison, 100% of impacts from the Czech case study is allocated to wheat, as no by-product is sold. The results presented in Figure 1 show only the impacts allocated to wheat. Figure 2 includes a representation of how the impacts allocated to wheat straw compare to impact allocated to wheat for climate change potential.

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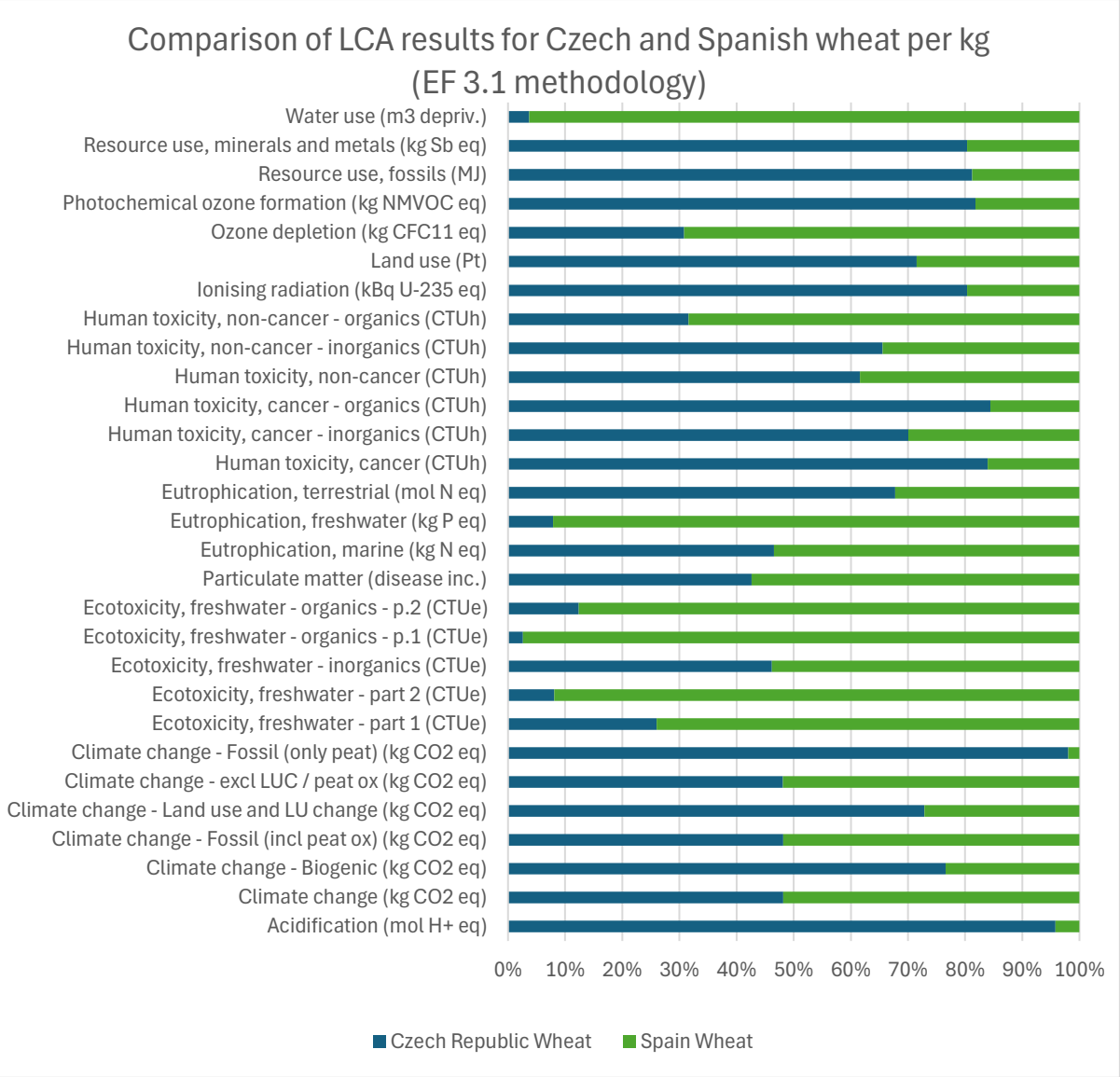

Figure 1: Wheat CZ and ES LCA results comparison

Figure 1 shows how the results for each impact category compare across Spain and Czech Republic for 1kg of Wheat. Life cycle contributions per category is not shown but will be described in the text where relevant and is available to view in the ECOREADY Observatory.

The Spanish case study has higher impacts for categories related to ecotoxicity, marine and freshwater eutrophication, ozone depletion, and water use (Figure 1). For all these categories (apart from water use), the field emissions from fertilizers and pesticides applied are the biggest contributors to impacts. For example: ammonia to air and nitrates to water from fertilizers contributing to eutrophication impacts, and flufenacet and diflufenican run off to soil, water, and air contributing to ecotoxicity. The ozone depletion impacts are caused by Chlorofluorocarbon gas released in the upstream production process of one of the pesticide chemicals used.

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For impact categories where the Czech case study has higher impacts compared to the Spanish one (such as climate change related categories, human toxicity, photochemical ozone formation, and resource use), the cause is diesel use. This is as the Czech living lab uses more diesel per kg of wheat produced, as field activities are required for both wheat and alfalfa cultivation. The use of the alfalfa green manure means that no additional synthetic or organic fertilizer are needed for cultivation, but the payoff is that more direct energy is used per kg of wheat. The only exceptions are acidification and terrestrial eutrophication where field emissions are the highest contributors, and ionizing radiation, where electricity is the highest contributor (as no electricity is used in the Spanish scenario). The Spanish case study also has the highest water deprivation potential[1] across all the Living labs, due to the water risks associated with Spain compared to the Czech Republic.

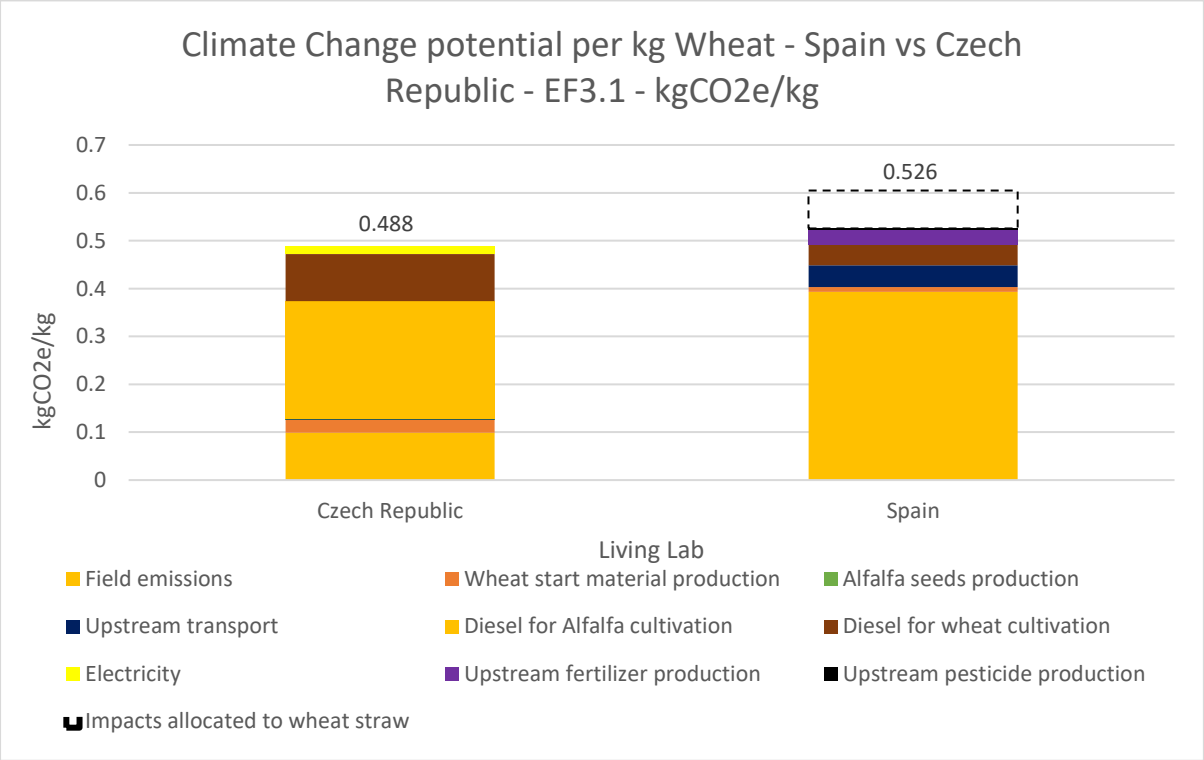

Figure 2: Climate change potential by life cycle stage for 1kg of wheat CZ and ES
**Impacts allocated to wheat straw are not included in total impacts of wheat, as it is not attributed to the wheat in the LCA.*

Both systems have a similar value for climate change potential per kg wheat: 0.526 kgCO2e and 0.495 kgCO2e respectively (shown in Figure 2). However, the hotspots that contribute to this impact are different for each case. For the Czech example, the diesel used in cultivation is the biggest contributor (71%), followed by field emissions (20%). For the Spanish case study, the biggest contributions come from field emissions (75%), followed by transport of manure and other inputs (9%), and diesel (8%). Therefore, the chosen agricultural practice of each site influences the hotspots; for CZ the additional diesel used for cultivating green manure has the biggest contribution, compared to ES, where less diesel is used, but there is large

[1] [1] Water deprivation potential is based on the AWARE model (Boulay et al., 2018).

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contribution from the impacts of additional fertilizers applied. One insight from this comparison is that no matter which management practice is used (organic vs. conventional), the need for fertilization is a large contributor to climate change potential, whether it be via direct impact from field emissions, or indirectly through additional fuel use for cultivating green manure.

Social impact

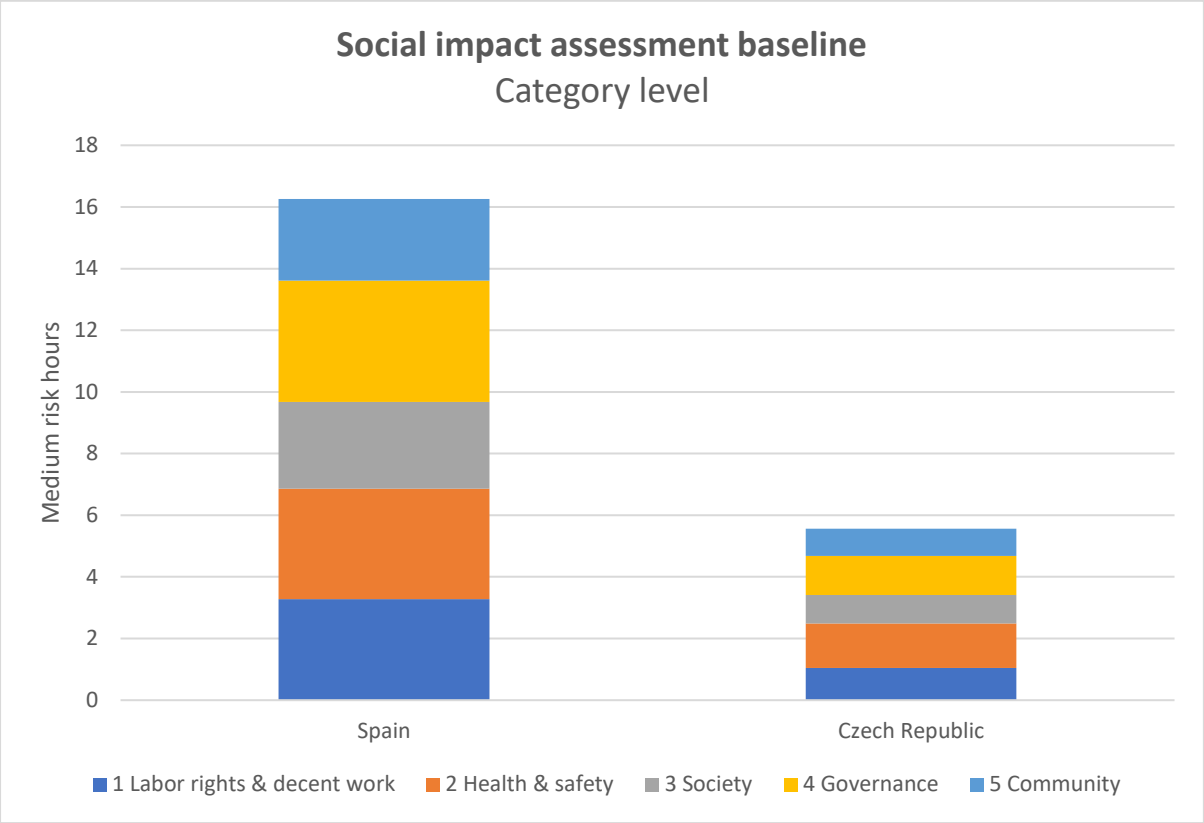

Figure 3: Upstream social impacts on impact category level for wheat from Spain (conventional) and Czech Republic (organic)

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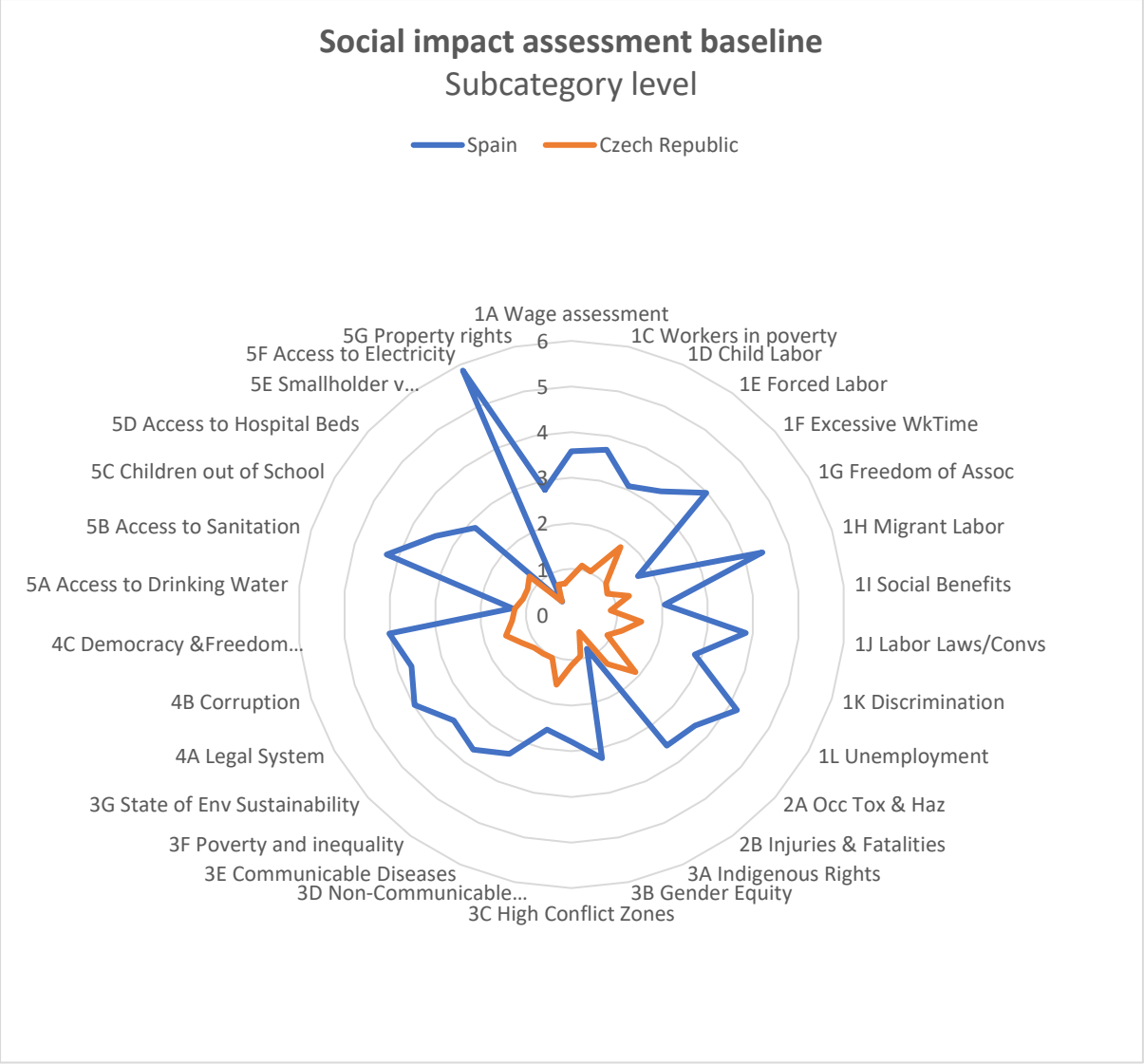

Figure 4: Upstream social impacts on impact subcategory level for wheat from Spain (conventional) and Czech Republic (organic)

Figure 3 as well as Figure 4 illustrate that the Spanish conventional wheat production system (data from 2024) generates higher total social impacts across all (sub)categories compared to the Czech organic wheat production system (data from 2023). Despite both being wheat production systems, their social impact profiles differ substantially.

In Spain, the governance category (number 4 in Figure 4, with indicators like corruption) is the most impacted, followed by health and safety (2), and labour rights and decent work (1). The highest subcategory impacts are observed in access to electricity, access to sanitation, and migrant labour and unemployment. The primary contributing processes are transport (especially for manure and other inputs) (70%), chemical inputs (27%), and the starting material (2%).

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The dominance of transport is largely driven by the movement of heavy inputs such as manure, which increases the relative importance of logistics services in the system. Within the applied SHDB framework, transport represents an economic flow linked to the transport sector, which carries country-specific social risk profiles. As such, the associated impacts reflect upstream risks in transport supply chains rather than direct farm-level practices. In the Spanish case, transport activities are mainly linked to petroleum and coal product sectors, which further connect to the transport service chain. The highest risks associated with these sectors include unemployment and occupational toxicities and hazards, explaining their prominence in the results.

In the Czech Republic, the health and safety (2) category is most affected, followed by governance (4), and labour rights and decent work (1). The leading subcategories are occupational toxicities and hazards, forced labour, and non-communicable diseases. The main processes driving these impacts are diesel usage (65%), alfalfa seed input (used as green manure) (33%) and electricity usage (2%).

These contributions also reflect upstream supply chain risks rather than direct on-farm effects. Diesel use links to fuel supply chains, including extraction, refining, and distribution processes. In this case, these flows are primarily associated with supplying countries such as Kazakhstan, Russia, and Malawi, where elevated risks of forced labour, wages below sector benchmarks, and occupational health hazards are reported. Similarly, alfalfa seed inputs are linked to the crop production sector in the Czech Republic, where the main risks include forced labour and occupational toxicities and hazards. Electricity use reflects the national energy production mix and its associated social risk profile.

Overall, the identified hotspots should therefore be interpreted as differences in exposure to upstream supply chain risks embedded in the inputs required by each system, rather than differences in direct farm-level social performance.

Conclusion environmental and social impact

When comparing the environmental and social LCA results, we see that for the Czech Republic the hotspot for both environmental and social impact is diesel use for alfalfa and wheat cultivation; with the impacts from both upstream extractions, and on-farm combustion. For the Spanish scenario, there results vary, as for the environmental LCA we see that the main hotpots are from field emissions, as well as chemical inputs such as fertilizers and pesticides, whilst transport is the main contributor to social impacts. One of the reasons for this difference is that in environmental LCA we characterise the impacts from direct emissions from land use and chemical application (run-off, leaching, volatilization etc.), whilst the social LCA only includes upstream impacts. Therefore, due to the slightly different system boundary, we see a change in hotpots.

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From the social LCA, we see that the Czech system consistently has lower impacts than the Spanish system (Figure 3 and Figure 4), which differs from the environmental LCA results where performance varies across impact categories depending on the system (Figure 1). Therefore, when comparing organic versus conventional production, the results suggest a social advantage for organic methods, while the environmental assessment indicates trade-offs between the two systems. A key difference is that the social impacts are driven mainly by upstream inputs, their associated monetary flows, and country-specific risk profiles embedded in the databases. In this case, the lower level of inputs per functional unit in the Czech system, combined with their respective risk profiles, results in a lower overall social impact compared to the Spanish system. Therefore, reduced social impact is not only due to it being an organic system, but is also influenced by other factors. The environmental LCA, on the other hand, also includes on-farm processes directly, which leads to more variation and trade-offs across impact categories. Overall, the social LCA provides complementary insight into upstream social risk patterns linked to the two production systems, adding a different perspective to the environmental results.

The comparisons between these two systems are not just a comparison of organic vs conventional production, due to the different geographic locations and climate of the case study sites. Therefore, whilst the results interpretation discusses how these two production methods could affect environmental and social impacts, the comparison is not exhaustive, and the findings may not be replicated across other farming systems.

2.2 Barley – Denmark, Germany, and Poland

Environmental impact

Barley was the representative product for three living labs, with 4 LCAs conducted in total as two sets of LCA inventory data were collected from the German LL. The data was collected for the years 2024 (Poland, Denmark, Germany 2) and 2023 (Germany 1). Figure 5 shows how the LCA results compare for each case study. For 24/29 categories, the Danish Barley has the highest impact. Whilst Figure 5 does not show life cycle contributions by life cycle stage for the 4 case studies, from results analysis we conclude that one of the main contributing factors to this trend is the lower yield produced by the Danish farm. Here, the yield is only 3000 kg/ha, compared to 8800 kg/ha, 9500 kg/ha, and 8000 kg/ha for the two German sites and the Polish sites respectively. This results in higher inputs of fuel and fertilizers per kg, amplifying the impacts per kg of barley. The reasons for different yield could vary, from weather conditions, specific agricultural practices used, and soil properties. When the functional unit is based on 1kg, yield becomes a sensitive factor when comparing LCA impacts of a production system.

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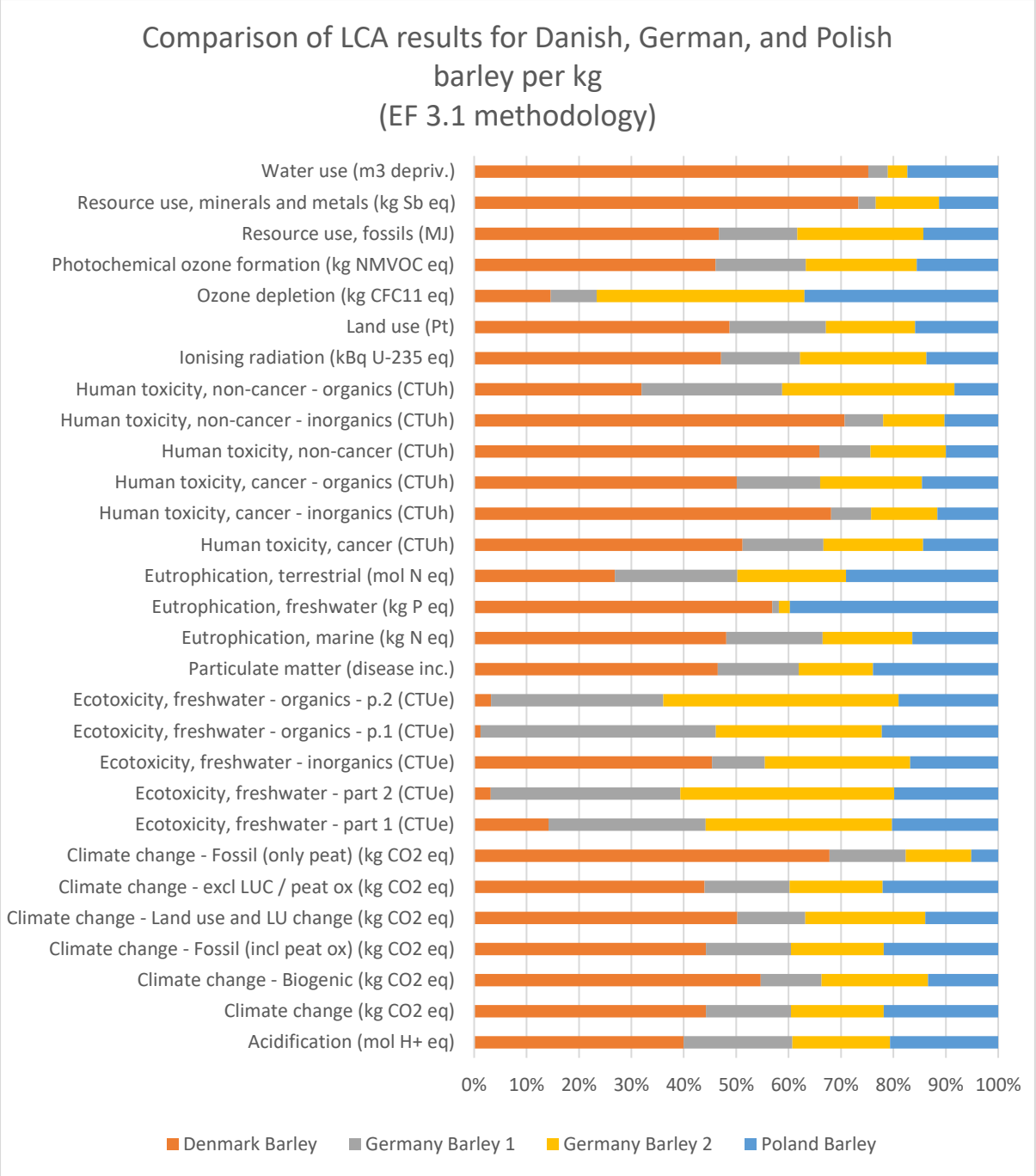

Figure 5: Barley DK, DE, and PL LCA results comparison

Figure 6 shows the contributions to climate change potential by life cycle stage for the 4 case studies, compared to the yield per ha. The ratio of contribution of each life cycle stage is consistent across all case studies; field emissions contributing the greatest, followed by fertilizer production, diesel, and start material in descending order. However, the total impact per kg decreases proportionally to increased yield. The impact of the Polish case study is further reduced as some of the impacts associated to production are allocated to the straw that is produced and sold. For this scenario, total impacts of the production site have been allocated based on

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economic value, and therefore only 84% of total impacts is allocated to barely, compared to 100% for the other living labs. This shows how different farm management approaches can influence LCA impacts. This trend of each case study having similar ratios of life cycle contributions to impacts, but total impacts inversely proportional to yield is observed for most of the 29 impact categories reported. The exceptions are impact categories where pesticides have the highest contribution. For example, Figure 7 shows the contribution to 5 impact categories related to freshwater ecotoxicity across the 4 case studies in comparison to yield. In this instance, the lower yield corresponds to lower impacts per kg of Barley. This is as the Danish case study uses less pesticides with an ecotoxic impact and overall lower inputs into the system, therefore, whilst the yield is decreased, the direct impact on the ecosystem is lower.

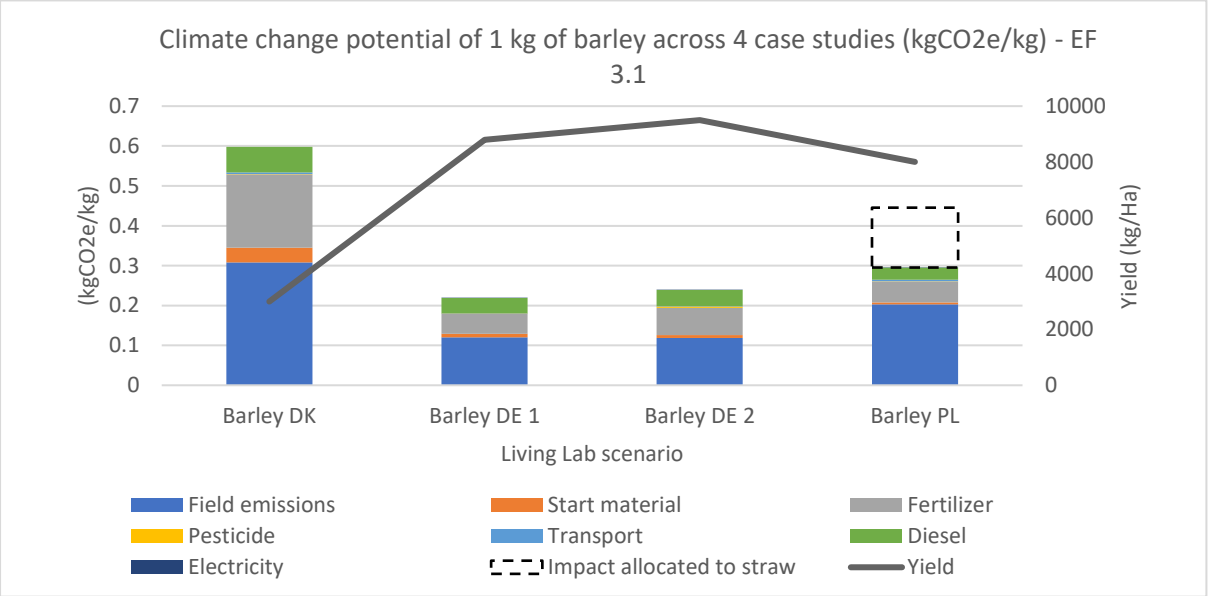

Figure 6 : Climate Change Potential comparison Barley
**Impact allocated to straw represents system inputs that are not allocated to barley, and therefore, result in overall reduction in impacts per kg of barley produced.*

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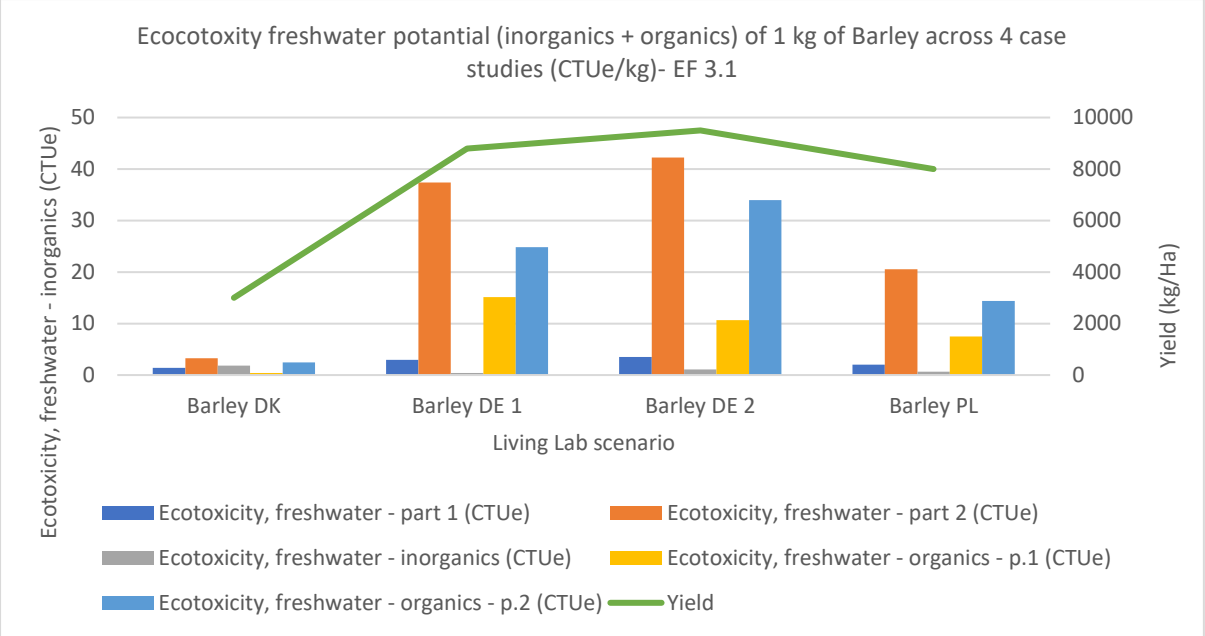

Figure 7: Ecotoxicity freshwater pt.1 comparison Barley (excludes impact allocated to straw)

Therefore, we observe across the 4 barley case studies that yield has a large effect on the impacts of barley production per kg, but that the chemical inputs used to achieve a higher yield can result in payoffs in environmental impacts in other categories, such as ecotoxicity. Here we see that there are trade-offs between different production systems, based on the agricultural practices used.

Social impact

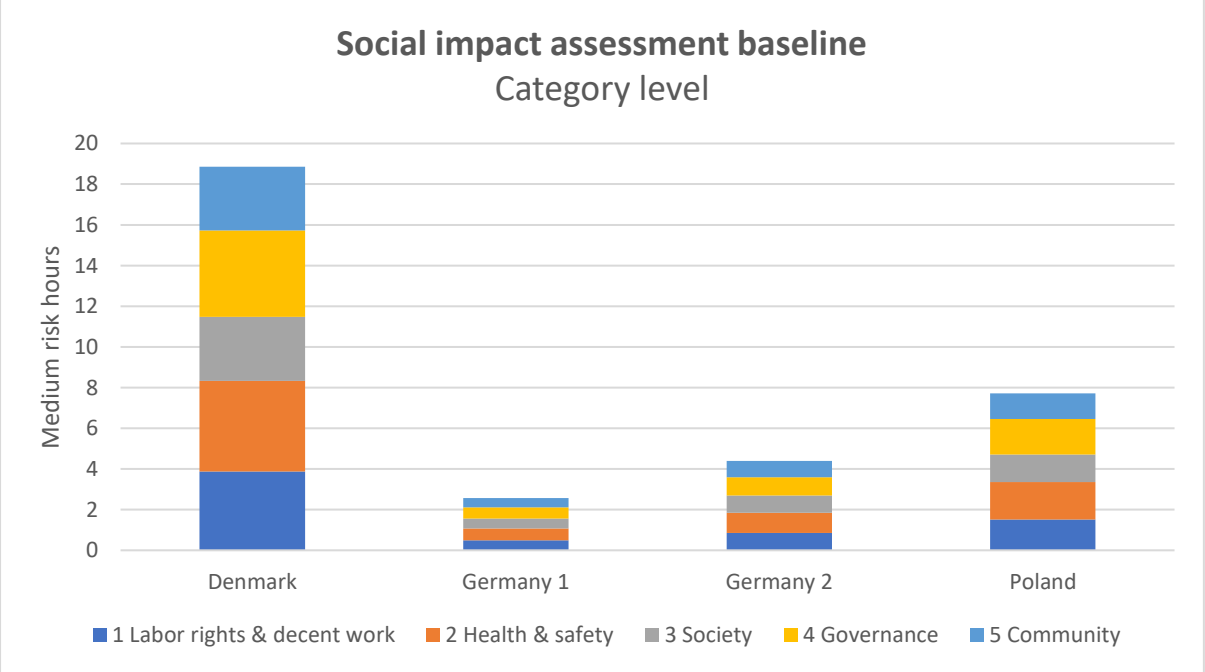

Figure 8: Upstream social impacts on impact category level for barley from Denmark, Germany and Poland

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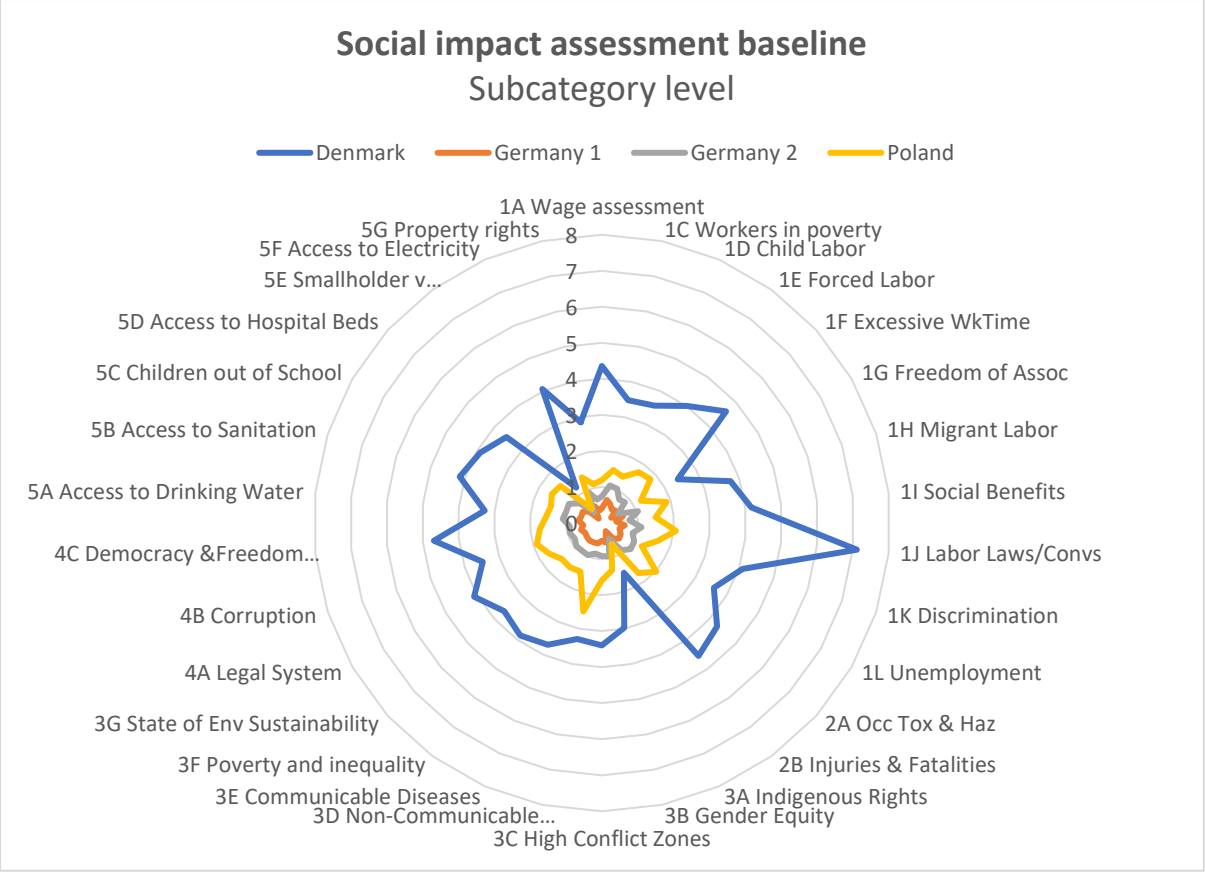

Figure 9: Upstream social impacts on impact subcategory level for barley from Denmark, Germany and Poland

Figure 8 and Figure 9 show that barley production from Denmark (data from 2024) stands out as the largest contributor to social impacts, followed by Poland (2024), Germany 2 (2024), and Germany 1 (2023). These differences reflect variations in input structures and the associated exposure to upstream supply chain risks rather than direct differences in on-farm social performance.

Denmark's barley production shows the highest impact across all categories and subcategories. The most affected areas are health and safety (2) and governance (4), with the greatest subcategory impacts observed in labour laws/conventions, injuries & fatalities, and occupational toxicities & hazards. The main drivers of these impacts are chemical inputs (75%), followed by the starting material (13%), diesel usage (8%), and transport (4%).

In contrast, both German production systems exhibit a more balanced distribution of social impacts across categories. For Germany 1, the highest subcategory impacts are access to drinking water, workers in poverty, and occupational toxicities & hazards, primarily driven by chemical inputs (49%) and diesel usage (42%). Germany 2 shows a similar pattern, with the same top subcategories, with chemical inputs (45%), and additional contributions from straw inputs (24%), diesel usage (21%) and mineral inputs (5%).

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Poland's conventional barley production is most impactful in the health and safety (2) and governance (4) categories, with the highest subcategory impacts in non-communicable diseases, labour laws/conventions, and occupational toxicities & hazards. The main contributing processes are chemical inputs (66%), diesel usage (22%), and mineral inputs (8%).

Across all systems, chemical inputs are the dominant contributors to occupational toxicities and hazards. This is explained by the fact that these inputs are linked to upstream chemical production sectors, where higher risks related to hazardous working conditions are reported. Overall, the identified hotspots should therefore be interpreted as differences in exposure to upstream, sector-specific social risks embedded in input supply chains, rather than direct impacts occurring at the farm level.

Conclusion environmental and social impact

Both the environmental and social LCA show that the impact per kg is consistently high for the Danish case study, showing how a reduced yield results in more impact allocated per kg of product. For social LCA, the main hotspots are chemical inputs (fertilizers and pesticides), whilst for the environmental LCA we see that field emissions is also a hotspot (which is not captured in the social LCA). In the environmental LCA we also observe a trade-off from chemical use, which results in the Danish case study having lowest impacts in eco-toxicity related categories, despite the low yield resulting in its environmental impact per kg being highest in most other impact categories (for example climate change potential). Therefore, lower input systems can have environmental benefits as the total burden on the environment is lower, despite impacts per kg being higher.

2.3 Industrial tomato – Greece and Italy

Environmental impact

4 LCAs were completed for conventional industrial tomato production, one for Greece and three for three different locations in Italy. The data was collected from 2024 (Italy) and 2026 (Greece). Figure 10 compares the LCA results across the 29 EF3.1 impact categories. Greece has the lowest impacts in 24/29 impact categories, Italy 2 and Italy 1 in 2 each, and Italy 3 in 1. Italy 1 has the largest impact in 14/29 categories, followed by Italy 2 (8/29), Greece (4/29) and Italy 3 (3/29). Figure 5 does not show life cycle contribution to impacts. The Greek living lab has the highest yield per Ha, at 135 ton/Ha, compared to 95 ton/Ha, 100 ton/Ha, and 130 ton/Ha for the Italian case studies, and therefore, contributes to lower impact per kg of tomato produced.

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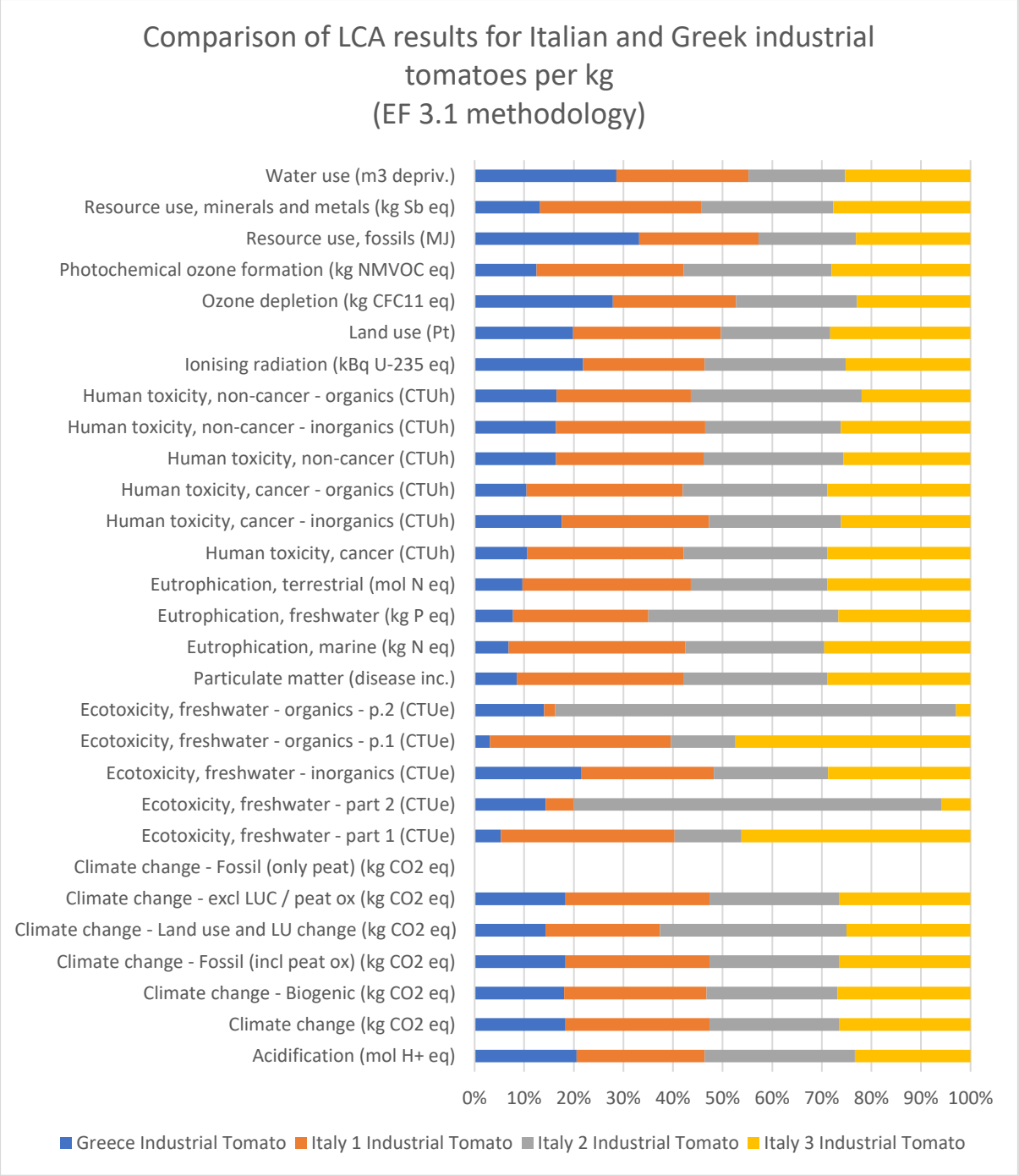

Figure 10: GR and IT Industrial Tomato LCA results comparison
**No results are shown for Climate change – Fossil (only peat) as no peat is used in the life cycle*

Figure 11 shows the life cycle stage contributions to climate change potential for the 4 case studies, compared to the total yield. Diesel use is the biggest contributor for the Italian case studies (49%, 53%, and 51% for Italy 1, 2, & 3 respectively), followed by field emissions (21%, 18%, and 19% for Italy 1,2, and 3 respectively), and then start material (18%, 15%, and 19% for Italy 1, 2, and 3 respectively). For all 4 industrial tomato case studies, seedlings are used as the start material and therefore have a higher upstream climate change impact than seeds or grains, as resources

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have already been used to germinate and grow the seedlings. For the Greek case study, the start material is the biggest contributor to climate change impact (39%), followed by diesel use (27%), and electricity (18%). Electricity use impacts are also higher for the Greek case study than the Italian ones, as electricity is used in the irrigation systems for water.

Figure 11 shows the impacts for ecotoxicity freshwater related impact categories for the 4 case studies, where the Italy 2 case study has significantly higher impacts than the other three. Greece also has the second highest impacts, therefore, the trend of the case study with highest yield having lower impacts is not observed here. Pesticide use is the biggest contributor to ecotoxic impact, in total contributing 75%, 79%, 83%, and 94% to the Greek, Italy 1, Italy 3, and Italy 2, case studies, respectively. For Greece, the main contribution is from run-off of s-metolachlor to soil, an active ingredient in one of the herbicides applied during cultivation. For the Italy 2 case study, the high impacts are caused by lambda-cyhalothrin run off to water (90%), which is an active ingredient in one of the insecticides applied. This insecticide was not used in the Italy 3 and Italy 1 locations; therefore, the impacts are much lower for those two case studies. This therefore highlights how chemical application can influence the life cycle impacts of production systems; unlike other inputs like energy and fertilizers their environmental burden per kg is not so directly linked to use efficiency and yield. Pesticide use is also not linked directly with amount applied, or even active ingredient amount applied, but rather to the characteristic of the active ingredients themselves. This conclusion was also observed in the Barley cluster.

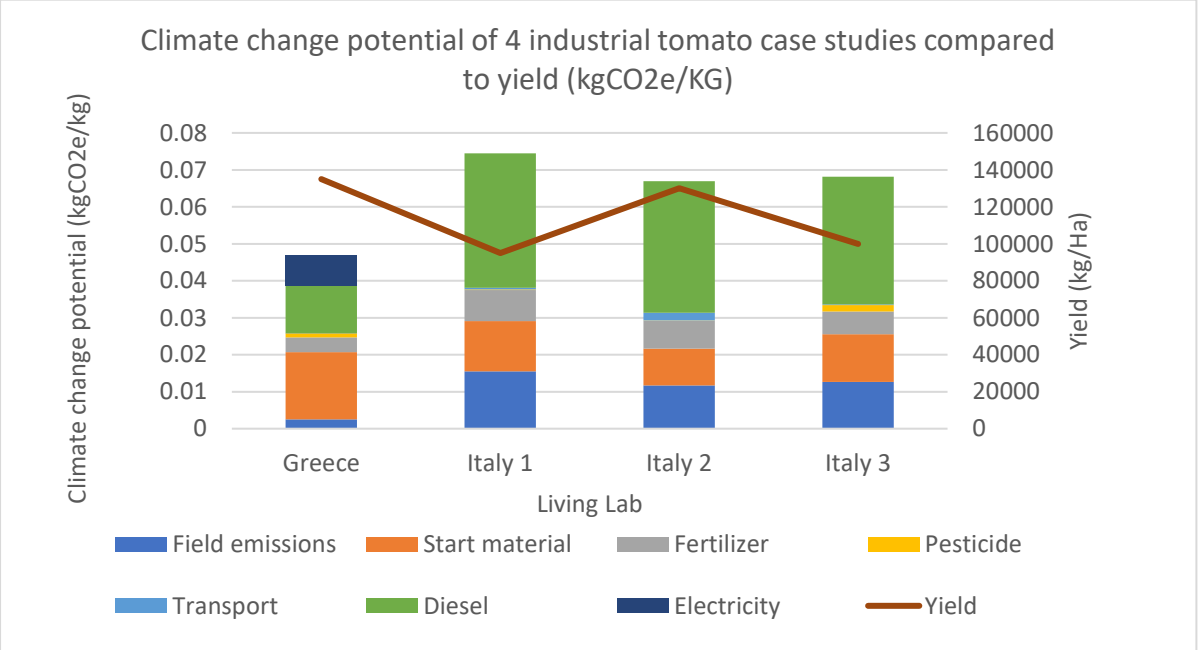

Figure 11: Climate Change potential industrial tomatoes

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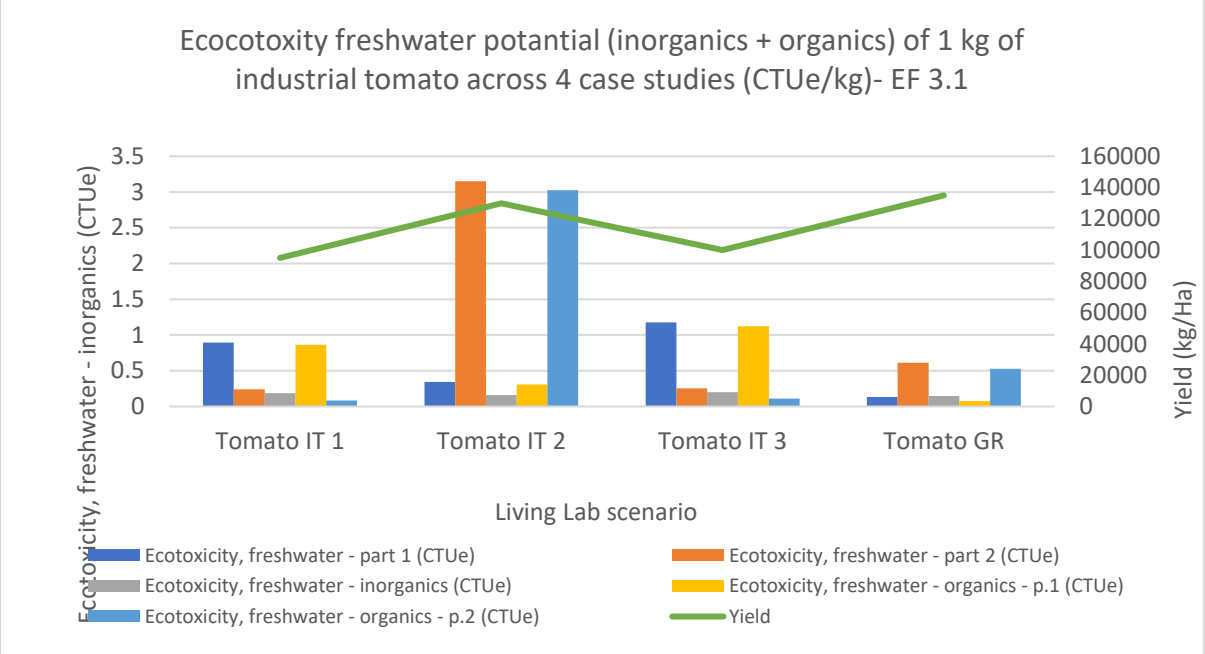

Figure 12: Freshwater ecotoxicity pt.2 potential industrial tomatoes

Social impact

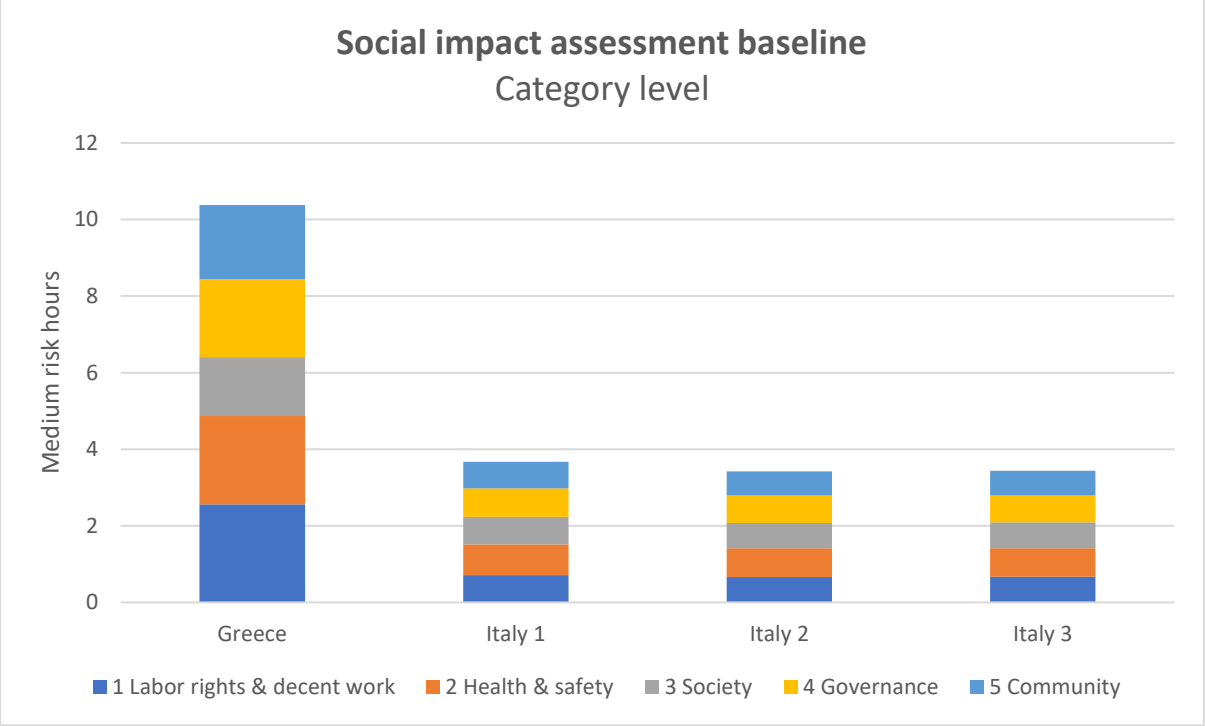

Figure 13: Upstream social impacts on impact category level for industrial tomato from Greece and Italy

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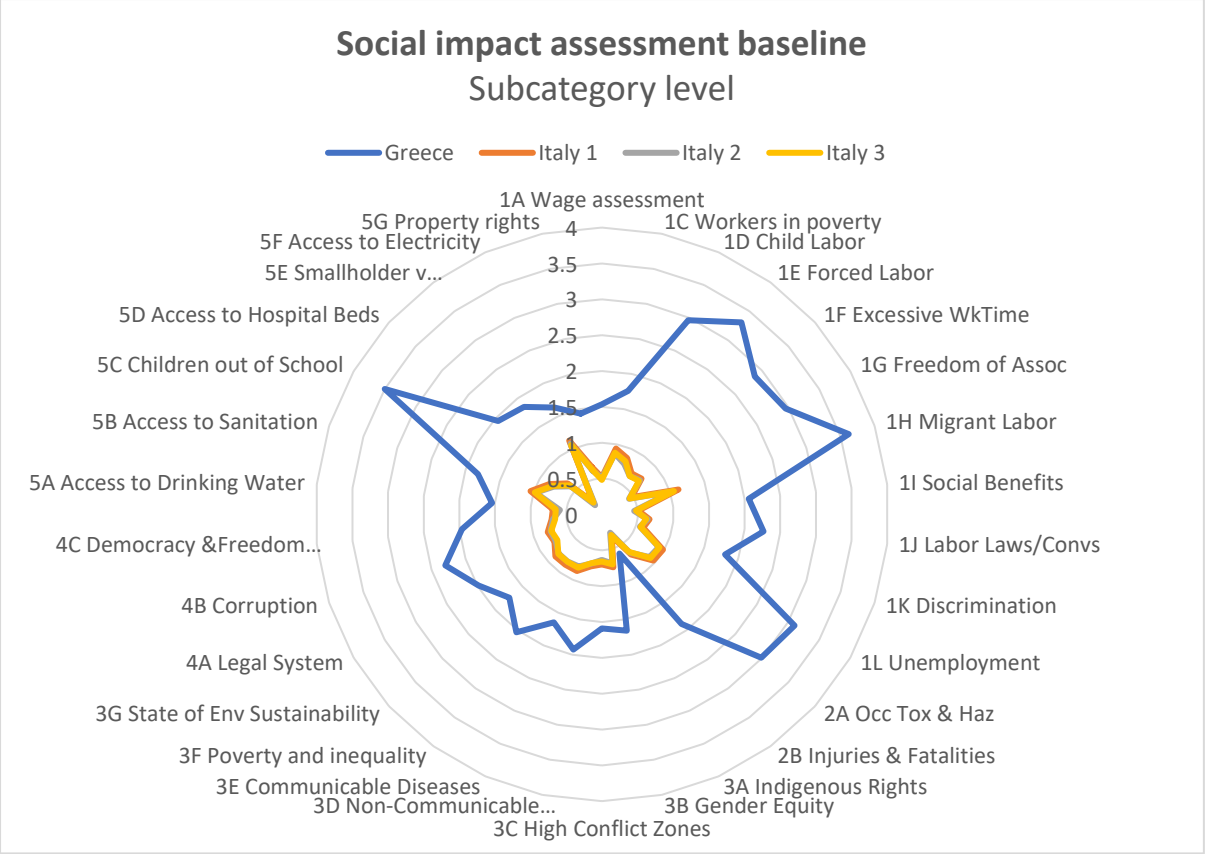

Figure 14: Upstream social impacts on impact subcategory level for industrial tomato from Greece and Italy

Out of the four industrial tomato production systems analysed, Greece (data from 2026) shows the highest social impact across all impact categories and impact subcategories compared to Italy (2024 data), as illustrated in Figure 13 and Figure 14. These results reflect differences in exposure to upstream supply chain risks rather than differences in direct farm-level practices.

The dominant impact category for Greece is labour rights and decent work (1), followed by health and safety (2). At the level of impact subcategories, the most significant contributions come from migrant labour, children out of school, and forced labour. In terms of contributing processes, most of the impact is associated with chemical inputs (60%), followed by starting material (34%), and electricity (4%). These contributions are driven by upstream supply chains linked to input production. Chemical inputs represent flows to chemical manufacturing sectors, which carry country-specific risks such as forced labour, excessive working time, migrant labour, and occupational toxicities and hazards. As a result, the high contribution of chemical inputs reflects embedded upstream risks rather than conditions at the farm level.

For the Italian processes, a similar pattern as well as magnitude of impact is observed across Italy 1, Italy 2, and Italy 3. The main impact category is health and safety (2), followed by governance (4). Across all three Italian systems, the most important impact subcategories are access to electricity and migrant labour, followed by access to sanitation. Regarding the contributing processes, diesel usage

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represents the largest share in all cases (47%, 49% and 47% for Italy 1, Italy 2, and Italy 3, respectively). This is followed by starting material (26%, 20%, and 26%, respectively) and chemical inputs (25%, 18%, and 26%, respectively). Transport contributes a relatively small share in Italy 1 (2%) and a more notable share in Italy 2 (13%), while it is not among the main contributors in Italy 3.

Across both countries, chemical and fuel related inputs consistently drive the main impacts due to their association with upstream production sectors characterised by occupational health risks, labour vulnerabilities, and governance issues. Differences between systems are therefore mainly explained by variation in input composition and the associated sector risk profiles rather than direct differences in on-farm production practices.

The higher social impacts for Greece compared to Italy are not driven by higher physical input use, but by higher monetary input values assigned to upstream sectors, particularly chemical inputs. In SHDB based S LCA, impacts are linked to these monetary flows (the activity variable), meaning that higher expenditure per functional unit increases exposure to sector specific social risk profiles, regardless of physical quantities. This is further influenced by the different reference years (2026 for Greece vs 2024 for Italy), where changes in price levels and market conditions affect monetary flows even when inflation adjustments are applied.

Conclusion environmental and social impact

The social and environmental LCA show different trends when comparing the impacts of the Italian and Greek case studies. Whilst for the environmental LCA, we see the Greek production system having lower impacts per kg of product, mainly due to its higher yield and therefore lower input intensity per functional unit. In contrast, the social LCA indicates higher upstream social risk for the Greek case compared to the Italian cases.

Based on the LCI comparison, this divergence is not explained by higher physical input quantities in Greece. In fact, several key inputs such as diesel and several fertilizers are lower per kilogram of output in Greece, which confirms that social risk is not directly proportional to physical input intensity or yield. Instead, the main driver of the higher social risk score is the higher monetary value of inputs in the Greek system, particularly for fertilizers and plant protection products. Because the SHDB method is driven by monetary flows, higher input prices translate into higher exposure to upstream social risk, even when physical quantities are similar or lower. This effect is further influenced by the different reference years (2026 for Greece and 2024 for Italy). Although inflation was corrected for, this does not fully capture broader input price dynamics and market volatility in agricultural inputs, particularly for agrochemicals.

For the social LCA results, diesel is found to be the main hotpot in all cases, with the same trend observed for climate change results in the environmental LCA. However, in the environmental LCA hotspots differ across impact categories, with pesticide use being a hotpot for ecotoxic impact, and diesel use and start material

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being a hotpot for climate impact and resource use. The environmental impact is also observed to be lower for the Greek case study for many impact categories, likely as the higher yield results in more efficient resource use per kg produced. An exception is from pesticide use, where the Greek case study does not have lowest impact, and the Italian case study with highest yield shows highest ecotoxic potential. Therefore, differences in social and environmental impact are observed here, as lower social impact does not always translate to lower environmental impact.

2.4 Leafy greens – Hungary and Sweden

Environmental impact

Two vertical farming systems growing leafy greens were compared, one in Sweden and one in Hungary. The data was collected from 2024 (Hungary) and 2020 (Sweden). Figure 15 shows how the LCA results compare across all impact categories. The Swedish case study has higher impacts than the Hungarian one for 28/29 impact categories (with the only exception being climate change potential from peat which is zero for both examples). For climate change potential, the impacts per kg are similar for both scenarios; 5.9kg CO2e/kg for Hungary compared to 6.9 kgCO2e/kg for Sweden, which are both in the typical expected range for vertical farming systems that use grid, or residual electricity. However, for other impact categories, such as land use, ozone depletion, ecotoxicity, and human toxicity, the Swedish system has significantly higher impacts. This is as the electricity consumed per kg of leafy green is higher.

For almost all impact categories, across both case studies, the electricity is the biggest contributor to impacts. The only exceptions are for climate change potential from land use (where aluminium ore mining in the upstream of the CAPEX has higher contribution for the Hungarian case study), and for ozone depletion potential, where PET plastic in the CAPEX has the highest impacts for the Swedish case study. Both case studies have low direct land use impacts as they are both urban vertical farming systems, with no land transformation done, and only minimal urban land occupation.

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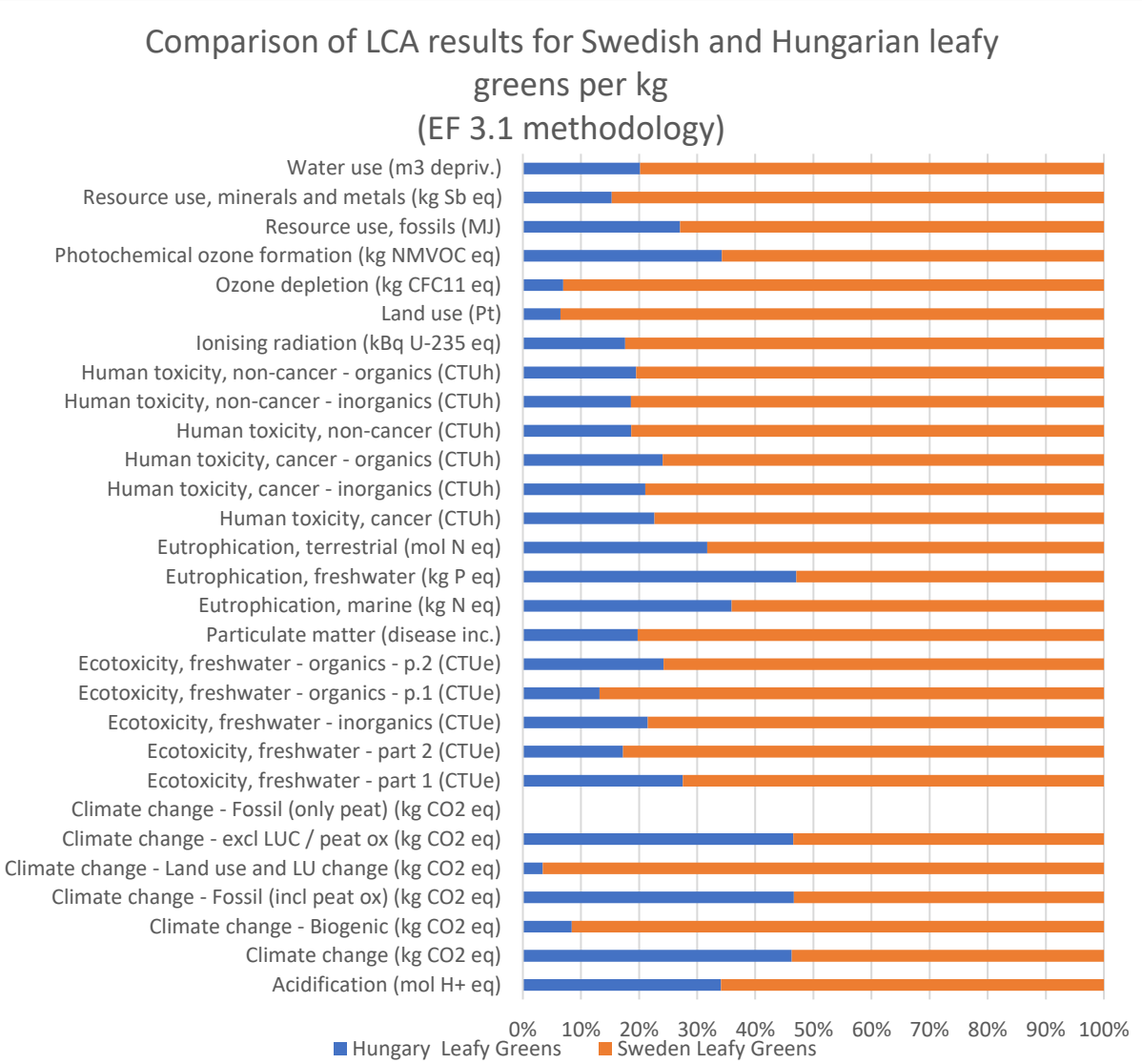

Figure 15: SE and HU Leafy greens LCA results comparison
**No results are shown for Climate change – Fossil (only peat) as no peat is used in the life cycle*

Electricity use is the main hotspot, and therefore the difference in LCA results across the two systems are primarily affected by amount of electricity consumption per kg of product, and the residual grid mix of the country. The electricity requirement per kg is much higher for the Swedish living lab than the Hungarian one (60kWh/kg compared to 14kWh/kg), and the yield lower (29 kg/m2 compared to 72kg/m2). The climate change potential per kg of leafy greens from each system are still within a similar range (5.9 and 6.9 kgCO2e/kg), as the Swedish residual grid has much lower carbon intensity than the Hungarian one (97 g CO2e/kWh compared to 402 g CO2e /kWh) (based on ecoinvent3.10). Therefore, a 77% reduction in climate change potential could be realized if the Swedish farm were able to achieve the same energy efficiency as the Hungarian one. The high electricity requirement is the reason that the Swedish system has higher impacts than the Hungarian one in all 28/29 impact categories, as mentioned above.

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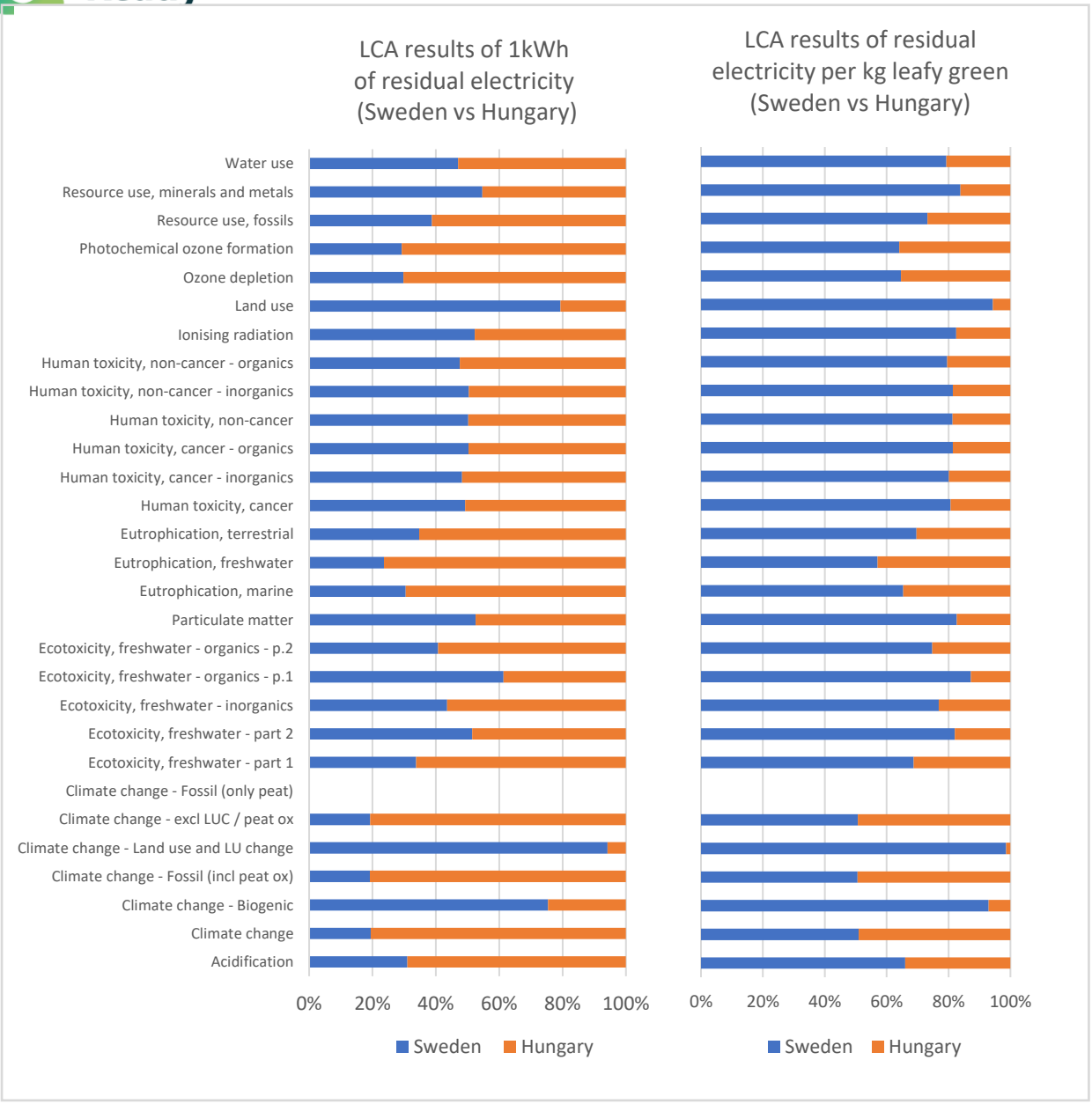

Figure 16: LCA results for SE and HU electricity (per kwh and per kg leafy green)

**No results are shown for Climate change – Fossil (only peat) as no peat is used in the life cycle*

Figure 16 shows how the LCA results vary for residual electricity for Sweden and Hungary per kwh, and per kg leafy green at both vertical farms. Whilst the Swedish grid is more low carbon and overall has lower impacts than the Hungarian grid, due to the lower efficiency of the vertical farm, the impacts associated with electricity per kg of leafy green are higher. The only impact categories where the Swedish grid has higher impacts per kwh than the Hungarian grid are ones related to biogenic carbon and land use, as more biofuel energy is used. Therefore, impacts from vertical farming can be reduced by improving production efficiency per kwh of electricity. It could also be reduced if a 100% renewable energy tariff was used by the grower, or even market-based tariff with lower fossil fuel use than in the residual grid. The LCA model in this assessment is based on the residual grid, following the

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guidelines of the freshproducePEFCR (Weststrate et al., 2026). However, additional scenario analysis could compare how the impacts of the production of 1kg of leafy greens would change under different electricity mix scenarios.

The vertical farms have very different results from the open field farm systems also compared in this work (like those for industrial tomatoes, wheat and barley), as there is more reliance on energy, and less on fertilizers and other chemical inputs. Future food production may come to rely more on vertical farming, as it offers an efficient use of land and the ability to grow food in urban areas. Therefore, the results presented here can offer an insight into what should be prioritized if these systems are to be used sustainably, which is to use renewable energy if possible, and to focus on achieving good production efficiency. The results for GHG potential found here are still almost tenfold higher than typical GHG emissions from leafy greens grown in open field conditions (Blom et al., 2022), therefore, from a LCA perspective these systems do not currently offer lower impacts than their conventional counterparts. Focus should be on improving efficiency, and prioritising renewable energy sources. Additionally, the controlled indoor environments offered by these systems could offer as a future climate resilient food production method, if yields in field cultivation were to decrease. These systems may however, still be vulnerable to other climate risks, for example: risks to energy infrastructure.

Social impact

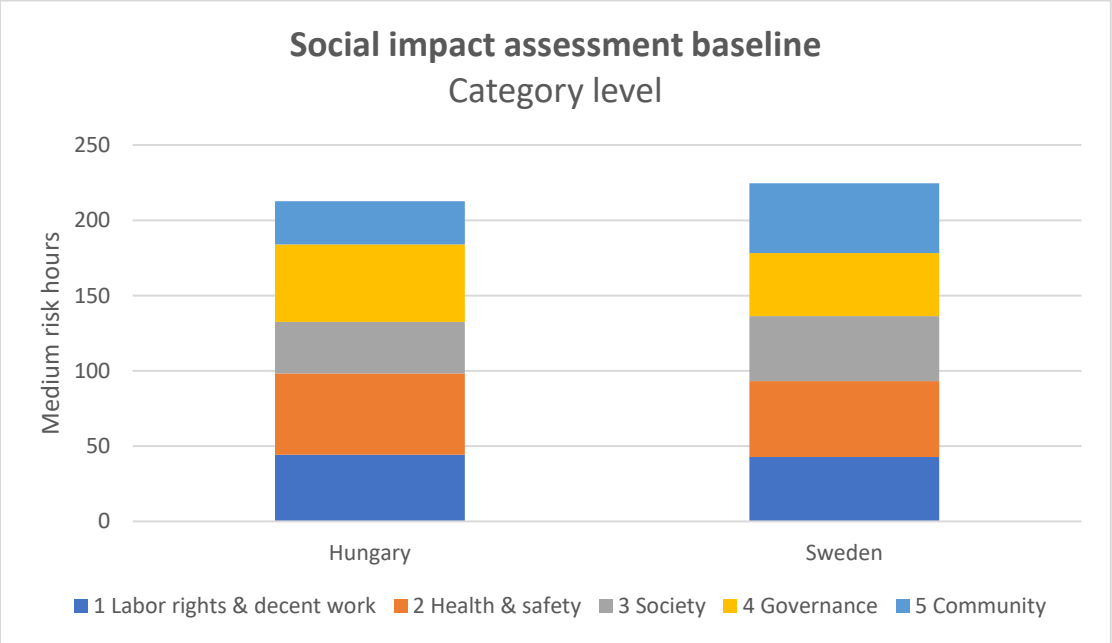

Figure 17: Upstream social impacts on impact category level for leafy greens from Hungary and Sweden

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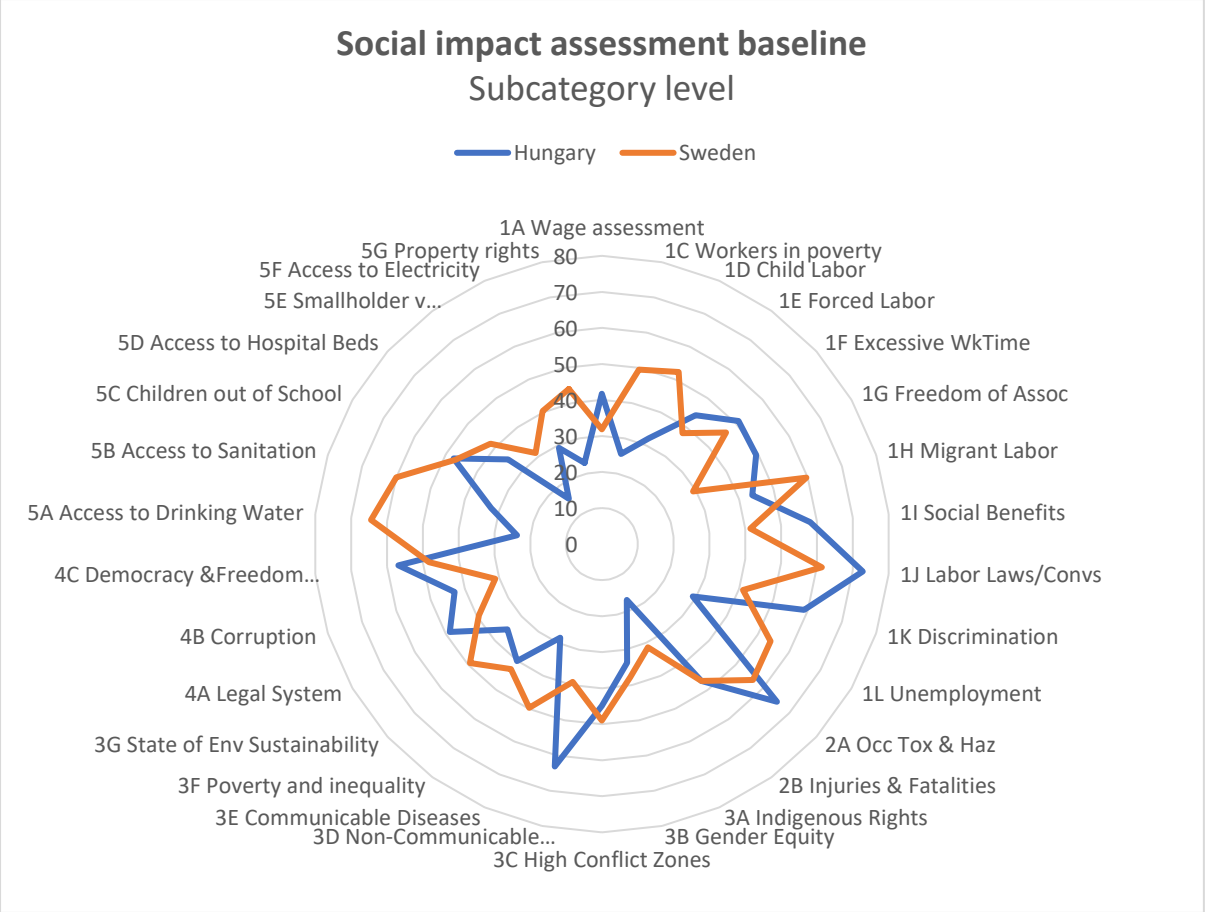

Figure 18: Upstream social impacts on impact subcategory level for leafy greens from Hungary and Sweden

Both systems represent vertical farming production, which is typically characterised by relatively high input intensity and, as a result, tends to show higher associated social impacts compared to more conventional production systems. Figure 17 indicates that Sweden (data from 2020) has a slightly higher overall impact compared to Hungary (2024). However, this difference is not consistent across all dimensions, as Figure 18 shows that the relative performance varies depending on the specific impact subcategory considered. It is also important to account for the difference in reference years. The Swedish data reflects conditions in 2020, while the Hungarian system is based on 2024 data. This gap is particularly relevant in the context of vertical farming, where rapid technological innovation and efficiency improvements can significantly alter input structures and, consequently, the associated social impact profiles over a relatively short period of time.

For Sweden, the dominant impact category is health and safety (2), followed by community (5). At the level of impact subcategories, access to drinking water is most prominent, followed by labour laws and conventions and access to sanitation. These impacts are primarily driven by starting material and growing media (crops sector) (43%), with additional contributions from electrical equipment (22%), electricity use (20%), and chemical inputs (14%).

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The strong contribution of starting materials and growing media is linked to the crops nec sector used as a proxy in the SHDB. This sector includes not only domestic agricultural activity in Sweden, but also upstream supply chain contributions from higher risk regions, such as Ethiopia. Because agriculture is labour intensive and these regions have higher social risk levels, even smaller upstream flows can significantly influence the results. At the same time, the Swedish sectors themselves show relevant direct risks. Both the electricity and crops sectors indicate elevated risks for migrant workers and occupational toxics and hazards. These reflect structural aspects of the sectors rather than weak regulation. However, the crops sector still dominates overall due to its higher labour intensity and stronger link to global supply chains, while electricity remains more domestic and capital intensive.

For Hungary, health and safety (2) is again the leading impact category, followed by governance (4). The most relevant impact subcategories are labour laws and conventions, occupational toxicity and hazards, and non-communicable diseases. The main contributing processes are electricity use (44%), electrical equipment (37%), rockwool (9%), and starting material (5%).

In contrast to Sweden, the Hungarian results are clearly driven by electricity use. This is partly explained by the higher electricity price (0.4 EUR/kWh compared to 0.04 EUR/kWh in Sweden), which increases the monetary weight of electricity in the model. In addition, the Hungarian electricity sector shows a relatively balanced contribution across sources, without a single dominant upstream country, indicating that the impact is more evenly distributed across the supply chain. At the level of direct impacts, the Hungarian electricity sector is mainly associated with higher risks related to discrimination in the workplace, limitations in collective bargaining and the right to strike, and occupational toxics and hazards. These factors increase the overall risk intensity of electricity, reinforcing its role as the main hotspot.

Overall, the comparison highlights that social LCA results are not driven by physical input quantities alone. While Sweden uses significantly more electricity per kilogram of product, its lower electricity price and lower risk profile reduce the associated impacts. Hungary shows the opposite pattern, where higher monetary flows and higher risk intensity make electricity the dominant contributor. This illustrates how SHDB based results are shaped by monetary valuation, sector specific labour intensity, and country specific risk profiles, as well as the structure of global supply chains.

Conclusion environmental and social impact

Electricity consumption is the biggest hotspot across the environmental LCA results, however, for social LCA we see that the hotspots are more varied and distributed between growing media, electrical equipment, and chemical inputs.

This difference highlights the fundamentally different drivers behind the two assessments. Environmental impacts are largely driven by physical input quantities, such as energy use, which explains the dominant role of electricity. In social LCA, however, impacts are shaped by a combination of monetary flows, labour intensity,

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and country specific risk profiles as defined in the SHDB. As a result, processes that are less significant from an environmental perspective, such as growing media or equipment, can become more relevant socially if they are linked to labour intensive sectors or higher risk supply chains.

Overall, this comparison shows that environmental and social hotspots do not necessarily align, and that combining both perspectives provides a more comprehensive understanding of the sustainability performance of vertical farming systems.

2.5 Mushrooms - France

Environmental impact

Only one LCA of mushrooms was conducted, which was based on data from the French living lab. Therefore, no comparison across different countries or production areas is possible. The data was collected for the year 2023. Figure 19 shows the life cycle contribution to LCA impact categories by life cycle stage for Mushroom production.

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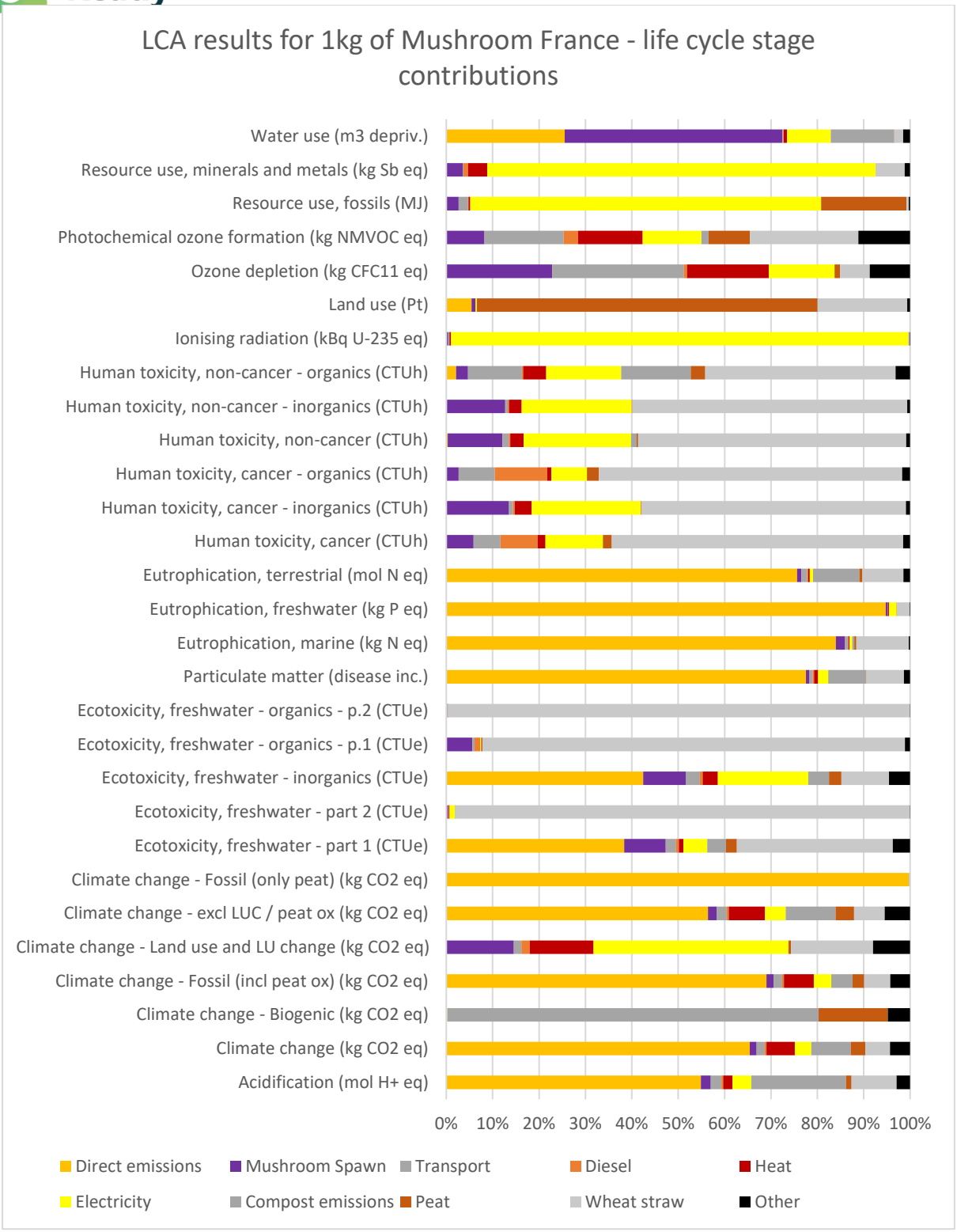

Figure 19: LCA results for Mushroom FR

Direct emissions, and emissions from compost are the main hotspot for many impact categories, including climate change (total, and biogenic), acidification, and eutrophication. This is due to the emissions released from the peat used as a growing medium, as well as from compost. Wheat straw is also a hotspot for categories

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related to human toxicity and freshwater ecotoxicity, due to pesticide use in the upstream production of the straw (which is based on background datasets from ecoinvent3.10, not primary data from the grower). Electricity use is also a hotspot for resource use and ionizing radiation, due to the high contribution of nuclear energy to France's residual grid, which results in electricity that is low carbon, but has higher relative environmental burdens in these other impact categories. Finally, peat production is the main land use hotspot, as the impact of peat extraction on land quality is significant, causing long-term degradation of soil organic carbon and biodiversity loss (Räsänen et al., 2023).

As this was the only scenario where Mushroom cultivation was assessed, there is no direct comparison available with other production locations or systems. The closest comparison is with the vertical farms (as they both represent indoor systems, in a controlled agricultural environment). However, we see that the hotspots are very different across the two types of systems, as in the vertical farm electricity use is the main hotspot, whilst for the Mushroom farm impacts from the casing and substrates used are the main contributors to environmental impact. This more closely resembles the trends seen in open field systems where hotspots are mainly from the fertilizer and nutrition requirement for cultivation. The Mushroom case study is also the only scenario which directly uses peat in its operations, which can have a significant negative environmental impact (as highlighted above). To ensure long term sustainable production, alternative mediums could be investigated by the grower (Goglio et al., 2025).

Social impact

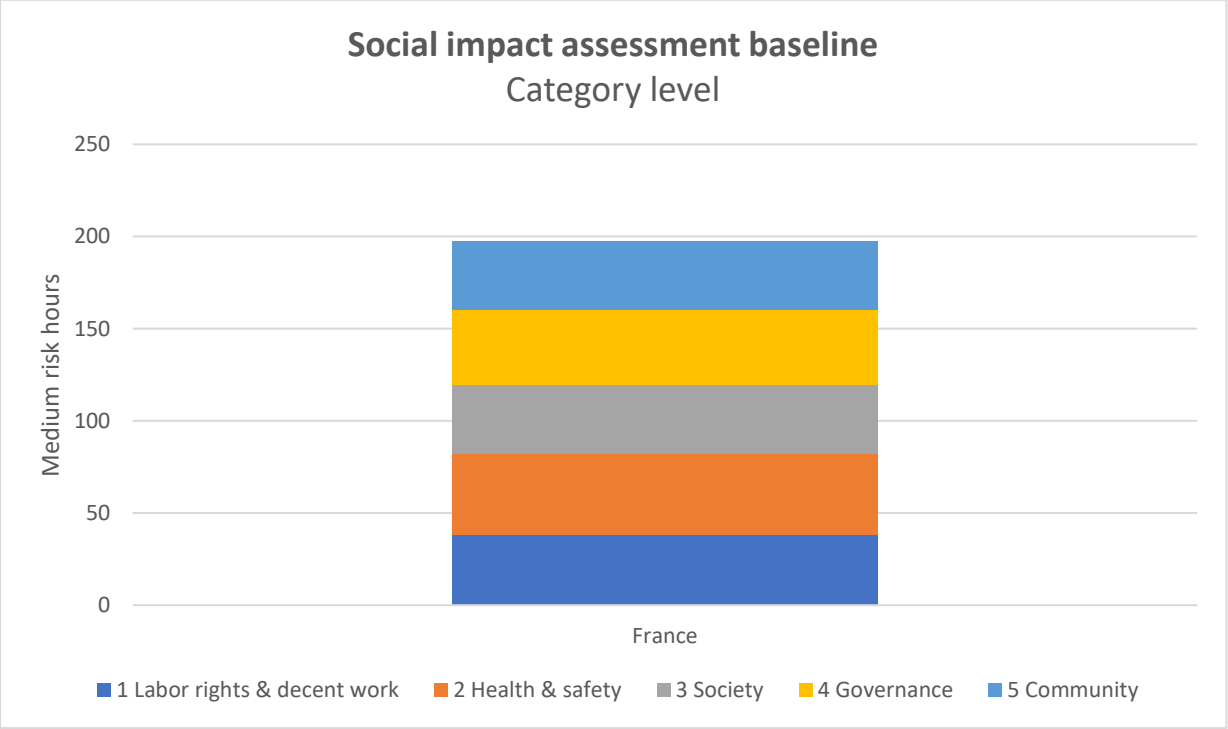

Figure 20: Upstream social impacts on impact category level for mushrooms from France

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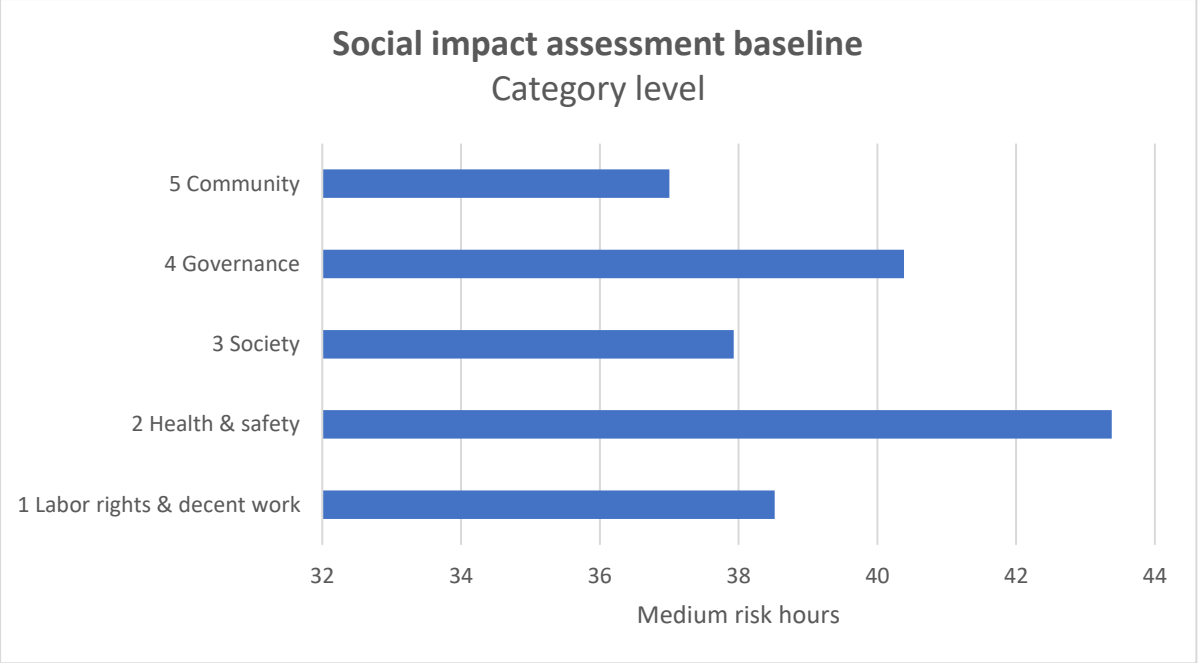

Figure 21: Upstream social impacts on impact subcategory level for mushrooms from France

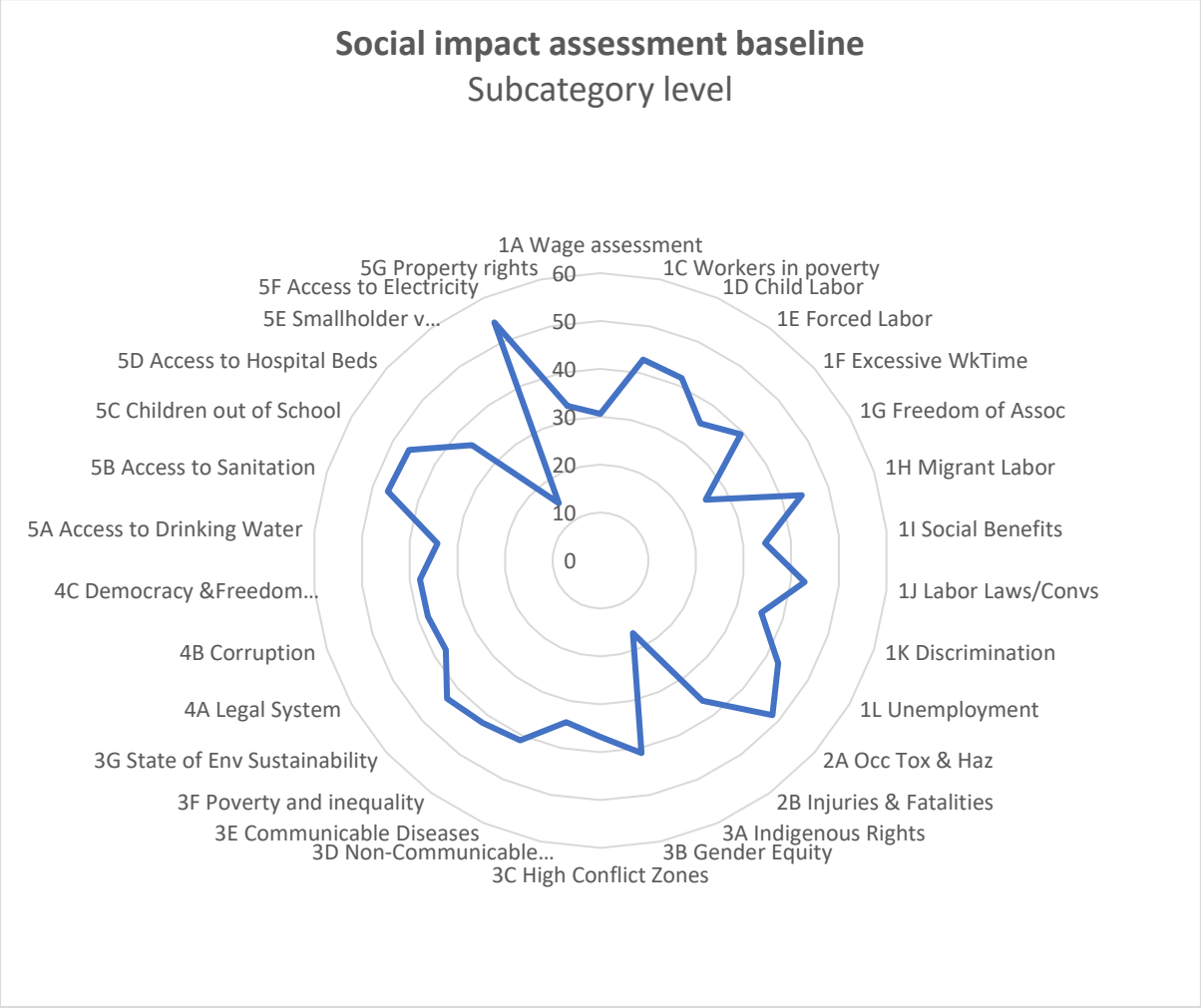

Figure 22: Upstream social impacts on impact subcategory level for mushrooms from France

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For French mushroom production in 2024, the most significant impact category is health and safety (2), followed by governance (4), as shown in Figure 20 and Figure 21. At the level of impact subcategories (Figure 22), the main contributors are access to electricity and occupational toxicity and hazards. The largest contributing processes are tuffeau/limestone (modelled as minerals) (43%) and spawn (26%), the latter representing the starting material modelled as cereal grains. Overall, the impact profile is therefore mainly driven by mineral inputs, with a secondary contribution from biological starting materials.

The results for French mushroom production do not show a single clearly dominant upstream country or sector driving the impacts. Instead, contributions are relatively distributed across supply chain elements. A slightly higher contribution can be observed from transport (XCB), indicating that logistics and intermediate supply steps play a non-negligible role in the overall social impact profile. At the level of direct impacts in France, both mineral extraction and cereal-based inputs are mainly associated with occupational toxics and hazards. This reflects exposure risks in upstream production processes such as extraction activities and agricultural handling, rather than issues within the mushroom cultivation process itself.

Conclusion environmental and social impact

In the social LCA results we see that limestone and spawn have the highest contribution to social risk, whilst from the environmental LCA the life cycle stage with highest contribution varies by impact category, with wheat straw and direct emissions being the most common hotspots. This indicates that environmental and social hotspots do not necessarily align, reflecting the different underlying mechanisms captured by each assessment. For example, environmental impacts associated with wheat straw are partly driven by pesticide use and related ecotoxicity, which is reflected in environmental impact categories but is not represented in social LCA indicators. On the other hand, the social LCA reflects the upstream social risks associated with mineral extraction processes linked to limestone, which is not captured by environmental metrics. Together, these results highlight that environmental and social LCAs describe different dimensions of upstream production burdens. Rather than overlapping, they provide complementary perspectives, where environmental LCA captures emission and ecosystem-related pressures, while social LCA highlights labour-related and socio-economic risks across global supply chains. Combining both therefore provides a more complete understanding of the sustainability profile of food production systems.

2. MAGNET scenario results

Prospective analysis was conducted using the outputs of the MAGNET model. The output of MAGNET tells us how things may change in the future; specifically, how energy, chemical, and other inputs used by each sector and country are projected to change. Using LCA, we investigate how a change of input quantities would

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influence the environmental and social impact of food production. Annex 4 includes a more detailed explanation of the methodology. The results from prospective LCA as presented based on the scenario results from three shared socio-economic pathways (SSP1,2 and 3) run with the MAGNET model. We compare the green road (SSP1), middle road (SSP2), and rocky road (SSP3) scenarios, for two timesteps (2030 and 2050). Therefore, for each baseline result from the environmental and social LCAs, six corresponding prospective results are found. Table 1 shows the range of prospective LCA results calculated, which are all available to view in the ECOREADY observatory.

Table 1: Prospective LCA results available in the observatory (✓shows that results are available)

Living lab product	**Social LCA impact per kg:** *Labour rights and decent work, Health and safety, Human rights, Governance, Community infrastructure, Migrant labour*							**Environmental LCA impact per kg:** *Acidification, Climate change, Ecotoxicity, Particulate matter, Eutrophication, Human toxicity, Land use, Ozone depletion, Photochemical ozone formation, Resource use, Water use*						
	Baseline	SSP1		SSP2		SSP3		Baseline	SSP1		SSP2		SSP3	
		2030	2050	2030	2050	2030	2050		2030	2050	2030	2050	2030	2050
Wheat, CZ	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Barley, DK	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mushroom, FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Barley, DE (1 & 2)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tomato, GR	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Leafy Greens, HU	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tomato, IT(1,2, & 3)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Barley, PL	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wheat, ES	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Leafy Greens, SE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Whilst the observatory shows the individual results per living lab and product, here we reflect on the general trends observed across the prospective analysis and link the interpretation to the underlying assumptions of the MAGNET model itself. Figure 23 shows the overall trend across all 10 living lab products for climate change

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potential. The results are presented relative to the baseline result, with the baseline value represented by 100%, and the results of the prospective scenarios represented as a percentage of the baseline. Values under 100% represent a proportional reduction in climate change potential per kg of product, and values over 100% represent an increase.

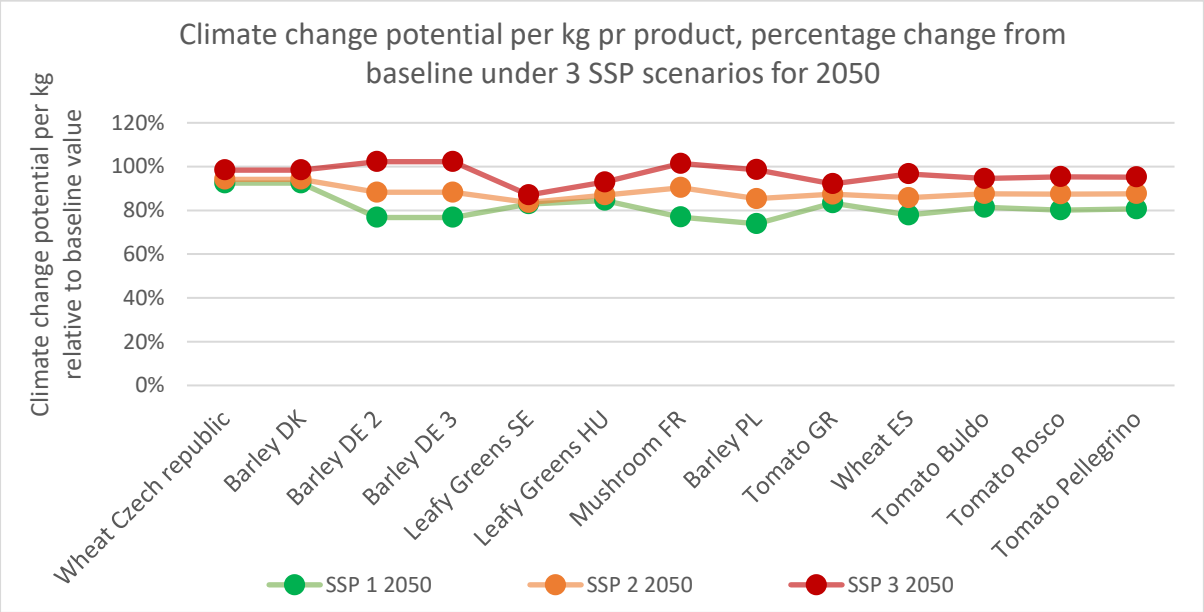

Figure 23: Change in climate change potential per kg of product across 3 SSP scenarios

The figure shows that for most scenarios, the value for climate change potential per kg of product decreases, even for SSP3 (rocky road). However, there is a more significant decrease in the SSP1 (green road) scenario. This is as this scenario sees a move to less intensive production methods, and therefore a decrease in fertilizer and chemical use, as well as energy efficiency improvements that reduce the diesel and electricity consumption per kg of product.

Living lab scenarios with higher inputs of fertilizers, chemicals and energy also see the largest change in projected impacts per kg. For example, the Czech Wheat case study has no inorganic fertilizer or chemical inputs and therefore sees less changes. This is only one noticeable parameter changes here (energy use), whilst for other living labs the impacts from fertilizers and chemical inputs also change, resulting in a compounding reduction in impacts. This underscores the fact that lower input, already sustainable systems are less impacted by policies meant to discourage unsustainable practices (such as a greenhouse gas emissions tax).

Figure 24 combines data across all 10 living labs, and all environmental impact categories, to show the overall trend across the SSP scenarios for environmental impact. Therefore, whilst in figure z we see only the results for climate change potential, here we can observe the general trend. The biggest reductions are observed for SSP1 2050, but this category also shows the biggest range of results. In comparison, SSP3 2050 shows a smaller range, and smaller average reduction in impacts. This is also the only scenario that shows some instances of increased

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environmental impact; for the Danish, German, and French living labs (where the LCAs are for Barley and Mushrooms). This is due to two factors: first the projected change in the market estimated by MAGNET for these sectors and countries, and second, the impact hotspots for the LCA results. The MAGNET scenarios vary by country and sector, and therefore, more extreme increases in fertilizer and chemical use can be observed for these scenarios than others, coupled with the fact that the LCA results themselves are more sensitive to adjustments in inputs.

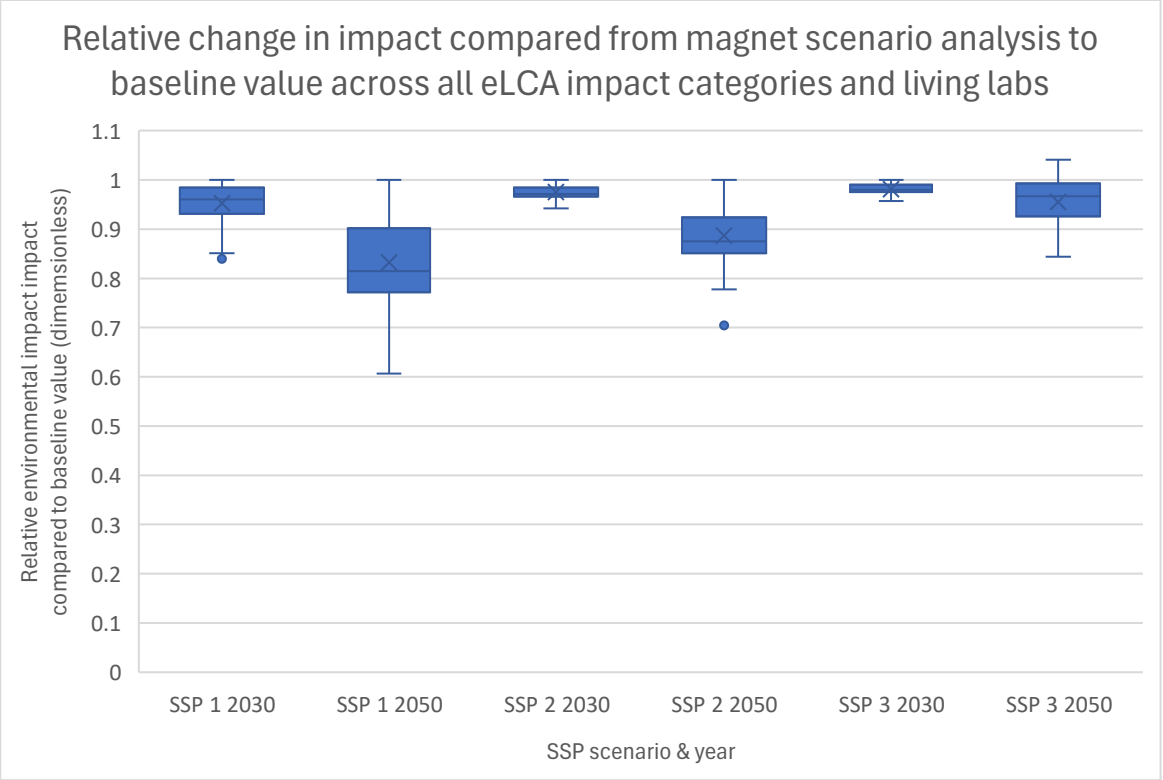

Figure 24: Relative change in environmental impact from SSP scenarios

The biggest decreases in impact per kg of product are observed for the tomato case studies; for example, acidification potential of 1kg of Greek industrial tomatoes is expected to decrease by 34% under the SSP1 2050 scenario. This as the main hotspot for this impact category is field emissions from inorganic fertilizer applied to the field, and as the MAGNET SSP1 scenario projection that fertilizer use will decrease by around 45% in the Greek fruits sector by 2050. Therefore, we see the compounding effect of changes predicted by MAGNET, and the LCA hotpots.

3. Limitations

The work presented here is based on 10 living labs, and therefore, comparisons made across countries, products, and production systems are case study specific. Observed trends are not necessarily representative of all food production systems, and therefore, whilst the strength of the work is in its relevance and applicability to the

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living labs involved in the ECOREADY project, there is a limitation found due to the sample size of products and locations compared.

We also observe a limitation from the prospective analysis, as in this work we combine living lab level data from the LCAs, with country and sector level data from the MAGNET model. Therefore, there is a discrepancy related to the level of detail and aggregation available across both data sources, where in many cases the MAGNET model can only give trends for larger sector aggregates such as vegetables instead of mushrooms or leafy greens. The outcomes of this novel approach to a prospective analysis are therefore speculative and a non-exhaustive investigation into the potential future impacts of food production systems.

Finally, we observe limitations of LCA as a method, as LCA does not quantify all sustainability metrics. Additional factors such as biodiversity, soil quality, and nutritional value, are not captured here, but are still important to consider when building a sustainable food system. LCA also compared impact per product unit (in this case per kg), and therefore, does not compare impacts per land area, or the total cumulative impacts of different product sectors. A further consideration is the temporal representativeness of the data: inventory data was collected for a specific year, while the environmental and social background databases used do not necessarily correspond to that same year, and the primary data reflects a single growing season rather than multiple years, meaning weather and yield fluctuations across years are not captured. Future work could build on these findings with a dedicated uncertainty or sensitivity analysis to further strengthen confidence in the results.

Similarly, the S-LCA results presented in this report are based on secondary data from the SHDB database rather than data collected directly from the living lab farms, reflecting the most likely social risks associated with each farm's geographic location and value chain rather than the actual social conditions on site, since this type of assessment relies on sector and country level averages rather than farm specific practices or worker experiences.

Given these limitations, we recommend that the conclusions from this work are complemented with Annex 5 (a qualitative report on the social impacts of the living labs, based on primary data) and Annex 6 (findings from a workshop with the farmers), as well as with other outcomes of the ECOREADY project, so that a more holistic picture can be considered.

4. Conclusions

10 representative products were investigated using environmental and social LCA, along with prospective scenario analysis based on the MAGNET model. These results are integrated into the ECOREADY observatory, to show the environmental and social impacts of these 10 products, as well as their prospective future impacts based on a green road, middle road, and rocky road socio-economic scenario.

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Although environmental and social hotspots differ by product, system, and country, several consistent trends stand out. Most environmental hotspots are associated with fuel use, fertilizers, and pesticides, whereas social hotspots upstream are more often tied to chemical inputs, diesel, electricity, transport, and starting materials. It was found that yield is a sensitive parameter, and for many environmental and social impact categories (including climate change potential) lower yields result in higher impact per kg of product as resources are used less efficiently. Exceptions to this are related to the ecotoxic impact of pesticides and the social impacts more broadly, since these depend jointly on the physical input required per functional unit and its monetary value.

From the MAGNET results, we find that environmental and social impacts of products decrease the most under the green road SSP1 scenario, and the least under the rocky road SSP3 scenario. This is due to underlying assumptions included in the MAGNET model; where the green road scenario sees more efficiency gains and lower energy consumption per kg of product as well a concerted effort towards sustainability such as a tax on greenhouse gas emissions and a reduction in meat consumption. Under the rocky road, on the other hand, we see less investment into technological development, and more intensive resource use, increased meat consumption and a fragmentation of global trade which increase prices. The findings therefore show that the future scenario with lowest social impact also has the lowest environmental burdens. It also shows that proposed strategies implemented within the SSP1 scenario (such as higher carbon taxes) could have a positive effect on environmental and social impacts.

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Chapter 2: Methodology report for LCA & MAGNET-prospective LCA



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1. Introduction

This methodology report is presented as supplementary document to the LCA results seen in the ECOREADY Observatory. It outlines the background data, inventories, and assumptions made in modelling 10 separate social and environmental LCA models for the 10 ECOREADY living labs.

2. Goal and Scope

As part of the ECOREADY project, 10 life cycle assessments were completed, based on data collected from each participating living lab. These living labs span a range of European geographies and production systems and are described in more detail in D1.4.

Across all living labs, over 40 unique food products are produced, ranging from livestock and animal products, cereals, oilseeds, roots, fruits, and vegetables. From each living lab, one horticultural product was chosen to be modelled using life cycle assessment.

The products were chosen to achieve representativeness across multiple products and locations, but also to group product types together into "clusters" that could therefore provide comparison across the production of the same product in various locations. For example, barley is compared across three locations, whilst wheat, tomatoes, and leafy greens are compared against two locations. Only one location is considered for mushrooms. There is also a variation of cultivation types; three examples of vertical farms or soilless systems, one organic cultivation scenario, with the remainder being open field conventional production systems. The selection of products for LCA modelling was determined in collaboration with each Living Lab. To ensure comparability across different countries and production systems (organic vs. conventional), a set of product clusters was established. These clusters reflect the crops of highest interest to the Living Labs and include wheat, barley, tomato, leafy greens, and mushrooms. Table 2 provides an overview of each Living Lab and the corresponding product chosen for LCA modelling.

Table 2: Overview of products modelled with LCA

Living Lab name and location	Total products produced	Product chosen for LCA	Functional unit
PROBIO, Czech Republic	Pork, Buckwheat, Spelt, Alfalfa, Crimson Clover	Wheat (organic)	1 kg
LivOrganic, Denmark	Milk and Dairy (cow's milk), Apples, Potatoes, Rapeseed, Sugar Beets, Barley	Barley	1 kg
LOFS, France	Wheat, Milk (grass-fed cows), Lettuce, Rapeseed, Mushroom	Mushroom	1 kg

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ESAPPIN, Germany	Barley, Raspberries, Strawberries, Oats, Rapeseed for edible oil and protein extraction, Champignons	Barley	1 kg
THALLA, Greece	Honey, Table olives, Tomatoes (industrial), Wheat, Gilthead seabream & European seabass	Industrial tomatoes	1 kg
EcoVitaLL, Hungary	Wheatgrass, Baby-leaf salad, Millet, Red clover, Sunflower, Amaranth	Baby leaf salad	1 kg
AideMec, Italy	Barley, Tomatoes, Durum wheat, Local beans, Mono varietal field-"Cortina" olives	Industrial tomatoes	1 kg
EcoReadyMasuria, Poland	Milk, Fodder maize, Barley, Red clover, Sunflower	Barley	1 kg
CONCAT LL, Spain	Poultry, Apples, Wheat, Flathead grey mullet, Olive trees for either olive oil or table olive production	Wheat	1 kg
SECO-Collab, Sweden	Leafy greens, Herbs, Microgreens, Chilli, Brassica	Leafy Greens	1 kg

The intended application of study is for use in the ECOREADY Observatory, and in the wider ECOREADY project. The baseline LCA results are presented as examples and are based on specific case study data. They should therefore not be taken as representative values for wider geographies or production systems.

The LCA analyses were conducted using Simapro Analyst 10.3.01 [1] (Environmental LCA) and OpenLCA [2] (Social LCA). Background datasets were used from AGRIBALAYSE [3] ecoinvent v3.11 [4], and Social Hotspots Database (SHDB) [5]. The freshproducePEFCR was used as a guiding document in executing all the eLCA models [6].

The baseline LCA data is then used along with inputs from the MAGENT general equilibrium model to conduct a prospective social and environmental life cycle assessment of the 10 assessed products (Figure 25). The methodological approach for prospective analysis is described in section 6 (page 87), and more details related to the MAGNET model are given in D1.5.

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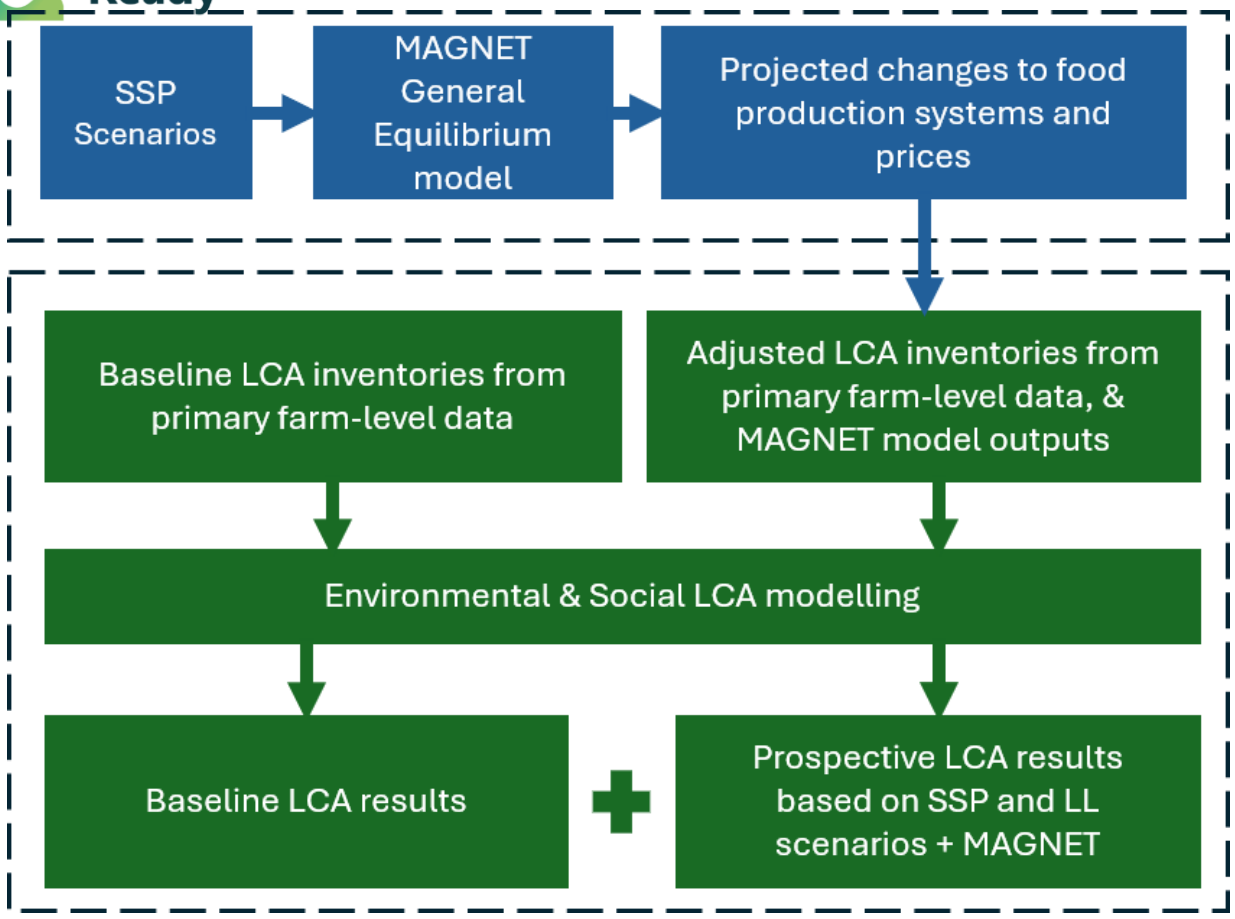

Figure 25: Workflow overview for baseline + prospective LCA

3. Inventory Analysis by Living Lab

Where possible, the inventories for the life cycle assessments were based on primary data collected from each living lab. This included data collection on fertilizer, pesticide, and herbicide use, agricultural activities, processing, and any other relevant activities undertaken. Supplementary secondary data was used where primary data was not available, along with relevant background datasets [3], [4], [5]. For the social impact assessment, next to the amount of product used in the system, also the monetary value of each input had to be identified to model in the Social Hotspots Database (SHDB) which works based on monetary flows. Where available, primary data from the Living Labs, including procurement prices in the reference year, were used. In cases where this information was missing, secondary data sources were consulted to estimate the USD value of the inputs for the same reference year. The resulting price data are not reported in this methodology report due to confidentiality and privacy constraints.

The inventory tables specify whether inputs are included in both LCIs, or only in the environmental or social LCI. In general, elements that are relevant for the environmental impact assessment but have no associated social impact are excluded from the social LCI. This includes, for example, land occupation, manure as a by-product of livestock, and rain or well water. Next to that, plant protection products

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are represented as active ingredients in the environmental LCI, and in the tables below as well, while the social LCI uses total pesticide formulations. This is because environmental modelling focuses on substance-level emissions, whereas social data is linked to commercially available products for which price data can be obtained, since only formulated products have observable market prices.

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3.1. Wheat (organic) - PROBIO, Czech Republic

Data inputs for this LCA were collected in collaboration with the LL with data points on production volume, yield, fertilizer use, and agricultural activities provided. This living lab is an organic food producer, where wheat crops are grown in rotation with nitrogen fixing alfalfa. Alfalfa is cultivated for 2.5 years, after which it is incorporated into the soil to build up soil organic matter and enhance nutrient cycling and microbial activity. As the organic farm does not use any chemical fertilizers, this stage is crucial in ensuring that enough nitrogen is available in the soil for the winter wheat crop. The impacts from alfalfa cultivation are therefore also allocated to the wheat crop, as it acts as a fertilizer. Fuel consumption for alfalfa cultivation was based on annual fuel consumption of the farm, allocated by area of the field, and multiplied by growing time (2.5 years). No mineral fertilizers or pesticides are used. The reference unit is the production of 3500kg of wheat over 1 Hectare, with a functional unit of 1 kg. Table 3 presents the respective inventory data.

Table 3: LCA Inventory for Wheat in CZ

Inputs	Amount	Unit	Included in environmental (E) and/or social (S)	Comment
Occupation, annual crop, CZ	1	Ha	E	
Water, unspecified natural origin, CZ	2685	m3	E	Taken from publication on water footprints and crop water use [7]. Excluded in Social LCA since no direct social impacts are linked to water from natural sources.
Wheat grain, start material, at seed production {CZ} Economic, U	215	Kg	E + S	Based on activity data
Alfalfa seed, organic, at farm gate {FR} S	20	Kg	E + S	Based on recommended sowing rate of alfalfa as green manure (20kg/Ha) [8].

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Energy, from diesel burned in machinery {RER} Economic, S	7975	MJ	E + S	Fuel for alfalfa cultivation – based on activity data allocated by area and time.
Electricity, low voltage {CZ}| electricity, low voltage, residual mix | Cut-off, S	78	kWh	E + S	Based on activity data 71 kWh for cultivation, and 6 kWh for storage.
Energy, from diesel burned in machinery {RER} Economic, S	3190	MJ	E + S	Fuel for wheat cultivation – based on activity data allocated by area and time.
Transport, freight, lorry, >32 metric ton, diesel, EURO 6 {RER}| transport, freight, lorry, >32 metric ton, diesel, EURO 6 | Cut-off, U	30,600	Kg.km	E + S	Transport scenarios calculated based on default FreshProducePEFCR [6] transport distance of 130km for goods transported to the farm.
Outputs				
Organic wheat	3500	Kg		Activity data

3.2. Barley - LivOrganic, Denmark

This farm is 5 ha, where conventional Barley is grown with one round. Primary data was used for all inputs apart from water use and transport distances to farm. The reference unit is 3000kg of Barley produced over 1 hectare. Table 4 presents the respective inventory data.

Table 4: LCA Inventory for Barley in DK

Inputs	Amount	Unit	Included in environmental (E) and/or social (S)	Comment
Occupation, annual crop, DK	1	Ha	E	
Water, unspecified natural origin, DE	2120	m3	E	Taken from publication on water footprints and crop water use [7].

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				Excluded in Social LCA since no direct social impacts are linked to water from natural sources.
Barley grain, start material, at seed production {DK} Economic, U	170	kg	E + S	Primary data
NPK compound (NPK 15-15-15), at plant {RER} Economic, U	616	kg	E + S	Proxy for YARA NPK 21-4-10
Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), at plant {RER} Economic, U	59.4	kg	E + S	Proxy for Flexi foliar NPK 20-1-4. Value provided by the living lab in L/Ha. Divided by density to fix units.
Pyridine-compound {RER}| pyridine-compound production | Cut-off, U	0.047	kg	E + S	Primary data - active ingredient in pesticide
Triazine-compound {RER}| triazine-compound production | Cut-off, U	0.044	kg	E + S	Primary data - active ingredient in pesticide
Phenoxy-compound {RER}| phenoxy-compound production | Cut-off, U	0.563	kg	E + S	Primary data - active ingredient in pesticide
[sulfonyl]urea-compound {RER}| [sulfonyl]urea-compound production | Cut-off, U	0.0025	kg	E + S	Primary data - active ingredient in pesticide
Pesticide, unspecified {RER}| pesticide production, unspecified | Cut-off, U	0.043	kg	E + S	Primary data - active ingredient in pesticide
Transport, freight, lorry, >32 metric ton, diesel, EURO 6 {RER}| transport, freight, lorry, >32 metric ton, diesel, EURO 6 | Cut-off, U	1.10E+05	Kg.km	E + S	Transport scenarios calculated based on default FreshProducePEFCR [6] transport distance of 130km for goods transported to the farm.

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Energy, from diesel burned in machinery {RER} Economic, U	50	litre	E + S	Primary data
Outputs				
Barley	3000	Kg		Activity data

3.3. Mushrooms - LOFS, France

This living lab represents mushrooms grown in casings, using a growing medium of straw, manure, chicken droppings, and peat. The functional unit is 1kg of mushrooms. **Due to requests from the data provider, the LCA inventory for this product is not shared in this report.** Primary data from living lab was primarily used. Secondary data from Boldrin et al. 2011 was used for modelling peat substrate [9], and data from growing media PEFCR used for direct emissions from casing [6]. Yield and type of mushroom is also not disclosed to maintain data privacy for the grower.

3.4. Barley - ESAPPIN, Germany

For Germany, 2 separate inventories from 2 farms were collected. The first farm is an 88-acre farm, farmed by a single farmer. Primary data was used for most inputs, apart from diesel use, transport distances to farm, and water use, which were based on default values (PEFCR) or literature studies. The reference unit is 8800kg of barley grown over 1 hectare, with a functional unit of 1 kg of barley. Table 5 presents the respective inventory data.

Table 5: LCA Inventory for Barley in DE (Farm 1/2)

Inputs	Amount	Unit	Included in environmental (E) and/or social (S)	Comment
Occupation, annual crop, CZ	1	Ha	E	
Water, unspecified natural origin, DE	794	m^3	E	Taken from publication on water footprints and crop water use [7].

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				Excluded in Social LCA since no direct social impacts are linked to water from natural sources.
Barley grain, start material, at seed production {DE} Economic, U	140	kg	E + S	Primary data
Liquid urea-ammonium nitrate solution (NPK 30-0-0), at plant {RER} Economic, U	500	kg	E + S	Primary data for mineral fertilizer use. The fertilizer is ammonium nitrate urea 28%. 30% N urea-ammonium nitrate is used as a proxy background dataset.
Acetamide-anillide-compound, unspecified {RER}| acetamide-anillide-compound production, unspecified | Cut-off, U	0.1932	kg	E + S	The herbicide the active ingredients are flufenacet and diflufencian. Acetamide-anilide compound is used as a proxy for flufenacet. In social LCA this is included in the 0.6 kg Herold.
Transport, freight, lorry, >32 metric ton, diesel, EURO 6 {RER}| transport, freight, lorry, >32 metric ton, diesel, EURO 6 | Cut-off, U	8.32E4	Kg.km	E + S	Transport scenarios calculated based on freshproducePEFCR [6] default transport distance of 130km for goods transported to the farm.
Pyridine-compound {RER}| pyridine-compound production | Cut-off, U	0.0966	kg	E + S	The herbicide active ingredients are flufenacet and diflufencian. Pyridine-compound is used as a proxy for diflufencian.

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				In social LCA this is included in the 0.6 kg Herold.
Electricity, low voltage {DE}| electricity, low voltage, residual mix | Cut-off, S	2.84	kWh	E + S	Electricity consumption in storage. No electricity or fuel consumption in cultivation was provided. Divided by the harvested area of the crop.
Energy, from diesel burned in machinery {RER} Economic, U	3128.7	MJ	E + S	Diesel use was not provided, therefore is estimated based on literature data, with average diesel consumption of 86 litre/Ha. Energy content per litre assumed as 42.8MJ/kg, and conversion from litre to kg based on density of 0.85kg/litre [10].
Outputs				
Barley	8800	Kg		Activity data

The second farm in Germany is 16.2 Ha in total. Primary data was collected and used for all inputs, apart from water consumption and transport distances. The reference unit is 9500 kg of barley grown over 1 hectare, with a functional unit of 1 kg of barley. Table 6 presents the respective inventory data.

Table 6: LCA Inventory for Barley in DE (Farm 2/2)

Inputs	Amount	Unit	Included in environmental (E) and/or social (S)	Comment
Occupation, annual crop, DE	1	Ha	E	
Water, unspecified natural origin, DE	794	m^3	E	Taken from publication on water footprints and crop water use [7].

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				Excluded in Social LCA since no direct social impacts are linked to water from natural sources.
Barley grain, start material, at seed production {DE} Economic, U	130	kg	E + S	Primary data
Liquid urea-ammonium nitrate solution (NPK 30-0-0), at plant {RER} Economic, U	385	kg	E + S	AHL 28%N Primary data
Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), at plant {RER} Economic, U	110	kg	E + S	SSA fertilizer Primary data
Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), at plant {RER} Economic, U	100	kg	E + S	Primary data
Korn-Kali fertilizer	150	kg	E + S	Primary data for amount used. No background dataset was available for this fertilizer; therefore, a proxy inventory was used, based on chemical inputs [11]: potassium chloride (0.64kg/kg), magnesium sulfate (0.17kg/kg), sodium chloride (0.1lg/kg), magnesium chloride (0.02kg/kg) and potassium sulfate (0.02kg/kg)
Magnesium sulfate {RER}| magnesium sulfate production | Cut-off, U	10	kg	E + S	Primary data
Acetamide-anillide-compound, unspecified {RER}| acetamide-anillide-compound production, unspecified | Cut-off, U	0.1968	kg	E + S	Primary data

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				Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
[sulfonyl]urea-compound {RER}| [sulfonyl]urea-compound production | Cut-off, U	0.38	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Pyrazole {RER}| pyrazole production | Cut-off, U	0.1	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Pyridine-compound {RER}| pyridine-compound production | Cut-off, U	0.12	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Triazine-compound {RER}| triazine-compound production | Cut-off, U	0.3	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Morpholine {GLO}| morpholine production | Cut-off, U	0.13	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Dinitroaniline-compound {RER}| dinitroaniline-compound production | Cut-off, U	0.45	kg	E + S	Primary data

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				Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Phthalimide-compound {RER}| phthalimide-compound production | Cut-off, U	0.75	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Ethephon {GLO}| ethephon production | Cut-off, U	0.216	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Transport, freight, lorry, >32 metric ton, diesel, EURO 6 {RER}| transport, freight, lorry, >32 metric ton, diesel, EURO 6 | Cut-off, U	1.15E+05	Kg.km	E + S	Transport scenarios calculated based on default FreshProducePEFCR [6] transport distance of 130km for goods transported to the farm.
Energy, from diesel burned in machinery {RER} Economic, U	100	litres	E + S	Primary data
Electricity, low voltage {DE}| electricity, low voltage, residual mix | Cut-off, S	2.75	kWh	E + S	Primary data
Outputs				
Barley	9500	Kg		Activity data

3.5. THALLA, Greece

For tomatoes in Greece, primary data was used for all inputs, apart from transport distances. The reference unit is 145000 kg of tomatoes grown over 1 hectare, with a functional unit of 1 kg of tomatoes. Table 7 presents the respective inventory data.

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Table 7: LCA Inventory for Tomatoes in GR

Inputs	Amount	Unit	Included in environmental (E) and/or social (S)	Comment
Water, well, GR	6000	M3	E	Taken from publication on water footprints and crop water use [7]. Excluded in Social LCA since no direct social impacts are linked to water from natural sources.
Occupation, annual crop, GR	1	Ha	E	
Transport, freight, lorry, >32 metric ton, diesel, EURO 6 {RER}| transport, freight, lorry, >32 metric ton, diesel, EURO 6 | Cut-off, U	3.91E+04	Kg.km	E + S	Transport scenarios calculated based on default FreshProducePEFCR [6] transport distance of 130km for goods transported to the farm.
Imidazole {RER}| imidazole production | Cut-off, U	0.08	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Morpholine {GLO}| morpholine production | Cut-off, U	0.09	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.

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[thio]carbamate-compound {RER}| [thio]carbamate-compound production | Cut-off, U	0.1	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Pyridine-compound {RER}| pyridine-compound production | Cut-off, U	0.1	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Triazine-compound {RER}| triazine-compound production | Cut-off, U	0.12	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Acetamide-anillide-compound, unspecified {RER}| acetamide-anillide-compound production, unspecified | Cut-off, U	0.2	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Cyanoacetic acid {RER}| cyanoacetic acid production | Cut-off, U	0.5525	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Copper oxide {RER}| copper oxide production | Cut-off, U	0.7119	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Insecticide, at plant/RER Economic	1.52505	kg	E + S	Primary data

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				Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Pesticide, unspecified {RER}| pesticide production, unspecified | Cut-off, U	1.8288	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Dinitroaniline-compound {RER}| dinitroaniline-compound production | Cut-off, U	11.375	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Chloroacetic acid {RER}| chloroacetic acid production | Cut-off, U	12.48	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Organophosphorus-compound, unspecified {RER}| organophosphorus-compound production, unspecified | Cut-off, U	2	kg	E + S	Primary data Included as total formulated products in Social LCA, whereas this number represents just the active ingredient.
Potassium nitrate {RER}| potassium nitrate production | Cut-off, S	25	kg	E + S	Primary data
Inorganic nitrogen fertiliser, as N {CN}| nutrient supply from ammonia, anhydrous, liquid | Cut-off, U	34	kg	E + S	Primary data
Urea {RER}| urea production | Cut-off, U	40	kg	E + S	Primary data

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NPK (15-15-15) fertiliser {RER}| NPK (15-15-15) fertiliser production | Cut-off, S	41	kg	E + S	Primary data
Calcium ammonium nitrate {RER}| calcium ammonium nitrate production | Cut-off, U	44	kg	E + S	Primary data
Tomato seedling, for planting {IT}| tomato seedling production, in unheated greenhouse, for planting | Cut-off, S	62,910	p	E + S	Secondary data from ecoinvent3.11 [4] process for RoW tomato growing in open field.
Ammonium nitrate {RER}| ammonium nitrate production | Cut-off, U	86	kg	E + S	Primary data
Energy, from diesel burned in machinery {RER} Economic, U	1.68E4	MJ	E + S	Primary data
Electricity	4920	MJ	E + S	Estimated, based on electricity requirement for drip irrigation. Electricity per m3 irrigation taken from ecoinvent3.11 [4] process for drip irrigation in Spain (0.82 MJ/m3) multiplied by total water use. Blue water requirement of tomatoes in Greece is estimated to be 6000 m3/Ha (Based on water requirement data from ref [7]) Therefore, irrigation energy use is therefore estimated to be 0.82*6000MJ.
Outputs				
Tomatoes	135000	Kg		Activity data

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3.6. Leafy Greens - EcoVitaLL, Hungary

The Hungarian leafy greens are grown in a vertical farm, therefore, the capital infrastructure for growing is also accounted for in the inventory. The reference unit is 72 kg of tomatoes grown over 1 m^2, with a functional unit of 1 kg of leafy greens. Table 8 presents the respective inventory data.

Table 8: LCA Inventory for Leafy Greens in HU

Inputs	Amount	Unit	Included in environmental (E) and/or social (S)	Comment
Occupation, urban, HU	1	M^2	E	
Lettuce, seed, conventional, at production site {FR} S	0.0006	kg	E + S	Primary data on seeds: weight 0.001 gr/pc, with 55000 seeds used per year
Rock wool EU average	0.816	kg	E + S	Primary data
Calcium nitrate {RER}| calcium nitrate production | Cut-off, S	550	g	E + S	YaraLivaCalcinit Primary data
Magnesium sulfate {RER}| magnesium sulfate production | Cut-off, S	280	g	E + S	Primary data
Nitric acid, without water, in 50% solution state {RER w/o RU}| nitric acid production, product in 50% solution state | Cut-off, S	0.15	g	E + S	Primary data, diluted to 1%.
EDTA, ethylenediaminetetraacetic acid {RER}| ethylenediaminetetraacetic acid	20	g	E + S	Fe(EDDHA) – EDTA chelate used as a proxy. Primary data.

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production, alkaline cyanomethylation of ethylenediamine | Cut-off, S				
EDTA, ethylenediaminetetraacetic acid {RER}| ethylenediaminetetraacetic acid production, alkaline cyanomethylation of ethylenediamine | Cut-off, S	10	g	E + S	Tradecorp Bentley, proxy for EDTA chelate. Primary data.
Potassium sulfate {RER}| potassium sulfate production | Cut-off, S	190	g	E + S	Primary data
Monoammonium phosphate {RER}| monoammonium phosphate production | Cut-off, S	80	g	E + S	Momoammonium phosphate used as proxy for monopotassium phosphate.
Potassium nitrate {RER}| potassium nitrate production | Cut-off, S	130	g	E + S	YaraTera Krista K. Primary data.
Vertical farm CAPEX (HU)	1/86.4	p	E + S	Total CAPEX is for 1 year. Therefore, input is annual CAPEX divided by growing area which is 86.4m2.
Tap water {Europe without Switzerland}| market for tap water | Cut-off, S	0.1	kg	E + S	Primary data
Transport, freight, lorry, >32 metric ton, diesel, EURO 6 {RER}| transport, freight, lorry, >32 metric ton, diesel, EURO 6 | Cut-off, U	1.68E+03	km	E + S	Transport scenarios calculated based on default FreshProducePEFCR [6] transport distance of 130km for goods transported to the farm.
Electricity, low voltage {HU}| electricity, low voltage, residual mix | Cut-off, S	1000	kWh	E + S	Primary data
Outputs				

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Leafy Greens	72	Kg	Activity data

Capital expenditures (CAPEX) for the vertical farm are also based on primary data. The material lifespans are based on the same assumptions as used for the Swedish vertical farm (Unni Barge, 2020). Table 9 presents the respective inventory data.

Table 9: LCA sub-inventory for vertical farm CAPEX in HU

Inputs	Amount	Material lifespan (years)	Input	Included in environmental (E) and/or social (S)	Comment
Aluminium, primary, ingot {IAI Area, EU27 & EFTA}| aluminium production, primary, ingot | Cut-off, S	3000 kg	50	60 kg	E + S	Primary data
Section bar extrusion, aluminium {RER}| processing | Cut-off, S	3000 kg	50	60 kg	E + S	Processing for aluminium
Polypropylene, granulate {RER}| polypropylene production, granulate | Cut-off, S	1200 kg	15	80 kg	E + S	Primary data
Light emitting diode {GLO}| light emitting diode production | Cut-off, S	1.88 g	6	0.313 g	E + S	LED light, assuming each light weight 0.01grams (expert judgement).
Stretch blow moulding {RER}| stretch blow moulding | Cut-off, S	1200 kg	15	80 kg	E	Processing for polypropylene

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Outputs					
Vertical farm CAPEX (HU)	1	n/a	1		1 farm, allocated by area and operational years.

3.7. Industrial Tomatoes - AideMec, Italy

Three tomato production sites were considered. The reference units are 95,000 kg, 130,000 kg and 100,000kg of tomatoes grown over 1 hectare for farm 1, 2, and 3 respectively, with a functional unit of 1 kg of industrial tomatoes. Table 10 presents the respective inventory data.

Table 10: LCA Inventory for Industrial Tomatoes in IT

Inputs		Farm 1	Farm 2	Farm 3	Included in environmental (E) and/or social (S)	Comments
Water, river, IT	m^3	6000	6000	6000	E	Taken from publication on water footprints and crop water use [7]. Excluded in Social LCA since no direct social impacts are linked to water from natural sources.
Occupation, annual crop, IT	ha.yr	1	1	1	E	
Tomato seedling, for planting {IT}| tomato seedling production, in unheated greenhouse, for planting | Cut-off, U	p	33000	33000	33000	E + S	Primary data

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Tomato plant debris - IT		kg	2500	2500	2500	E	Dummy proxy for organic waste residues after tomato cultivation that us left in the field.
Biodigestate (Olive pomace using anaerobic digestion)		kg	0	42	0	E + S	NPK content was taken from an online publication, with average of data points taken [12].
Humic acid		kg	0.25	1.6	1.33	E + S	Dummy proxy for humic acid. No included in emission modelling since it is used as soil amendment.
NPK compound (NPK 15-15-15), at plant {RER} Economic, U		kg	400	250	250	E + S	Yara partner in Social LCA. For farm 1, NPK is used as a proxy for Timac F1 and Magnific fertilizers.
Calcium nitrate 15.5 + calcium fertilizer	Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), at plant {RER} Economic, U	kg	220.5	220.5	220.5	E+S	Value including only CAN without CaO
	Limestone, unprocessed {RoW}| limestone quarry operation | Cut-off, U	kg	142.305	142.305	142.305		Amount of calcium added to fertilizer. % CaO 26.5. Conversion factor CaO to CaCO3 - 1.79
Ammonium sulfate, as 100% (NH4)2SO4 (NPK 21-0-0), at plant {RER} Economic, U		kg	200	150	150	E + S	

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Urea phosphate	Phosphoric acid, merchant grade (75% H3PO4) (NPK 0-54-0), at plant {RER} Economic, U	kg	50	30	30	E + S	Urea phosphate is modelled based on equal quantities of phosphoric acid and urea
	Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), at plant {RER} Economic, U	kg	50	30	30		
Acetamide-anillide-compound, unspecified {RER}| acetamide-anillide-compound production, unspecified | Cut-off, U		kg	0.074	0.074	0.074	E + S	Taken as Herbicide total amount of product in Social LCA.
Triazine-compound {RER}| triazine-compound production | Cut-off, U		kg	0.175	0.465	0.175	E + S	Taken as Herbicide total amount of product in Social LCA.
[sulfonyl]urea-compound {RER}| [sulfonyl]urea-compound production | Cut-off, U		kg	0.0125	0.0125	0.0125	E + S	Taken as Herbicide total amount of product in Social LCA.
Pyrethroid-compound {RER}| pyrethroid-compound production | Cut-off, U		kg	0	0.0092	0	E + S	Taken as Insecticide total amount of product in Social LCA.
Pesticide, unspecified {RER}| pesticide production, unspecified | Cut-off, U		kg	0.08	0.28	0.1	E + S	Taken as Pesticide total amount of product in Social LCA.
Insecticide, at plant {RER} Economic, U		kg	0.9046	0.2393	0.80978	E + S	Taken as Insecticide total amount of product in Social LCA.

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Copper sulfate {GLO}| copper sulfate production | Cut-off, U	kg	0	0.6	0.6	E + S	Taken as Fungicide total amount of product in Social LCA.
Diammonium phosphate {RER}| diammonium phosphate production | Cut-off, U	kg	0	250	0	E + S	
Transport, freight, lorry, >32 metric ton, diesel, EURO 6 {RER}| transport, freight, lorry, >32 metric ton, diesel, EURO 6 | Cut-off, U	km	3.86E+05	2.63E+06	1.32E+05	E + S	Transport scenarios calculated based on: - Bio digestates 15 km (primary data) - Bovine blood 10 km (primary data) - Organic phosphorus fertilizer 600km (primary data) - Default FreshProducePEFCR [6] transport distance of 130km for all other inputs
Energy, from diesel burned in machinery {RER} Economic, U	kg	747	1000	747	E + S	
Pyridine-compound {RER}| pyridine-compound production | Cut-off, U	kg	0.216	0	0.216	E	
Morpholine {GLO}| morpholine production | Cut-off, U	kg	0.3	0	0.16	E	
Nutriemo (Bovine liquid blood)	kg	0.5	0	0	E + S	Based on blood, beef, raw, processed in FR from Agribalyse [3].
[thio]carbamate-compound {RER}| [thio]carbamate-compound production | Cut-off, U	kg	0	0	1.1	E	

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Organic phosphorus fertiliser, as P2O5 {GLO}| market for organic phosphorus fertiliser, as P2O5 | Cut-off, U	kg	0	0	33.33333	E + S	
Output						
Industrial tomatoes	Kg	95,000	130,000	100,000		Total yield per Ha

3.8. Barley- EcoReadyMasuria, Poland

The reference unit is 8000 kg of barley and 3000 kg of straw grown over 1 hectare, with a functional unit of 1 kg of barley. Table 11 presents the respective inventory data.

Table 11: LCA inventory for Barley in PL

Inputs	Amount	Unit	Included in environmental (E) and/or social (S)	Comment
Occupation, annual crop, PL	1	Ha		
Water, unspecified natural origin, PL	2813	m^3	E	Taken from publication on water footprints and crop water use [7]. Excluded in Social LCA since no direct social impacts are linked to water from natural sources.
Barley grain, start material, at seed production {PL} Economic, U	80	kg	E + S	
Horse manure (ECOREADY)	20	ton	E	Excluded in Social LCA since no direct social impacts are linked to manure production,

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				since it is a side product from livestock farming.
NPK compound (NPK 15-15-15), at plant {RER} Economic, U	250	kg	E + S	Proxy for Polisfoka NPK 6-2-30
Calcium ammonium nitrate (CAN), (NPK 26.5-0-0), at plant {RER} Economic, U	300	kg	E + S	Proxy for Salestrosan 26
Limestone, unprocessed {RoW}| limestone quarry operation | Cut-off, U	2000	kg	E + S	Proxy for chalk lime
Insecticide, at plant/RER Economic	0.00696	kg	E + S	
Acetamide-anillide-compound, unspecified {RER}| acetamide-anillide-compound production, unspecified | Cut-off, U	0.147	kg	E + S	
Triazine-compound {RER}| triazine-compound production | Cut-off, U	0.174	kg	E + S	
Trinexapac-ethyl {GLO}| trinexapac-ethyl production | Cut-off, U	0.075	kg	E + S	
Pyrazole {RER}| pyrazole production | Cut-off, U	0.105	kg	E + S	
Pyrethroid-compound {RER}| pyrethroid-compound production | Cut-off, U	0.0021	kg	E + S	
Pesticide, unspecified {RER}| pesticide production, unspecified | Cut-off, U	0.0525	kg	E + S	
Diphenylether-compound {RER}| diphenylether-compound production | Cut-off, U	0.075	kg	E + S	

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Transport, freight, lorry, >32 metric ton, diesel, EURO 6 {RER}| transport, freight, lorry, >32 metric ton, diesel, EURO 6 | Cut-off, U	3.45E+05	Kg.km	E + S	Transport scenarios calculated based on default FreshProducePEFCR [6] transport distance of 130km for goods transported to the farm.
Energy, from diesel burned in machinery {RER} Economic, U	75	litre	E + S	
Electricity, low voltage {PL}| electricity, low voltage, residual mix | Cut-off, U	0.69	kWh	E + S	
Outputs				
Barley production	8000	kg		Economic value and allocation used (0.14 EUR/kg) (provided by LL)
Straw, from barley	3000	kg		Economic value and allocation used (0.07EUR/kg) (provided by LL)

3.9. Wheat - CONCAT LL, Spain

The reference unit is 5042 kg of wheat and 5000 kg of wheat grown over 1 hectare, with a functional unit of 1 kg of wheat. Economic allocation used for impact allocation across wheat and straw produced. Economic value data was provided by the living labs. Table 12 presents the respective inventory data.

Table 12: LCA inventory for Wheat in ES

Inputs	Amount	Unit	Included in environmental (E) and/or social (S)	Comment
Occupation, annual crop, ES	1	Ha	E	

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Water, unspecified natural origin, ES	2750	m^3	E	Taken from publication on water footprints and crop water use [7]. Excluded in Social LCA since no direct social impacts are linked to water from natural sources.
Wheat grain, start material, at seed production {ES} Economic, U	81.78	kg	E + S	
Manure (cow), at farm {RER} Economic, U	8.62E4kg	kg	E	Based on annual manure use (209200 kg) divided by area of farm (24.26 Ha). Excluded in Social LCA since no direct social impacts are linked to manure production, since it is a side product from livestock farming.
Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), at plant {RER} Economic, U	150	kg	E + S	
Acetamide-anillide-compound, unspecified {RER}| acetamide-anillide-compound production, unspecified | Cut-off, U	0.2	kg	E + S	Taken together as plant protection products in Social LCA.
Triazine-compound {RER}| triazine-compound production | Cut-off, U	0.26	kg	E + S	Taken together as plant protection products in Social LCA.
Pyrethroid-compound {RER}| pyrethroid-compound production | Cut-off, U	0.05	kg	E + S	Taken together as plant protection products in Social LCA.

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Pesticide, unspecified {RER}| pesticide production, unspecified | Cut-off, U	2.11	kg	E + S	Taken together as plant protection products in Social LCA.
Diphenylether-compound {RER}| diphenylether-compound production | Cut-off, U	0.1	kg	E + S	Taken together as plant protection products in Social LCA.
Transport, freight, lorry, >32 metric ton, diesel, EURO 6 {RER}| transport, freight, lorry, >32 metric ton, diesel, EURO 6 | Cut-off, U	2.62E+06	kgkm	E + S	Transport scenarios calculated based on default FreshProducePEFCR [6] transport distance of 30km for manure, and 130km for other goods transported to the farm.
Energy, from diesel burned in machinery {RER} Economic, S	65.31	Litre	E + S	Taken from literature study as average diesel use per Ha, as no primary data was provided by the living lab [13].
Outputs				
Wheat production	5042.04	kg		Economic allocation, 0.2 EUR/kg (provided by LL)
Straw from wheat production	5000	kg		Economic allocation, 0.03 EUR/kg (provided by LL)

3.10. Leafy Greens - SECO-Collab, Sweden

Data for this living lab was not available, and therefore, secondary data from literature was utilized instead [14]. This data was collected for another study for the same production facility, and therefore, whilst it is from a secondary source, it is highly representative of the farm. Two scenarios were used in the study, a "current" scenario and a prospective scenario with higher production volume. The current scenario was taken in this assessment to ensure that real life data was used. The reference unit is 10800 kg of leafy greens grown, with a functional unit of 1 kg of leafy greens. Table 13 presents the respective inventory data.

Table 13: LCA Inventory for Leafy Greens in SE

Inputs	Amount	Unit	Included in environmental	Comment

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			(E) and/or social (S)	
Occupation, urban, SE	1	M^2	E	
Ammonium nitrate {RER}| ammonium nitrate production | Cut-off, S	61	kg	E + S	Included as a sum of all nutrients (61 + 22.8 + 7.7 + 12 + 40.1 + 10.3 kg = 276.6 kg nutrients) in Social LCA.
Ammonium nitrate {RER}| calcium nitrate production | Cut-off, S	22.8	kg	E + S	Included as a sum of all nutrients (61 + 22.8 + 7.7 + 12 + 40.1 + 10.3 kg = 276.6 kg nutrients) in Social LCA.
Lettuce, seed, conventional, at production site {FR} S	0.533332	kg	E + S	266666 seeds each weighing 0.002grams.
Magnesium oxide {RER}| magnesium oxide production | Cut-off, S	7.7	kg	E + S	Included as a sum of all nutrients (61 + 22.8 + 7.7 + 12 + 40.1 + 10.3 kg = 276.6 kg nutrients) in Social LCA.
Phosphate (P2O5) synthetic fertilizer application mix, at farm {GLO} Economic, S	12	kg	E + S	Included as a sum of all nutrients (61 + 22.8 + 7.7 + 12 + 40.1 + 10.3 kg = 276.6 kg nutrients) in Social LCA.
Potassium chloride, as K2O {RER}| potassium chloride production | Cut-off, S	40.1	kg	E + S	Included as a sum of all nutrients (61 + 22.8 + 7.7 + 12 + 40.1 + 10.3 kg = 276.6 kg nutrients) in Social LCA.
Rock wool EU average	2000	kg	E + S	Based on each plug weighing 15 grams [14] Included as growing media in Social LCA.

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Sulfur trioxide {RER}| sulfur trioxide production | Cut-off, S	10.3	kg	E + S	Included as a sum of all nutrients (61 + 22.8 + 7.7 + 12 + 40.1 + 10.3 kg = 276.6 kg nutrients) in Social LCA.
Tap water {Europe without Switzerland}| market for tap water | Cut-off, S	26795	kg	E + S	
Transport, freight, lorry, >32 metric ton, diesel, EURO 6 {RER}| transport, freight, lorry, >32 metric ton, diesel, EURO 6 | Cut-off, U	2.04E+06	Kg.km	E + S	Transport scenarios calculated based on - Rockwool 1000km (primary data) - Default FreshProducePEFCR [6] transport distance of 130km for all other goods
Vertical farm CAPEX (Sweden)	1	year	E + S	Split up in steel (1500 kg, aluminium 1400 kg and plastics 10200 kg) in Social LCA
Electricity, low voltage {SE}| electricity, low voltage, residual mix | Cut-off, S	646485.5	kWh	E + S	
Outputs				
Leafy Greens	10800	kg		

The CAPEX of the vertical farm is calculated based on 1 year of lifetime. The lifespan of materials were based on the literature source used for the inventory data [14]. Table 14 presents the respective inventory data.

Table 14: LCA sub-inventory for vertical farm CAPEX in SE

Inputs	Amount	Unit	Included in environmental (E) and/or social (S)	Material lifespan (years)	Comment

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Steel, low-alloyed {Europe without Switzerland and Austria}| steel production, electric, low-alloyed | Cut-off, S	1500	kg	E + S	50	
Aluminium, primary, ingot {IAI Area, EU27 & EFTA}| aluminium production, primary, ingot | Cut-off, S	1400	kg	E + S	50	
Polyvinylchloride, bulk polymerised {RER}| polyvinylchloride production, bulk polymerisation | Cut-off, S	4590	kg	E + S	25	45% of total plastic weight Included as total plastic (10200 kg) with a lifespan of 15 years.
Polyethylene terephthalate, granulate, amorphous {RER}| polyethylene terephthalate production, granulate, amorphous | Cut-off, S	4590	kg	E + S	3	45% of total plastic weight Included as total plastic (10200 kg) with a lifespan of 15 years.
Packaging film, low density polyethylene {RER}| packaging film production, low density polyethylene | Cut-off, S	336.6	kg	E + S	15	3.33% of total plastic weight Included as total plastic (10200 kg) with a lifespan of 15 years.
Polypropylene, granulate {RER}| polypropylene production, granulate | Cut-off, S	336.6	kg	E + S	15	3.33% of total plastic weight Included as total plastic (10200 kg) with a lifespan of 15 years.

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Polyester resin, unsaturated {RER}| market for polyester resin, unsaturated | Cut-off, U	336.6	kg	E + S	1	3.33% of total plastic weight Included as total plastic (10200 kg) with a lifespan of 15 years.
Light emitting diode {GLO}| light emitting diode production | Cut-off, S	0.5	kg	E + S	6	Only 5% of total weight assumed to be LED diode.
Electronics, for control units {RER}| electronics production, for control units | Cut-off, S	130	kg	E	10	
Heat pump, 30kW {RER}| heat pump production, 30kW | Cut-off, S	1	Pcs.	E	20	
Pump, 40W {RoW}| pump production, 40W | Cut-off, S	32	Pcs.	E	10	
Refrigerator {GLO}| refrigerator production | Cut-off, S	1	Pcs.	E	10	
Ventilation control and wiring, central unit {RER}| ventilation control and wiring production, central unit | Cut-off, S	1	Pcs.	E	20	
Industrial machine, heavy, unspecified {RER}| production | Cut-off, S - Copied from Ecoinvent S	150	kg	E	10	
Ventilation duct, steel, 100x50 mm {RER}| ventilation duct production, steel, 100x50 mm | Cut-off, S	1200	m	E	50	
Outputs					
Vertical farm CAPEX (Sweden)	1	Year			Inputs are divided by their lifetime to give impacts of vertical farm per year.

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4. Inventory Analysis general assumptions and conversion factors

Whilst all the living labs have separate inventories; some assumptions and conversion factors are applied consistently across all models.

4.1. Diesel and energy

For diesel, the following conversion factors were used across all inventories

- Heating value of diesel = 42.8 MJ/kg [4]
- Heating value of natural gas = 31.65 MJ/kg [15]
- Density of diesel = 0.832 kg/litre [15]

4.2. Water use

Water use was based on primary data where possible. However, for some farms this level of data was not available, and therefore, water consumption was based on literature data [7].

4.3. Land use change

Direct land use change emissions were considered for all scenarios; however, no relevant direct land use change impacts were identified for any of the case studies investigated [16]. Indirect land use change was not considered. Land occupation was included for all case studies and are described in the individual inventory tables. Table 15 presents the respective inventory data.

Table 15: Land use change summary table

Country	Crop	Land use change
Czech Republic	Wheat	No land use change in last 20 years identified [16].
Spain	Wheat	No land use change in last 20 years identified [16].
Poland	Barley	No land use change in last 20 years identified [16].
Germany	Barley	No land use change in last 20 years identified [16].
Denmark	Barley	No land use change in last 20 years identified [16].
Sweden	Leafy Greens	Not relevant in vertical farm.
Hungary	Leafy Greens	Not relevant in vertical farm.
Italy	Tomatoes	No land use change in last 20 years identified [16].
Greece	Tomatoes	No land use change in last 20 years identified [16].

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France	Mushrooms	Not relevant as cultivation is soilless.

4.4. Capital expenditure (CAPEX)

Capital expenditure was only considered for the two vertical farms, as these were the only two scenarios where capital goods could noticeably contribute to environmental impacts. Impacts from capital goods were allocated to each m2 of the vertical farms by lifespan of material [14] and total production area available at the two farms.

4.5. Transport

Where possible, primary data on transportation was collected and used for the LCA scenarios. In most instances, primary data was not available, therefore, the default value from the freshproducePEFCR [6] was used consistently across all LCA models (30km for manure and 130 km for all other inputs). Downstream transport was excluded for all models, as the LCA boundary focused on cradle-to-farm gate production. Logistics of fresh produce are out of scope for this study.

4.6. Direct impacts from fertilizers and plant protection

Calculations for field emissions for all LCAs followed the same methodological approach. For fertilizers, the default approach outlined in the freshproducePEFCR [6] was used for all case studies.

Nitrogen, phosphorus and potassium content of organic fertilizers were calculated based on literature data [17]. For all mineral fertilizers, primary data was collected on nutrient make-up. Emissions from fertilizers were all calculated following the default modelling approach outlined in the freshproducePEFCR [6] , to ensure consistency across all case studies. Table 16 presents the approaches used by emission type.

Table 16: Modelling approaches for field emissions from fertilizers

Emission	Modelling approach
NH_3 and NO_x to air from N fertilizer application)	IPCC (2019) Tier 1
N_2O to air (direct and indirect) (from N fertiliser application)	IPCC (2019) Tier 1
CO_2 to air (from lime, urea, and urea-compounds application)	IPCC (2019) Tier 1
NO_3 to water unspecified (leaching from N fertiliser application)	IPCC (2019) Tier 1
PO_4 to water unspecified or freshwater (leaching and run-off of soluble phosphate from P fertiliser application)	EC (2021)
P to water unspecified or freshwater (soil particles containing phosphorous, from P fertiliser application).	EC (2021)

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For pesticides, modelling was conducted based on the OLCA-Pest model [18]. Active ingredients in each plant protection product are modelled, with runoff to water, air, and soil calculated based on the following percentages (Table 17):

Table 17: Modelling approaches for emissions from pesticide and plant protection

Compartment	Herbicide	Fungicide	Insecticide	Plant growth regulator
air, low population density	10%	10%	10%	10%
soil, agricultural	67%	27%	27%	9%
soil, natural/forest	1%	1%	1%	1%
water, surface/river	0%	0%	0%	0%
Crop	22%	62%	62%	80%

4.7. Waste treatment

Waste treatment scenarios are modelled based on primary information collected from each case study, see Table 18.

Table 18: Waste treatment summary table

Living Lab name and location	Waste produced
Czech Republic, Wheat	No waste reported
Barley, Denmark	No waste reported
Mushrooms, France	Waste from containers is sold to farmers. Waste plastic is recycled or incinerated.
Barley, Germany	No waste reported
Tomatoes, Greece	No waste reported
Leafy greens, Hungary	6400 kgs of organic waste 181 kg of plastic waste
Tomatoes, Italy	Crop residues are incorporated into the field, which is accounted for in the inventory inputs.
Barley, Poland	No waste reported
Wheat, Spain	No waste reported
Leafy Greens, Hungary	Organic waste 5.96 kg/m^2 year – composted; 1kg/m^2 plastic waste – incinerated; 0.25kg paper waste – recycled; Waste rockwool - incinerated

4.8. Storage (energy and resource use)

All energy use for storage has been incorporated into the inventories, based on primary data. Storage energy is only relevant for some living labs, and for some the energy is already included in the total energy requirement of the whole production system. Table 19 presents the respective data.

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Table 19: Storage energy summary table

Living Lab name and location	Storage scenario
Czech Republic, Wheat	1/3 of harvest is dried (0.4 kWh/m^3). No other energy or resource use for storage Electricity for storage (4kWh per 100m^3, with only 1/3 of volume dried) 3500kg at density of 770kg/m^3 equal to 4.54m^3 of grain, 1/3 of which is 1.5m^3, therefore 4*1.5 = 6kWh used for drying.
Barley, Denmark	Ambient storage only
Mushrooms, France	Energy for storage already included in cultivation energy use
Barley, Germany	For case study 1: 150 kWh is used for storage (already included in cultivation stage) For case study 2: 0.00275 MWh/m^3 is used for storage (already included in cultivation stage)
Tomatoes, Greece	No additional energy for storage reported
Leafy greens, Hungary	Energy for storage already included in cultivation energy use
Tomatoes, Italy	No additional energy for storage reported
Barley, Poland	Ambient storage only
Wheat, Spain	Ambient storage only
Leafy Greens, Hungary	Energy for storage already included in cultivation energy use

4.9. Packaging, retail, and downstream logistics.

Packaging, retail, and downstream logistics emissions are out of scope, as for all products the system boundary for LCA modelling is cradle-to-farm gate. Whilst some living labs provided data on these activities, they are excluded for all case studies to ensure consistency.

5. Impact Assessment

Environmental LCA

The environmental LCA was calculated based on the Environmental Footprint (EF) 3.1 methodology [19]. The inventory data presented above is multiplied by characterization factors, which reflects its relative contribution to specific impact

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categories. Table 20 provides an explanation of all the impact categories covered by the EF3.1 methodology, the equivalent unit used, and impact category indicator. The EF3.1 methodology was chosen as it is published by the European Commission and therefore aligned with EU policy, and because it uses current, revised characterization factors (publication date: 2023).

Table 20: Overview of environmental impact assessment categories (Environmental Footprint 3.1)

Impact category	Unit	Impact category Indicator
Acidification	mol H+ equivalents	Accumulated Exceedance – AE
Climate change	kg CO2 Equivalents	Radiative forcing as global warming potential – GWP100
Climate change-Biogenic	kg CO2-Equivalents	Radiative forcing as global warming potential – GWP100
Climate change-Fossil	kg CO2 Equivalents	Radiative forcing as global warming potential – GWP100
Climate change-Land use and land use change	kg CO2-Equivalents	Radiative forcing as global warming potential – GWP100
Ecotoxicity, freshwater	CTUe	Comparative Toxic Unit for ecosystems
Ecotoxicity, freshwater (inorganics)	CTUe	Comparative Toxic Unit for ecosystems
Ecotoxicity, freshwater (organics)	CTUe	Comparative Toxic Unit for ecosystems
EF-particulate Matter	disease incidence	Impact on human health
Eutrophication marine	kg N equivalents	Fraction of nutrients reaching marine end compartment
Eutrophication, freshwater	kg P equivalents	Fraction of nutrients reaching freshwater end compartment
Eutrophication, terrestrial	mol N equivalents	Accumulated Exceedance – AE
Human toxicity, cancer	CTUh	Comparative Toxic Unit for humans
Human toxicity, cancer (inorganics)	CTUh	Comparative Toxic Unit for humans
Human toxicity, cancer (organics)	CTUh	Comparative Toxic Unit for humans

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Human toxicity, non-cancer	CTUh	Comparative Toxic Unit for humans
Human toxicity, non-cancer (inorganics)	CTUh	Comparative Toxic Unit for humans
Human toxicity, non-cancer (organics)	CTUh	Comparative Toxic Unit for humans
Ionising radiation, human health	kBq U235 equivalents	Human exposure efficiency relative to U-235
Land use	dimensionless (pt)	Soil quality index, representing the aggregated impact of land use on: Biotic production; Erosion resistance; Mechanical filtration; Groundwater replenishment
Ozone depletion	kg CFC11 equivalents	Ozone Depletion Potential – ODP
Photochemical ozone formation - human health	kg NMVOC equivalents	Tropospheric ozone concentration increase
Resource use, fossils	MJ	Abiotic resource depletion, fossil fuels – ADP-fossil
Resource use, minerals and metals	kg Sb equivalents	Abiotic resource depletion – ADP ultimate reserves
Water use	m3-world equivalents	Weighted user deprivation potential

Social LCA

The S-LCA is conducted following a hybrid approach combining LCI data with monetary valuation and the SHDB. First, the analysis starts with the LCI from chapter 3, which provides all relevant physical input flows per FU. In a second step, all LCI inputs are translated into monetary terms using USD price data. These price values are not reported here for confidentiality and methodological reasons. This conversion results in a complete set of USD-denominated inputs per FU, enabling comparability across heterogeneous input types.

Subsequently, each monetised input is matched to the most appropriate SHDB sector (Table 21). This step involves selecting the closest available sectoral proxy, acknowledging that SHDB classifications are more aggregated than the original LCI categories. The mapping is therefore based on best-fit sector alignment rather than one-to-one correspondence.

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Table 21: Social Life Cycle Inventory matches with GTAP/SHDB sectors

LCA input group (examples grouped)	GTAP / SHDB sector
Seeds (barley seeds, wheat seeds, tomato seedlings, leafy greens seeds, alfalfa seeds), planting material	Cereals grains nec (GRO); Wheat (WHT); Vegetables, fruit, nuts (V_F); Crops nec (OCR)
Crop production outputs (barley, wheat, leafy greens, tomatoes, mushrooms)	Cereals grains nec (GRO); Wheat (WHT); Vegetables, fruit, nuts (V_F); Crops nec (OCR)
Organic soil inputs (straw, peat, growing media, crop residues)	Crops nec (OCR)
Animal-based inputs (chicken droppings, manure, organic fertiliser from livestock)	Bovine cattle, sheep and goats, horses (CTL)
Synthetic fertilisers (urea, ammonium nitrate, calcium ammonium nitrate, AHL, NPK/NK/PK compounds, phosphates, potassium fertilisers, magnesium sulphate, nitric acid, humic acid, biodigested fertiliser, nutrient solutions)	Chemical, rubber, plastic products (CRP); Minerals nec (OMN) (for raw mineral salts such as lime, potassium salts, magnesium compounds)
Crop protection products (herbicides, fungicides, insecticides, growth regulators, all commercial PPPs such as Ridomil, Vertimec, Movento, etc.)	Chemical, rubber, plastic products (CRP)
Plastics (PP, HDPE, films, irrigation pipes, packaging materials)	Chemical, rubber, plastic products (CRP)
Rockwool, cultivation substrates, greenhouse media	Manufactures nec (OMF)
Steel, aluminium, structural greenhouse materials	Ferrous metals (I_S); Metal products (FMP)
LED lighting systems, sensors, electronic control systems	Electronic equipment (ELE)
Water inputs (irrigation water, tap water, cleaning water)	Water (WAT)
Electricity (grid electricity, farm electricity use)	Electricity (ELY)
Fossil fuels (diesel, fuel oil, propane)	Petroleum, coal products (P_C)

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Transport (truck transport, sea freight, logistics, upstream transport)	Transport nec

The assessment is conducted using OpenLCA, where sector-linked monetary flows derived from the LCI are used as inputs. Each input is matched to the most appropriate Social Hotspots Database (SHDB) sector, based on best available alignment due to the higher level of aggregation in SHDB compared to the original LCI classifications. SHDB characterization factors are then applied to translate these sectoral inputs into potential social risks and impacts along global supply chains.

The analysis is carried out at both midpoint and endpoint level. At midpoint level, the "Social Hotspot 2022 Subcategory Method w Norm" is applied, using the "global per capita annual" normalization and weighting set. At endpoint level, the "Social Hotspot 2022 Category Method w Norm – Endpoint" is used, applying the same normalization and weighting assumptions. This dual-level approach enables interpretation at both detailed impact subcategory level and aggregated category level.

The model outputs consist of five SHDB impact categories and 30 associated impact subcategories. These indicators represent potential social risks associated with sector-average conditions in global production systems.

A key methodological consideration is that these results primarily capture upstream, indirect impacts embedded in the supply chains of inputs. They do not reflect direct, site-specific conditions at the farm or production level. No primary data on actual on-site working conditions (e.g., occupational safety, labour conditions, or community impacts at the farm) is included in this assessment; instead, the assessment relies entirely on secondary, database-driven risk information. The results should therefore be interpreted as upstream risk profiles linked to input production rather than observed social outcomes at the production site. These are captured in a separate qualitative social assessment (see Annex 5 to D5.5).

For detailed methodological background, definitions, and data sources of the SHDB indicators, see the SHDB documentation [20] . A summary of the impact categories and their underlying data sources is provided in Table 22.

Table 22: Definitions and example data sources of SHDB impact (sub)categories

Impact category	Impact subcategory	Definition	SHDB data sources
1 Labor rights & decent work	**1A Wage assessment**	Degree to which wages meet living wage or basic needs standards	ILOStat wage data; World Bank poverty lines; national statistics (KILM)
1 Labor rights & decent work	**1C Workers in poverty**	Share of employed people living under poverty conditions	World Bank PovcalNet; ILO working poverty estimates

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1 Labor rights & decent work	**1D Child Labor**	Employment of children below legal working age or in hazardous work	ILO SIMPOC; UNICEF; DHS surveys
1 Labor rights & decent work	**1E Forced Labor**	Risk or incidence of coerced or involuntary labour	ILO Forced Labour Estimates; Walk Free Global Slavery Index
1 Labor rights & decent work	**1F Excessive WkTime**	Prevalence of excessive working hours	ILOStat working time; national labour surveys
1 Labor rights & decent work	**1G Freedom of Assoc**	Ability to form/join unions and bargain collectively	ITUC Global Rights Index; ILO NORMLEX
1 Labor rights & decent work	**1H Migrant Labor**	Working conditions and vulnerability of migrant workers	UN DESA migration data; ILO migration indicators
1 Labor rights & decent work	**1I Social Benefits**	Access to employment-related social protection	ILO social protection database; national labour law data
1 Labor rights & decent work	**1J Labor Laws/Convs**	Compliance with labour laws and ILO conventions	ILO NORMLEX; national legislation databases
1 Labor rights & decent work	**1K Discrimination**	Unequal treatment in employment based on identity factors	ILO gender gap data; World Bank Gender Data Portal
1 Labor rights & decent work	**1L Unemployment**	Labour market unemployment levels	World Bank WDI; ILOSTAT
2 Health & safety	**2A Occ Tox & Haz**	Exposure to occupational hazards (chemical physical biological ergonomic)	ILO occupational risk datasets; WHO burden of disease occupational; SHDB models
2 Health & safety	**2B Injuries & Fatalities**	Workplace accidents injuries and deaths	ILO fatal injury statistics; Eurostat



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			OSH; national OSH agencies
3 Society	**3A Indigenous Rights**	Protection of Indigenous peoples rights	UNPFII reports; Human Rights Watch datasets
3 Society	**3B Gender Equity**	Equality in employment and social outcomes	WEF Global Gender Gap; World Bank Gender Data
3 Society	**3C High Conflict Zones**	Exposure to armed conflict or political instability	UCDP conflict database; World Bank fragility index
3 Society	**3D Non-Communicable Diseases**	Burden of chronic diseases	WHO Global Health Observatory; IHME GBD
3 Society	**3E Communicable Diseases**	Exposure to infectious diseases	WHO Global Health Observatory; IHME GBD
3 Society	**3F Poverty and inequality**	Income inequality and structural poverty	World Bank Gini index; UNDP HDI
3 Society	**3G State of Env Sustainability**	Macro environmental sustainability context	EPI Environmental Performance Index; World Bank environmental indicators
4 Governance	**4A Legal System**	Strength of rule of law and enforcement	World Bank Worldwide Governance Indicators
4 Governance	**4B Corruption**	Level of perceived corruption	Transparency International CPI; World Bank WGI
4 Governance	**4C Democracy & Freedom of Speech**	Political rights and civil liberties	Freedom House Index; V-Dem dataset
5 Community	5A Access to Drinking Water	Access to safe drinking water	WHO UNICEF JMP Water database
5 Community	5B Access to Sanitation	Access to sanitation infrastructure	WHO UNICEF JMP Sanitation database
5 Community	5C Children out of School	Share of children not attending school	UNESCO Institute for Statistics
5 Community	5D Access to Hospital Beds	Healthcare infrastructure availability	WHO Global Health Observatory; OECD Health Stats



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5 Community	5E Smallholder vs Commercial Farms	Farm structure and inequality	FAOSTAT; agricultural census data
5 Community	5F Access to Electricity	Electricity access levels	World Bank SE4ALL database
5 Community	5G Property rights	Security of land and property ownership	World Bank governance indicators; LGAF

6. Scenario development with MAGNET model

MAGNET is a multi-regional, multi-sectoral, applied general equilibrium model tailored for agri-food analysis [21]. It was used in the context of ECOREADY to model prospective future scenarios based on SSP1, 2, and 3. More details on how the scenarios were developed using MAGNET is available in D1.5. For this scenario analysis, the outputs of MAGNET were used to adjust the baseline LCA inventories, to perform a prospective analysis of how the social and environmental impact of the 10-case study LCAs might change in the future.

Aligning LCA inventories with MAGNET outputs

The LCA inventories are based on case-specific data from the Living Labs, whilst MAGNET is a country and sector level model. Therefore, to align the scope, connections were made between the LCA models, and the outputs available in from MAGNET (as presented in Table 23). There are limitations, as the level of disaggregation available in MAGNET is not the same as for the LCAs, therefore broader categories such as Vegetables and Cereal grains are chosen for some locations. The prospective analysis is therefore done under the assumption that the market changes predicted by MAGNET are equally applicable across the whole sector. This is a limitation of the approach, as some products are better represented by their sectors than others. For example, the total cultivation areas for tomatoes and lettuces in the EU were 208,000 Ha and 84,000 Ha, representing only 11% and 4.2% of the sector, respectively [22]. No data was available for mushrooms. Barley makes up for 19% of the cereals sector by weight produced, increasing to 34% when Wheat is excluded [23]. Therefore, the representativeness is best for Wheat, followed by Barley, Tomatoes, Leafy Greens, and finally mushrooms.

Table 23: MAGNET and LCA scope alignment for sectors

Living Lab name and location	Product chosen for LCA	Sector match in MAGNET	Match
PROBIO, Czech Republic	Wheat	Wheat	Good

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LivOrganic, Denmark	Barley	Cereal grains	Medium, as cereal grains will include other grain types.
LOFS, France	Mushroom	Vegetables	Low, as there are many other vegetables making up this sector.
ESAPPIN, Germany	Barley	Cereal grains	Medium, as cereal grains will include other grain types.
THALLA, Greece	Tomatoes	Vegetables	Medium-low, as there are many other vegetables making up this sector.
EcoVitaLL, Hungary	Baby leaf salad	Vegetables	Medium-low, as there are many other vegetables making up this sector.
AideMec, Italy	Tomatoes	Vegetables	Medium-low, as there are many other vegetables making up this sector.
EcoReadyMasuria, Poland	Barley	Cereal grains	Medium, as cereal grains will include other grain types.
CONCAT LL, Spain	Wheat	Wheat	Good
SECO-Collab, Sweden	Leafy Greens	Vegetables	Medium-low, as there are many other vegetables making up this sector.

Next, the sector outputs of MAGNET are matched to the inputs of the LCA inventories (Table 24). The granularity available in MAGNET is less detailed than in LCA, therefore, certain inputs are grouped together for the analysis. For example, whilst in the LCA different fertilizer and pesticide types (i.e. Urea, NPK, CAN) are modelled, in MAGNET the granularity is only available for certain chemical groups, and all fertilizers are grouped together.

Table 24: LCA Inventory item and MAGNET sector matches

LCA Inventory item	MAGNET sectoral match	Applicability	Match quality
Inorganic fertilizers	Fertilizers	Environmental & social	Good
Pesticides, and other plant protection products	Chemicals	Environmental & social	Medium-good. As chemicals can include many other non-pesticides, however, pesticides are one of the most common

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			non-fertilizer chemicals used in agriculture.
Diesel and other fuels	Petroleum products	Environmental & social	Good
Electricity	Electricity	Environmental & social	Good
Start materials (seeds etc)	Same sector as input	Social	Low

Establishing parameters for LCA scenario analysis

After matching the LCA inventories to MAGNET outputs, parameters for scenario analysis can be established. MAGNET can tell us how the use of fertilizers, chemicals, and other items will change in each sector, relative to production quantity, for the 3 SSP scenarios compared. For example, Figure 26 shows how fertilizer use per tonne is projected to change for the Czech Wheat sector, for green, middle and rocky road scenarios from 2025 to 2050.These outputs are therefore collected for all the relevant combinations of sectors and countries for the living labs. From these outputs, we can then establish a set of parameters for the LCA inventories, that show the projected changes in inputs according to MAGNET (Table 25). These parameters are collected by calculating the percentage change expected for each input, per tonne of goods produced, in comparison to the base year. The same exercise is completed for all living labs, so that LCA Inventory parameters for all 3 SSP scenarios from the baseline to 2050 can be established. The same parameters are used for the upstream social risk LCA, as well as the environmental LCA. From these parameters we then establish the prospective environmental impacts of the living lab food production systems under the 3 SSP scenarios, according to MAGNET projections. The results for all the completed scenario analysis are visible in the ECOREADY observatory.

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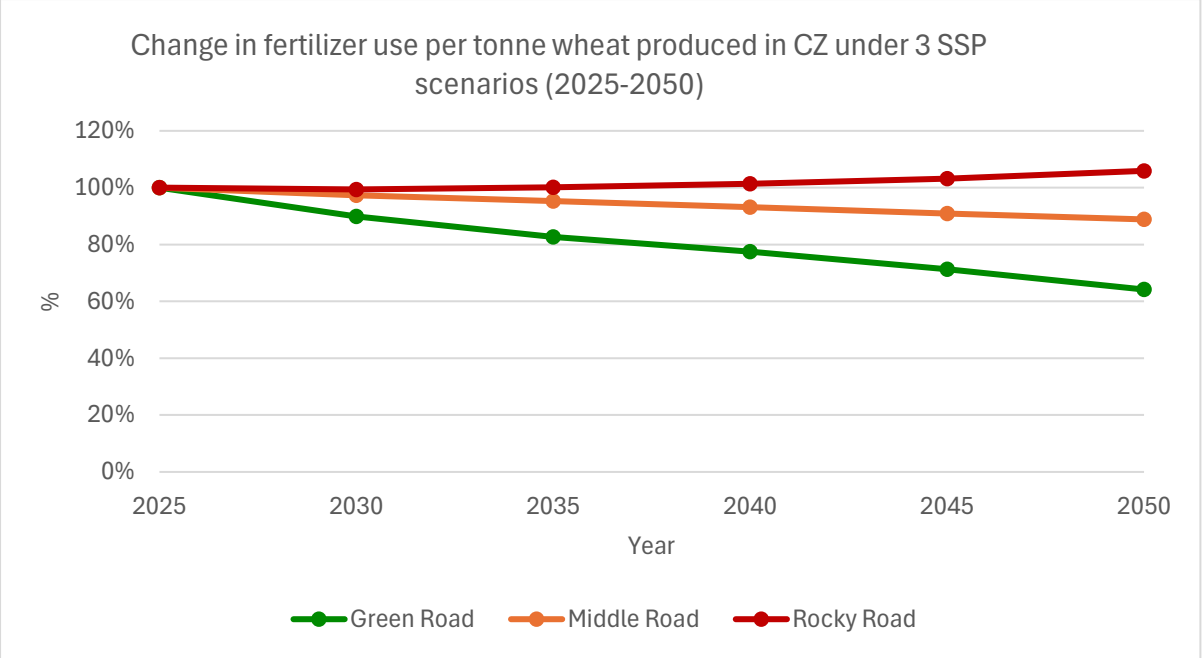

Figure 26: MAGNET output example - Change in fertilizer use per tonne Wheat in CZ

Table 25: Example of parameters for LCA scenario analysis from MAGNET

	Baseline	SSP 1		SSP 2		SSP 3	
MAGNET SECTOR	2025	2030	2050	2030	2050	2030	2050
Cereal grains nec	1.000	0.992	0.944	1.000	1.000	1.016	1.084
Chemical products	1.000	0.984	0.897	0.984	0.921	0.990	0.978
Transport sector	1.000	0.984	0.897	0.984	0.921	0.990	0.978
Petroleum, coal products	1.000	0.984	0.897	0.984	0.921	0.990	0.978
Electricity	1.000	0.984	0.898	0.984	0.921	0.990	0.978
Wheat	1.000	0.992	0.943	1.000	1.000	1.016	1.083
Crops	1.000	0.993	0.948	1.000	1.000	1.016	1.082
Paper & Paper products	1.000	0.999	0.977	1.000	1.000	1.008	1.040
Mineral products nec	1.000	0.984	0.897	0.984	0.921	0.990	0.978
Manure cattle	1.000	0.759	0.421	0.959	0.842	1.021	1.569
Manufactures nec	1.000	0.984	0.897	0.984	0.921	0.990	0.978

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Vegetables	1.000	0.992	0.944	1.000	1.001	1.016	1.081
Vegetable oils and fats	1.000	0.977	0.867	0.984	0.921	0.997	1.017
Services	1.000	0.984	0.897	0.984	0.921	0.990	0.978
Rubber and plastic products	1.000	0.984	0.897	0.984	0.921	0.990	0.978
Phosphorus fertilizer	1.000	0.899	0.755	0.972	0.892	0.993	1.069
Potassium fertilizer	1.000	0.899	0.755	0.972	0.893	0.993	1.069
Other agriculture	1.000	1.000	0.982	1.000	1.002	1.008	1.040
Nitrogen fertilizer	1.000	0.900	0.756	0.972	0.893	0.993	1.070
Minerals nec	1.000	0.984	0.897	0.984	0.921	0.990	0.978
Manure cattle	1.000	0.759	0.421	0.959	0.842	1.021	1.569
Manufacturing	1.000	0.984	0.897	0.984	0.921	0.990	0.978
Fossil gas	1.000	0.985	0.898	0.984	0.921	0.990	0.978
Crude oil	1.000	0.984	0.897	0.984	0.921	0.990	0.978
Crops	1.000	0.993	0.948	1.000	1.000	1.016	1.082
Coal	1.000	0.984	0.897	0.984	0.921	0.990	0.978

*Example values based on MAGNET projections, showing projected change relative to the 2025 baseline (1.000) for each SSP, used to adjust inputs relative to the yield in the LCA inventory data accordingly.

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Chapter 3: Report on social LCA impact assessment of all living labs in ECOREADY

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Introduction

An impact assessment was performed of the following living labs (Table 26):

Table 26 Living Labs

Living Lab name and location	Product chosen for LCA	Amount of farms
THALLA, Greece	Industrial tomatoes	1
EcoReadyMasuria, Poland	Barley	1
CONCAT LL, Spain	Wheat	1
PROBIO, Czech Republic	Wheat (organic)	1
ESAPPIN, Germany	Barley	2
LivOrganic, Denmark	Barley	1
SECO-Collab, Sweden	Leafy Greens	1
EcoVitaLL, Hungary	Baby leaf salad	1
LOFS, France	Mushroom	1
AideMec, Italy	Industrial tomatoes	3

Between June and September 2024, a survey was distributed among living lab coordinators and other affiliated people to these living labs, with a total of 27 respondents. Participants were asked to rank the 27 UNEP (2021) impact categories, linked to the stakeholder groups worker, local community, and society, according to their relevance. Based on these rankings, the six highest ranked categories were included for the social impact assessment, being technology development, working hours, occupational health and safety, smallholders including farmers, contribution to economic development and fair salary.

1. Technology development

Introduction

Technology development in agriculture is pivotal for enhancing productivity, sustainability, and resilience. The United Nations Environment Programme (UNEP) defines technology development as the extent to which organizations engage in joint research to develop efficient and environmentally sound technologies (UNEP, 2021). In the context of Social LCA, technology development is recognized as a critical factor influencing social performance, particularly concerning workers, local communities, and broader societal impacts.

According to UNEP (2021), technology development is a key element in promoting sustainability. Modern technologies can reduce environmental impacts and overcome underdevelopment, especially in developing economies. Successful technology transfer involves not only machines and equipment but also skills, abilities, knowledge, systems, and processes. This broader definition emphasizes



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technology as a total system that includes know-how, procedures, goods, services, and organizational measures.

Furthermore, early assessment of technology development within Social LCA can help identify social hotspots and areas for improvement during the initial stages of technology adoption (Traverso et al., 2014). This proactive approach ensures that social impacts are considered alongside environmental and economic aspects.

Background and statistics

Technology development in agriculture is a critical driver of innovation, sustainability, and productivity across the European Union (EU). Despite its importance, investment in agricultural research and development (R&D) has experienced fluctuations over the past decade. In 2014, agricultural R&D expenditure accounted for 1.8% of the EU's agricultural gross value added, a decline from 2.4% in 2009 (European Commission, 2015). This downward trend highlights challenges in sustaining consistent investment levels in agricultural innovation.

Public funding remains the predominant source of agricultural R&D in the EU, with over 90% of resources dedicated to agricultural knowledge and innovation stemming from individual member states' budgets (AgTech Navigator, 2023). This reliance on public financing underscores the need for strategic investments to support the green transformation of the EU's agricultural sector.

The distribution of agricultural output across EU member states is uneven. In 2020, Italy, France, Germany, and Spain collectively generated 60.2% of the EU's standard agricultural output, despite Romania accounting for about one-third of the EU's farms but only 3.3% of the standard output (Eurostat, 2020). This disparity reflects differences in farm sizes, productivity, and adoption of technological advancements.

The adoption of precision agriculture technologies is gaining momentum in Europe. The European precision agriculture market was valued at USD 4.28 billion in 2024 and is anticipated to reach USD 13.59 billion by 2033, growing at a compound annual growth rate (CAGR) of 13.7% during the forecast period (Market Data Forecast, 2024). Germany currently dominates this market due to significant agricultural revenue output and rapid adoption of new technologies.

However, the uptake of advanced technologies varies across different types of farms and regions. Larger farms with more resources are more likely to invest in R&D and adopt innovative practices, while smaller and traditional farms may face barriers such as limited access to capital and technical expertise. Additionally, the type of agricultural production influences technology adoption; for instance, crop farming has seen more integration of precision technologies compared to livestock farming.

Overall, while there is a growing trend towards technological advancement in EU agriculture, disparities in investment and adoption rates persist across member states and farm types. Addressing these disparities is crucial for ensuring a cohesive and sustainable agricultural sector across the EU.working hours, occupational health and safety, smallholders including farmerscontribution to economic development and fair salary.



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Data collection and analysis

A survey was conducted among nine agricultural Living labs to assess their involvement in technology development and transfer. Table 27 presents the indicators that were collected in the survey.

Table 27 Indicators collected for technology development

	Data point	***Guidance***	***Unit***
7,1	Technology development/transfer	*Is your organization involved in technology development?*	Yes / No / N/A
7,2		*If yes; what is the main aim?*	Open question
7,3		*Are there specific practices or technologies that have helped you improve your farm's productivity?*	Yes / No / N/A
7,4		*If yes; how did it improve your farm's productivity?*	Open question
7,5		*Is your organization involved in technology transfer?*	Yes / No / N/A
7,6		*Can you describe the nature of your involvement in technology development or technology transfer?*	Open question
7,7	Partnerships	*Does your organization have partnerships in research and development?*	Yes / No / N/A
7,8	Investment	*Approximately how much do you invest in technologies?*	#

Out of nine Living labs, six reported active involvement in technology development, primarily aiming to reduce environmental impacts and enhance financial viability. These farms employed precision farming techniques, optimizing input usage and improving efficiency. Technological innovations, including the use of sensors and automated machinery, replaced manual labour, leading to increased productivity. Some Living labs also adopted advanced irrigation techniques, pesticide reduction, and new cultivation methods.

Vertical farming Living labs faced unique challenges, relying heavily on advanced technologies such as AI, sensors, and LED systems to maintain optimal environmental conditions.

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Three Living labs were engaged in technology transfer, mainly through collaborations with research institutions and universities, which provided funding and support for developing and improving technologies.

Most Living labs maintained partnerships in research and development. Those without such partnerships were typically not involved in technology transfer. Investment in technologies ranged from €5,000 to €100,000 annually, with an average investment of €30,000 among those actively investing.

Integration into Social LCA

Technology development is not quantified in major databases like SHDB and PSILCA, making it challenging to benchmark performance. It is usually assessed based on organizational involvement or investments, but establishing a standard reference is difficult due to variations in products, countries, and farm sizes.

We propose a 5-level reference scale (Table 28) to categorize Living labs based on their engagement in technology development:

Table 28 Reference scale technology development

Score	Description
+2	Very high involvement (leading role in technology development, significant investments, consistent partnerships).
+1	High involvement (regular partnerships, consistent investments, significant improvements in sustainability).
0	Moderate involvement (occasional partnerships, some investments, minor improvements in sustainability).
-1	Limited involvement (minimal engagement, no partnerships, low investments).
-2	No involvement in technology development or transfer.

Based on this scale, the nine Living labs can be assessed and scored accordingly (Table 29). This approach allows for clearer categorization and comparison.

Table 29 Scores of the Living labs for technology development

Living Lab	Score	Justification
Greece	-2	No involvement in technology development or transfer.
Poland	0	No technology transfer/development, but moderate investment.
Spain	-2	No involvement in technology development or transfer.

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Czech Republic	+2	Significant investments, active R&D partnerships and technology development.
Germany 1	0	No technology transfer/development, but moderate investment.
Germany 2	0	No technology transfer/development, but moderate investment.
Denmark	+2	Strong, structured involvement in technology development and transfer, including Precision Agriculture, sensor-based systems, and model-based nutrient optimisation. Active R&D partnerships and development of frameworks intended for external testing and uptake indicate a leading innovation role, despite no reported investment amount.
Sweden	+1	Very involved in technology transfer/development, did not provide information on the investments in technologies.
Hungary	+2	Leading role, high financial commitment. Technology development is the key of vertical farming.
France	+1	Moderate to high involvement in technology development through regular R&D partnerships and internal improvement initiatives. Small-scale investment (~30,000 EUR) focused on environmental and operational improvements, including automation. No leadership role in technology transfer and limited financial scale compared to top-level innovators.
Italy 1	+1	Involved in technology development, not in technology transfer, moderate investments in technologies.
Italy 2	+1	Involved in technology development, not in technology transfer, moderate investments in technologies.
Italy 3	+1	Involved in technology development, not in technology transfer, moderate investments in technologies.

Incorporating technology development into Social LCA frameworks is essential for a comprehensive assessment of social impacts in agriculture. It is crucial to account for technology's role in enhancing productivity, sustainability, and social well-being. However, challenges persist in standardizing indicators and methodologies for assessing the social impacts of technological innovations. Discrepancies often arise due to varying stakeholder perspectives and the complexity of measuring qualitative social outcomes.

Conclusion

The majority of Living labs are actively engaged in technology development, with some demonstrating leadership through high investments and strong partnerships.

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These findings align with broader EU trends, where larger or better-funded farms are more likely to adopt advanced technologies. However, disparities exist, with some Living labs showing limited involvement. Integrating technology development into Social LCA provides a comprehensive understanding of social impacts, but standardizing indicators remains challenging due to context-specific factors.

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2. Working hours

Introduction

Working hours play a crucial role in ensuring a fair and sustainable working environment. According to the United Nations Environment Programme (UNEP), working hours should comply with applicable laws and industry standards, with a focus on ensuring workers have appropriate time off and are not regularly required to work beyond reasonable limits. Specifically, the ILO sets guidelines on working hours, stating that workers should not work more than 48 hours per week, with at least one day off per week, and that overtime, if required, should be voluntary, limited to 12 hours per week, and compensated appropriately (UNEP, 2021).

For the purposes of Social LCA, the definition of working hours includes evaluating whether a company or organization complies with these International Labour Organization (ILO) standards. When overtime occurs, compensation should either be in the form of additional pay or time off, reflecting a commitment to fair and sustainable working practices. This indicator is essential in determining whether farming or other industries maintain work-life balance and treat workers fairly by complying with labor laws and providing reasonable working conditions.

Background and statistics

The issue of working hours is particularly important as the structure of the global economy and work environments evolves. Work-life balance has become a significant focus in many sectors due to growing concerns over worker health and well-being. Over the past few decades, trends like globalization, technological advances, and the shift to a 24-hour economy have led to changes in production methods and the organization of work (ILO, 2021).

According to the European Union (EU) labor standards, the normal workweek is typically set at 40 hours, though individual countries may have slightly varying regulations. The EU Working Time Directive (2003/88/EC) establishes that working hours must not exceed 48 hours per week on average, including overtime, and workers are entitled to at least one day off per week. Regarding overtime, employees have the right to compensation, either in the form of additional pay or time off, depending on national laws (European Commission, 2020).

In 2023, the average actual weekly working hours for individuals aged 20-64 in their main job across the EU was 36.1 hours (Figure 27). However, this average masks significant variations between countries. For instance, Greece reported the longest working week at 39.8 hours, followed by Romania (39.5 hours), Poland (39.3 hours), and Bulgaria (39.0 hours). Conversely, the Netherlands had the shortest average working week at 32.2 hours, with Austria (33.6 hours) and Germany (34.0 hours) also reporting shorter working weeks (European Commission, 2023b).

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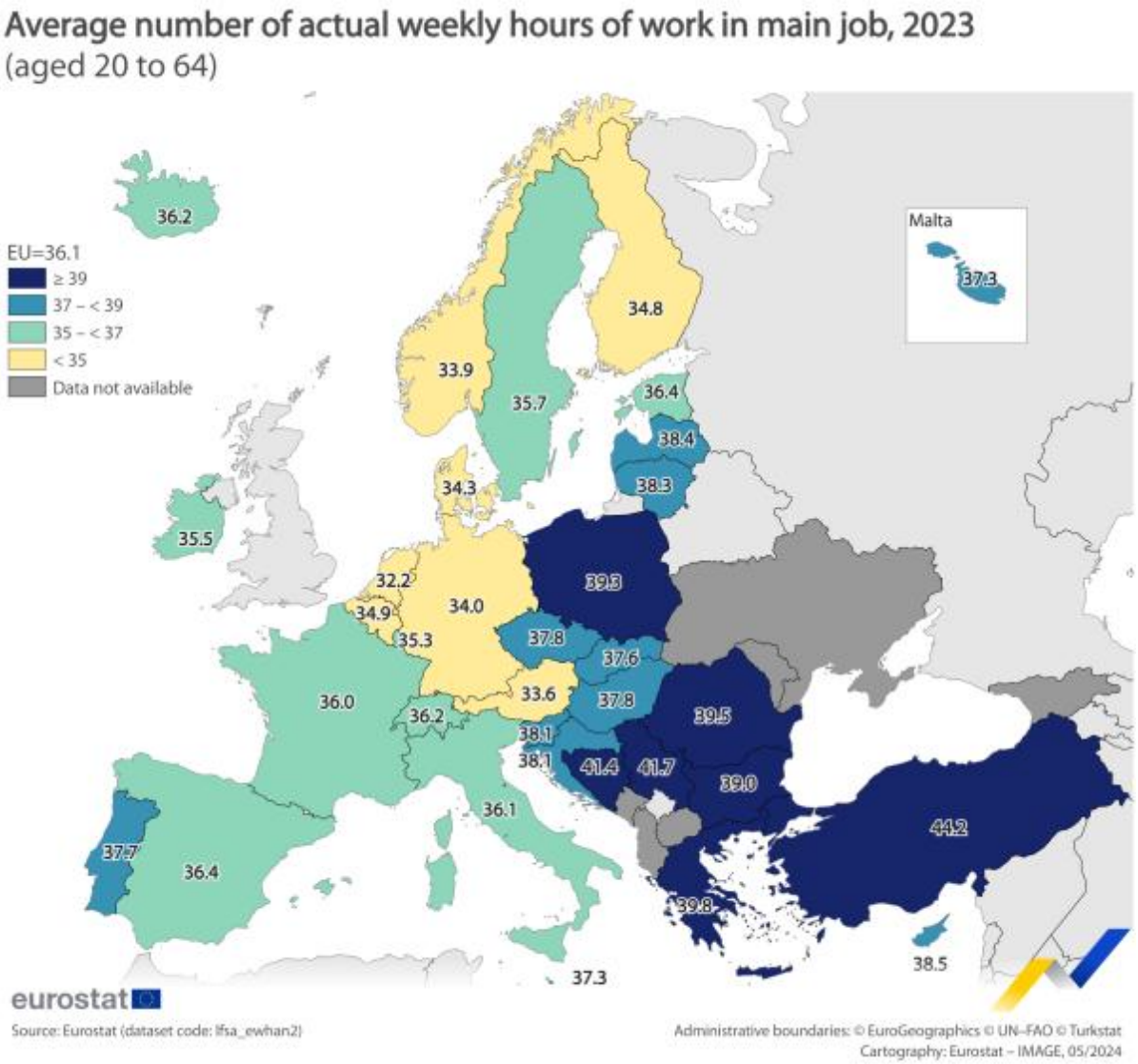

Figure 27 Average number of actual weekly hours of work in main job (European Commission, 2023b)

Agriculture presents unique challenges related to working hours due to its seasonality and harvest cycles. During peak periods such as sowing and harvesting, workers are often required to work extended hours to meet production demands. The physically demanding nature of farm work, combined with exposure to harsh environmental conditions, can increase the risks associated with overwork (European Commission, 2023a).

In 2023, the agriculture, forestry, and fishing sectors recorded the longest average actual weekly working hours at 41.5 hours, highlighting the high demand for labor in this sector (Figure 28). Skilled agricultural, forestry, and fishery workers reported the longest average actual weekly working hours at 42.4 hours, underscoring the intensive nature of these professions (European Commission, 2023b).

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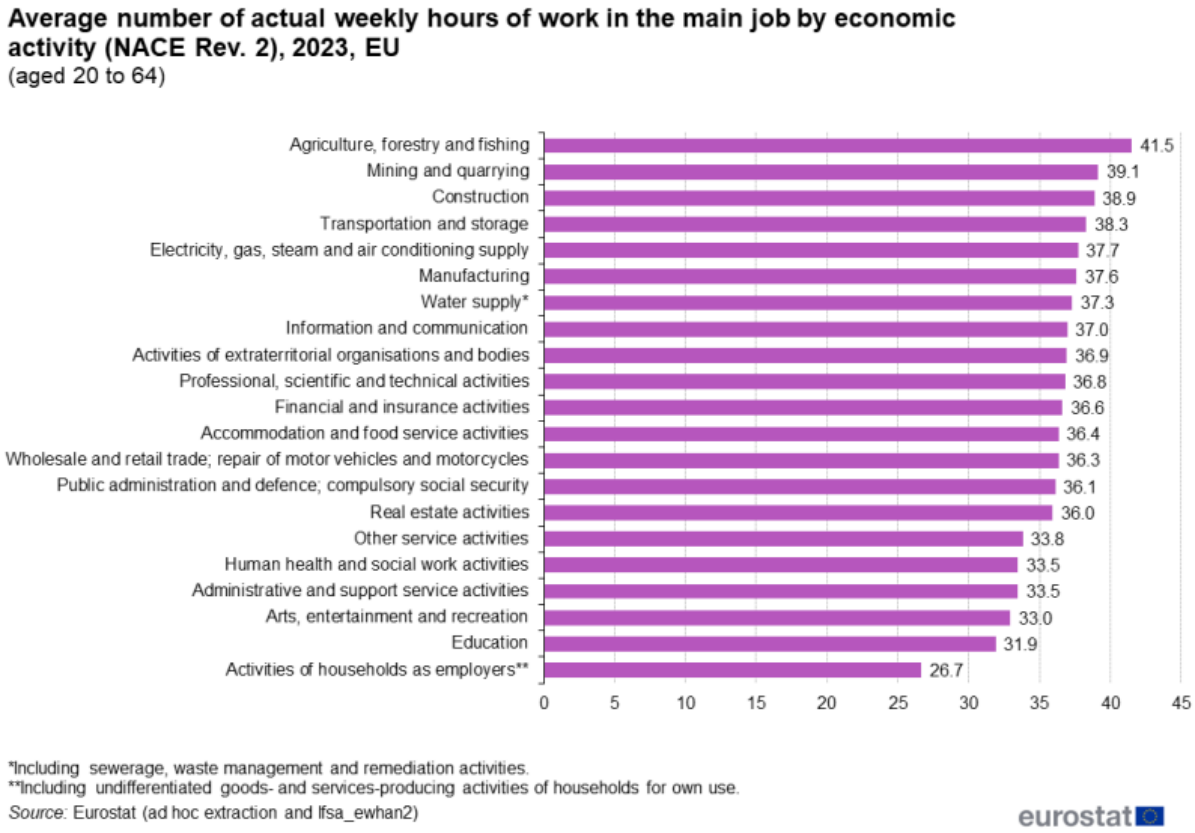

Figure 28 Average number of weekly hours by economic activity (European Commission, 2023b)

Data collection and analysis

A survey was conducted among nine agricultural Living labs to assess their involvement in working hours. Table 30 presents the indicators that were collected in the survey.

Table 30 Indicators collected for Working Hours

	Data point	***Guidance***	***Unit***
3,1	Job type and working hours	*Please specify the working hours per week per worker type:*	
			Job type & hours
			Job type & hours
			Job type & hours
			Job type & hours
			Job type & hours

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			Job type & hours
			Job type & hours
3,2	Rest	*Are attendance records kept?*	Yes / No / N/A
3,3	Overtime	*Do workers receive extra money for overtime?*	Yes / No / N/A
3,4	Work hours flexibility	*Are workers given time off for special occasions?*	Yes / No / N/A
3,5	Holidays	*Do workers use their number of mandatory holidays?*	Yes / No / N/A
3,6		*Do workers usually accumulate their holidays for the next year?*	Yes / No / N/A

Table 31 shows the description of the data of the Living lab for the roles and work hours.

Table 31 Scores of the Living labs for working Hours

Living Lab	**Score**
Greece	No data available (N/A) for roles or hours.
Poland	Mainly part-time roles with very low hours (farm manager 4.62 h/week, farm assistant 1.85 h/week). Staffing is minimal and mostly administrative or support roles.
Spain	Only two workers listed (worker 1 and worker 2, both 40 hours/week). Smaller team with fulltime hours, no specialized machinery or management roles indicated.
Czech Republic	Mix of fulltime and part-time roles: farm manager 40 h/week, administrative worker 40 h/week, warehouse operator 40 h/week, feeder 40 h/week, mechanist 20 h/week, tractor driver/mechanist 20 h/week. Well-staffed farm with operational and support roles.
Germany 1	No data available (N/A) for roles or hours.
Germany 2	No data available (N/A) for roles or hours.
Denmark	Very small presence, only agricultural technician (4 hours) and tractor driver (2 hours). Limited staffing and very low weekly hours.
Sweden	Smaller farm with mainly operators: operator 33 h/week, technical 9 h/week, customer service 2.25 h/week, trainee 20 h/week. Mix of fulltime and part-time roles, but all very specialized.

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Hungary	Staffing with mainly fulltime roles: manager 40 h/week, engineer 40 h/week, operator 40 h/week, and one part-time trainee 20 h/week. Shows a small but structured team with clearly defined responsibilities.
France	Mostly fulltime workforce (35–50 h/week) across diverse operational roles (manager, foreman, technicians, operators, logistics, administration), with limited part-time work driven by company needs and workload peaks. Two employment systems coexist: responsibility-based roles with flexible hours and hourly tracked roles with fixed monthly salaries aligned to the 35-hour French standard, with overtime compensated at higher rates. Structured but workload- and role-dependent working hour arrangements with some peak-related flexibility.
Italy 1	Balanced fulltime staffing: farm manager 70 h/week, harvester 38 h/week, tractor driver 38 h/week, forklift driver 38 h/week, treatment operator 38 h/week. Fulltime coverage across both management and operational roles.
Italy 2	Mostly fulltime operational and management roles: farm manager 70 h/week, harvester 38 h/week, tractor driver 38 h/week, forklift driver 38 h/week, treatment operator 10 h/week. Shows high management hours and fulltime operational coverage.
Italy 3	Mix of fulltime and part-time roles: farm manager 70 h/week, harvester 38 h/week, tractor driver 6.5 h/week, forklift driver 6.5 h/week, treatment operator 6 h/week. Uneven distribution of hours, with management workload much higher than operational staff.

In the Living labs, there is a variety of roles, including farm manager, foreman, line manager, maintenance technician, forklift driver, harvester, secretary, tractor driver, warehouse operator, feeder, machinist, treatment operator, engineer, trainee, manager, and customer service. Each of these roles comes with different responsibilities and varying types of contracts, such as part-time or full-time. The hours worked vary significantly per job type.

Variability in working hours:

- Farm managers: The working hours of farm managers are highly variable, ranging from 40 to 70 hours per week. This indicates that farm managers may experience periods of intense work, particularly in peak agricultural seasons.
- Other roles: Most other roles such as foreman, line manager, forklift driver, and warehouse operator have more consistent working hours, generally around 40 hours per week.
- Seasonal or part-time roles: There are workers with very low working hours, like the agricultural technician (4 hours per week) and farm assistant (1.85 hours per week). This suggests some workers may be part-time or engaged seasonally, especially for specialized tasks.

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Higher and lower working hours in certain positions:

- Higher: a significant portion of farm managers works 70 hours per week, which is quite high. This points to the potential for overwork and the need for careful attention to work-life balance in these roles. Some roles like forklift driver (37-40 hours), harvester (35-38 hours), and tractor drivers (38 hours) fall within standard workweek limits but are still on the higher end.
    - There are indications that some of these workers are likely to be engaged in overtime, especially farm managers and perhaps harvesters or forklift drivers during peak seasons. It would be interesting to investigate whether overtime pay is provided for these roles, especially given the high number of working hours in certain positions.
- Lower: agricultural technician (4 hours/week) and farm assistant (1.85 hours/week) have exceptionally low hours, possibly reflecting part-time or very specialized roles. These low-hour jobs may be seasonal or project-based.

Full-time and standard jobs:

- Roles like administrative worker (40 hours), engineer (40 hours), and maintenance technician (40 hours) are typically full-time positions with a standard workweek. These roles likely follow national standards for working hours and may have more predictable work schedules.

Except for two cases, all the Living labs keep attendance records. Additionally, all but one of the Living labs compensate employees for overtime work. All Living labs adhere to their mandatory holiday entitlements, though only two allow workers to accumulate holidays for the following year, while the rest do not.

Integration into Social LCA

When integrating working hours into Social LCA, several challenges arise which limited our ability to use the reference scale approach. Instead we opted to describe the results in a qualitative way. The issues we faced when trying to use the reference scale approach can be categorized into these issues:

- **Different contract types (full-time, part-time, seasonal):** When assessing working hours, it is essential to know the type of employment contract, as full time, part time and seasonal contracts each imply different expectations and risks. Full time workers usually have fixed hours, while part time and seasonal workers may face fluctuating schedules, with seasonal workers often experiencing very long hours during peak periods followed by little or no work in off seasons. Without this contract information, and having only the actual hours worked, it is not possible to judge whether workers are working within normal conditions or are exposed to risks such as underemployment or overwork. In addition, overtime can be either voluntary or involuntary, which makes a difference for worker well-being, as involuntary overtime may result from high demands or insufficient staffing and can increase risks of stress, burnout and health problems. Excessive overtime, especially when sustained over long periods, is known to negatively affect worker health and work life balance. Since we do not have data on contract types or on whether reported hours include voluntary or involuntary overtime, we



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cannot make a fair judgment on working conditions or meaningfully score the Living labs on a reference scale.

- **Seasonality and Seasonal Peaks:** Agriculture is inherently tied to seasonal cycles. During planting or harvesting periods, workers may be required to work significantly more hours than usual. These seasonal peaks can cause considerable variations in the average number of working hours over the course of the year. While workers may have relatively low hours in off-seasons, the peak seasons can lead to substantial increases in working hours, often beyond standard working hours.
- **Country-Specific Standards for Working Hours:** As with many industries, agricultural work is subject to country-specific standards for working hours. For example, France typically has a 35-hour workweek, while in Germany, the standard is 40 hours. These standards can vary widely across regions, making it more challenging to compare working hours and assess risk in a Social LCA. Agricultural sectors may also follow more flexible schedules, adapting to weather conditions or crop cycles, which complicates the assessment.

Both PSILCA and SHDB assess working hours and overtime as key social risk indicators but differ in their approach:

- PSILCA: Uses a standardized reference scale to categorize working hours. It focuses on the percentage of workers exceeding thresholds like 49 or 60 hours per week. Based on these thresholds, PSILCA classifies the risk level as low, medium, high, or very high, applying the same criteria across all sectors and countries.
- SHDB: While SHDB also uses similar thresholds for working hours, it incorporates contextual factors, such as national labor laws and sector-specific conditions. For example, it adjusts its risk assessments to account for differences between industries like agriculture and manufacturing, providing a more tailored and localized risk evaluation.

For these above mentioned reasons and missing data to do a good impact assessment, we opted for a descriptive and qualitative approach instead. This allows us to highlight and compare the observed differences between countries and roles, without forcing the data into a scoring system that does not adequately reflect the diverse realities of agricultural work (see Table 31).

Conclusion

The analysis of working hours across the Living labs shows substantial variation between countries, farms, and roles. Core operational roles such as farm manager, tractor driver, harvester and forklift driver dominate the workforce and are generally full time positions with relatively high working hours. By contrast, support or specialized roles such as secretary, customer service or technical staff are often part time or limited hour positions.



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Farm managers consistently work more than other roles, with several cases in Italy reporting up to 70 hours per week, well above standard thresholds. Line managers and foremen also tend to hold full time positions across most farms, while forklift and tractor drivers usually appear as full time roles but with somewhat lower average hours.

The vertical farms in Hungary and Sweden stand out as having a more specialized workforce structure, including roles such as trainee, customer service and technical operators, while lacking traditional agricultural positions like tractor or forklift drivers.

Overall, working hours typically fall within the range of 35 to 45 hours per week, though some outliers, particularly farm managers, work substantially more. These findings underline that what is considered normal working hours is highly dependent on both country and job type, which makes it difficult to apply a uniform scoring approach. Instead, the qualitative differences observed between farms provide a more accurate reflection of the diversity of agricultural labour conditions.

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3. Occupational health and safety

Introduction

Occupational Health and Safety (OHS) is focused on safeguarding workers' well-being by preventing work-related accidents, injuries, and illnesses. As defined by the International Labour Organization (ILO), OHS aims to promote physical, mental, and social well-being, addressing risks that arise from the work environment, and ensuring that work is adapted to the worker's capabilities (ILO, 2020). The United Nations Environment Programme (UNEP) expands on this by emphasizing the importance of assessing the extent to which an organization causes incidents or accidents and evaluating the measures in place to prevent work-related incidents or ill health (UNEP, 2021). A safe and healthy workplace is not just about the absence of disease or injury but also about minimizing risks related to working conditions,



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such as exposure to hazardous substances and physical strain (ILO, 2020; UNEP, 2021).

In sectors like agriculture, OHS concerns are particularly urgent. Agriculture remains one of the most hazardous sectors, with workers facing significant risks from machinery-related accidents, falls from heights, exposure to chemicals and pesticides, and musculoskeletal disorders from repetitive tasks and heavy lifting (EU-OSHA, 2021; ILO, 2020). In addition, agricultural workers are exposed to environmental risks, including extreme weather conditions, zoonotic diseases, and injuries from animal-related accidents (ILO, 2021). UNEP highlights the importance of assessing these risks and understanding the prevention measures implemented by companies, as these factors directly impact workers' health and safety (UNEP, 2021).

Background and statistics

OHS is a significant concern in Europe, particularly within high-risk sectors such as agriculture. Agriculture consistently ranks as one of the most hazardous sectors in terms of fatal and non-fatal work-related accidents. In 2020, agriculture, forestry, and fishing had a fatal accident rate of 5.0 per 100,000 workers, far exceeding the EU average of 1.6 (EU-OSHA, 2021; ILO, 2020). The sector also accounts for 19% of non-fatal injuries in the EU (EU-OSHA, 2023). These high rates highlight ongoing challenges in improving worker safety within the industry.

The main risks in agriculture include machinery-related accidents, falls, exposure to chemicals and pesticides, and musculoskeletal disorders from repetitive tasks and heavy lifting. Furthermore, agricultural workers are exposed to extreme weather, zoonotic diseases, and traumatic accidents involving animals (ILO, 2020; EU-OSHA, 2023). These hazards contribute to the sector’s high accident rates, with additional concerns over long-term health effects, such as chronic conditions from exposure to chemicals or repetitive movements (ILO, 2021).

OHS performance varies significantly across European countries. Nordic nations like Sweden and Finland have some of the lowest accident rates, attributed to strong safety regulations, active enforcement, and better training programs (EU-OSHA, 2021). Conversely, countries such as Greece and Bulgaria face higher accident rates, often due to weaker enforcement and insufficient worker training (EU-OSHA, 2021; ILO, 2020). For instance, Greece struggles with inadequate safety measures, poorly maintained equipment, and limited access to protective gear (ILO, 2020). Regional differences are also reflected in the exposure to agricultural chemicals, with Mediterranean countries such as Spain and Italy showing higher pesticide use, which increases health risks (EU-OSHA, 2021).

The ILO and Eurostat highlight that agriculture continues to be one of the most hazardous sectors globally, especially in countries with lower safety standards. While countries like Denmark and the Netherlands report lower fatal injury rates due to better safety enforcement and technology, Southern European nations such as Italy and Spain still struggle with high injury rates, in part due to insufficient regulation and safety training (ILO, 2020; Eurostat, 2023).



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Data collection and analysis

A survey was conducted among nine agricultural Living labs to assess their OHS. Table 32 presents the indicators that were collected in the survey.

Table 32 Indicators collected for occupational health and safety

	Data point	***Guidance***	***Unit***
5,1	Policies	*Does your organization have a policy/guidelines or program related to the health and safety of employees?*	Yes / No / N/A
5,2		*If yes; can you elaborate on the policy related to health and safety of employees?*	Open question
5,3	Accidents	*Are there any preventative measures and emergency protocols regarding accidents and injuries?*	Yes / No / N/A
5,4		*If yes; can you elaborate on these?*	Open question
5,5		*Are accidents notified and reported?*	Yes / No / N/A
5,6		*How many work accidents occured (in the reference year)?*	#
5,7	Protocols	*Are there documents related to safety procedures to detect, prevent, and minimize potential risks to health and safety of employees?*	Yes / No / N/A
5,8		*Has your organization acquired certification for occupational health and safety in the facilities, such as OHSAS 18001 or ISO 45001?*	Yes / No / N/A
5,9	Training	*Do your employees get a health and safety training?*	Yes / No / N/A

Across the Living labs, the majority have established policies or guidelines addressing the health and safety of employees, demonstrating a commitment to worker well-being. Only two Living labs lack such policies, indicating a potential gap in their OHS management.

Preventive measures and emergency protocols are widely implemented, with all but one Living lab confirming their existence. These measures typically include company-specific training sessions, adherence to standardized safety protocols, regular inspections of critical equipment, and first aid training for designated workers. Such precautions ensure that employees are equipped to prevent accidents and respond effectively when incidents occur.

Regarding incident reporting, nearly all Living labs affirm that accidents are consistently notified and documented. However, one Living lab marked this aspect

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as “N/A,” leaving it unclear whether this reflects a lack of accidents or an absence of reporting procedures. In terms of incident frequency, nearly all Living Labs reported zero accidents in the reference year, with a single exception (an Italian farm where two accidents were recorded). The nature of injuries across the Living labs primarily involves minor incidents such as cuts, burns, and sprained ankles.

The presence of documented safety procedures to detect, prevent, and minimize health and safety risks is also widespread. Only one Living lab lacks such documentation, suggesting room for improvement in formalizing safety practices. Despite these generally positive findings, certification in OHS standards such as OHSAS 18001 or ISO 45001 is not yet universal. Four Living labs have achieved certification, four have not, and one marked this aspect as “N/A,” indicating either a lack of certification or an uncertain status.

Finally, while most Living labs offer health and safety training to their employees, two do not. This gap highlights an area where further improvement is necessary to ensure all workers are adequately prepared to maintain a safe working environment.

Integration into Social LCA

OHS is a critical aspect in Social LCA and is the impact subcategory which is probably quantified the most.

Integrating OHS into Social LCA involves assessing the presence of policies, preventive measures, accident rates, and employee training to ensure worker well-being.

- PSILCA: uses a quantitative approach, measuring the number of non-fatal occupational accidents per 100,000 employees, with risk categories ranging from very low (<750) to very high (>3000). These thresholds provide a clear, data-driven method for assessing OHS risks.
- SHDB: also uses accident data but defines different thresholds: very high (>2000), high (>500), medium (>100), and low (<100) accidents per 100,000 workers. This method is simpler and allows for a faster assessment.

We integrate OHS into Social LCA by developing a scoring scale ranging from +2 to -2 in Table 33, based on accident rates and the existence of preventive measures, training, and certification:

Table 33 Reference scale occupational health and safety

Score	Description
+2	Fewer than 100 non-fatal accidents per 100,000 employees, with clear preventive measures and emergency protocols in place. Certified in occupational health and safety (e.g., ISO 45001). Regular training for all employees.

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+1	Fewer than 100 non-fatal accidents per 100,000 employees, but no clear measures in place, OR between 100 and 500 with measures. Most employees receive training. Certification process ongoing.
0	Between 100 and 500 non-fatal accidents per 100,000 employees, with no clear measures in place. Some employees receive training. No certification, but basic procedures exist.
-1	More than 500 non-fatal accidents per 100,000 employees. Limited preventive measures, inconsistent reporting, and few employees receive training. No certification.
-2	More than 2,000 non-fatal accidents per 100,000 employees. No health and safety policy, no preventive measures, no training, and no certification.

Based on this scale, the nine Living labs can be assessed and scored accordingly in Table 34. This approach allows for clearer categorization and comparison.

Table 34 Scores of the living labs for occupational health and safety

Living Lab	**Score**	**Justification**
Greece	-1	No accidents were reported, but there are no policies, preventive measures, safety procedures, certifications, or health and safety training in place, although accidents are formally reported and notified.
Poland	-1	No accidents reported, but no measures, protocols or certification in place at all.
Spain	+2	No accidents reported, measures, protocols and certification are in place and employees receive regular training.
Czech Republic	+2	No accidents reported, measures, protocols and certification are in place and employees receive regular training.
Germany 1	+1	No accidents reported, some measures in place, but no regular training/certification.
Germany 2		No accidents reported, some measures in place, but no regular training/certification.
Denmark	+2	No accidents reported, measures, protocols and certification are in place and employees receive regular training.
Sweden	+2	No accidents reported, measures, protocols and certification are in place and employees receive regular training.

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Hungary	+1	No accidents, some measures in place, regular training, but no formal health and safety policy or certification.
France	+2	No accidents reported, measures, protocols and certification are in place and employees receive regular training.
Italy 1	+2	No accidents reported, measures, protocols and certification are in place and employees receive first aid training. Next to that, the farm is obliged to draft a risk assessment document covering the most common risks.
Italy 2	-1	Two accidents at one farm, but all preventive measures are in place and the employees do receive first aid training.
Italy 3	+2	No accidents reported, measures, protocols and certification are in place and employees receive first aid training. Next to that, the farm is obliged to draft a risk assessment document covering the most common risks.

The scores from the living labs indicate a generally positive trend in OHS performance, with most sites reporting low accident rates and a strong commitment to preventive measures. Most living labs have implemented robust safety policies, training programs, and protective measures, which has contributed to a safer work environment. These results are particularly noteworthy considering the typically high-risk nature of the agricultural sector, where accidents and health issues are more prevalent.

However, there are still some gaps, particularly in terms of certification and the consistent application of safety protocols across all sites. While many living labs have policies in place, the lack of standardized certification and occasional lapses in protocol enforcement suggest room for improvement. Overall, the Living labs are performing better than the broader agricultural sector, showing that with the right measures and commitment, OHS outcomes can significantly improve in high-risk industries.

Conclusion

OHS is a key subcategory in Social LCA for measuring social impact, especially in high-risk sectors like agriculture. Our assessment of the Living labs highlights a generally strong commitment to OHS, with most having policies, preventive measures, and training in place. However, gaps remain, particularly regarding certification and the consistent implementation of safety protocols. Despite agriculture's typically poor OHS performance, the living labs show fewer accidents, which is surprising given the sector's usual risk profile.

Comparing our approach with PSILCA and SHDB, we observe that our method not only considers accident rates but also evaluates preventive measures, training, and certification status, providing a more nuanced view of OHS performance. This approach allows us to capture both the existence of protective measures and their effectiveness, offering a more comprehensive perspective on workplace safety.

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4. Smallholders including farmers

Introduction

Smallholder production can refer to small-scale agriculture, low-income farms, family farms, subsistence farming, etc. Therefore, smallholders are often defined based on different socioeconomic characteristics, and farm size and resources. The criteria defining a smallholder farmer differ across countries and agro-ecological zones. A general definition of 'smallholders' is so-far lacking. Assessment of this impact subcategory aims to capture the relation with the market, the role of the family, (economic) farm size and the presence of production factors (UNEP, 2021).

Smallholders are considered to play a key role in sustainable development, through food production, biodiversity conservation and protection of cultural heritage. As such this subcategory contributes to various sustainable development goals (SDGs) (UNEP, 2021). At the same time, smallholders are vulnerable to shocks and changes in economic- and climate conditions, as well as policy changes (SHDB, 2019).

Background and statistics

Although several factors can determine whether a farmer is considered a smallholder, farm size and the extent of family labour are the most apparent ones. In Europe, there were 9.1 million agricultural holdings in 2020. About 93% of those

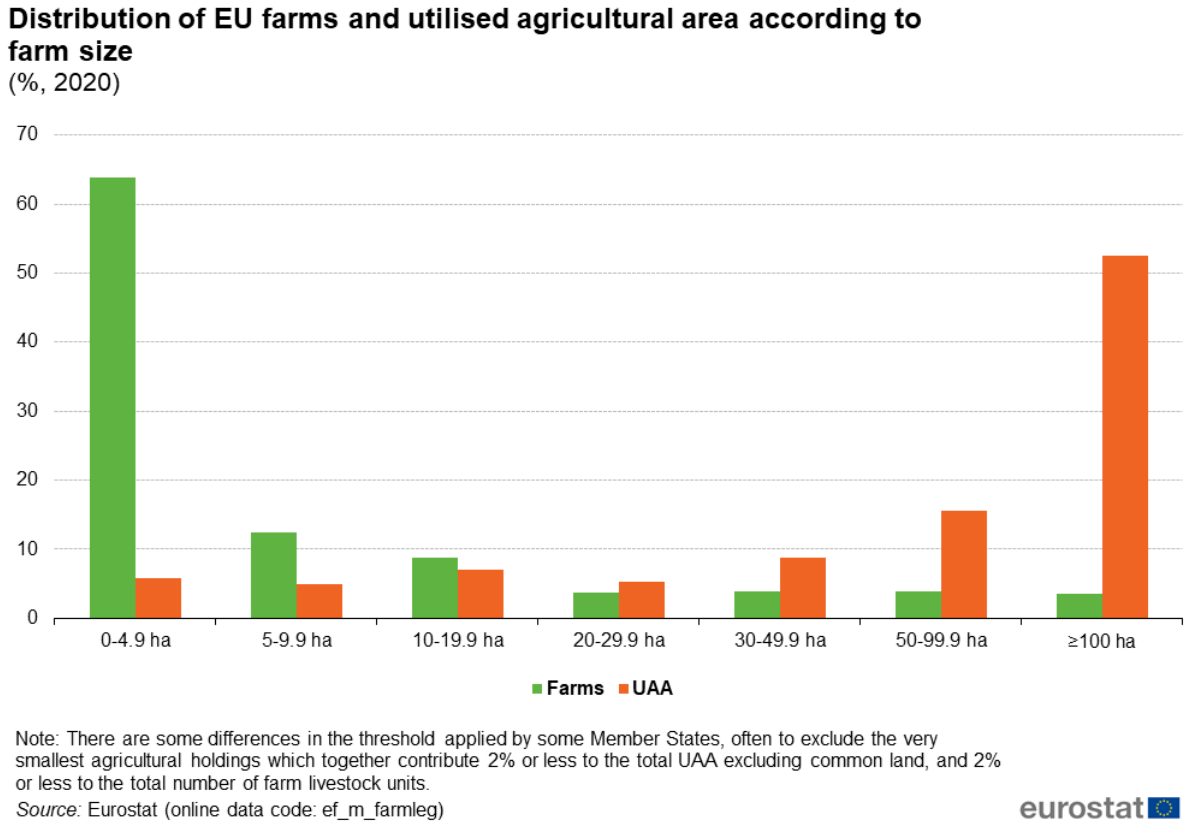

Figure 29 Farm sizes and utilized agricultural area (UAA) in EU member states (Eurostat, 2022)

can be classified as family farms (where 50% or more of the labor is provided by family members). However, EU countries differ substantially from each other.

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Although family farms are the most common farm type in Europe overall, this is only a minority in France (42.5%).

Overall, the majority of farms was smaller than 5 hectares. Only 7.5% of the farms was larger than 50 ha (see Figure 29). Very small and small farms accounted for 63.7 % of all farms in the EU in 2020, and typically had an economic output up to EUR 8 000 per year. Farms of less than 5 ha were also typical in Malta (96.6 % of the total), Cyprus (87.5 %), Greece (74.0 %), Portugal (73.4 %), Croatia (70.6 %), Hungary (64.9 %) and Bulgaria (64.0 %), and in some regions in southern Poland and the coastal areas in Spain and Italy (Eurostat, 2022).

Data collection and analysis

To define smallholders, it would require very specific (farm) data that is not always easily available or accessible. However, in this research this information has been made available by the living labs, which offers a unique possibility of assessing the subcategory. The indicators that have been collected in the survey are presented in Table 35.

Table 35 Indicators collected for smallholders including farmers

6,1	Livelihood and well-being	*Does the farm concern a smallholders farm? See definition above.*	Yes / No / N/A
6,2		*How many hectares does your farm have?*	hectares
6,3		*Do you feel that your farming activities provide enough income to meet your family's basic needs?*	Yes / No / N/A
6,4	Inclusiveness (ownership ad participation in farmers' organizations)	*Who is the primary owner or decision-maker on your farm (e.g., individual, family, shared ownership)?*	Open question
6,5		*Are you or your family members part of any farmers' organizations, cooperatives, or associations?*	Yes / No / N/A
6,6		*If yes, how have they supported your farming activities?* *(e.g. agronomic assistance, fair trade initiative that helps you get better market access, access to inputs such as fertilizers and seeds, capital, etc.)*	Open question
6,7		*Do you feel included in decision-making processes within these organizations or cooperatives?*	Yes / No / N/A
6,8		*Have you experienced any challenges related to ownership or participation in farmers' organizations?*	Yes / No / N/A
6,9		*How has being part of a cooperative or farmers' group helped you access better resources, training, or market opportunities?*	Yes / No / N/A
6,1	Access to services	*Which of the following factors do you have access to?*	
		Credit	Yes / No / N/A

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		Capital	Yes / No / N/A
		Land for farming	Yes / No / N/A
		Water for irrigation	Yes / No / N/A
		Quality seeds	Yes / No / N/A
		Fertilizers	Yes / No / N/A
		Other inputs for your farm	Yes / No / N/A
6,11	Trading relationships	*Where do you sell your farm products (e.g. local markets, cooperatives, direct to consumers)?*	Open question
6,12		*Do you face challenges in reaching markets or getting fair prices for your products?*	Yes / No / N/A
6,13	Next generation farmers/holders	*What is the age of the farm/company manager or the person who generally makes the decisions?*	#
6,14		*Are there children or younger family members interested in continuing the family farm of pursuing a career in agriculture?*	Yes / No / N/A
6,15		*How are you preparing the next generation to take over the farm? Are they involved in daily farming activities, and do they receive any formal agricultural education or training?*	Open question
6,16		*Do you have a plan in place for transferring ownership and responsibilities of the farm to the next generation? What challenges do you foresee in this transition?*	Yes / No / N/A
6,17		*What challenges do you think the next generation will face in farming (e.g., climate change, market access, financial barriers)? What opportunities might they have that were not available to you?*	Open question
6,18		*Do your children or younger family members have access to the resources (e.g., land, financial support, technology) they would need to succeed as future farmers? What additional support would be helpful for them?*	Open question

*The definition questions 6.1 is referring to is: ***Smallholders refer to individuals or households that manage relatively small plots of land, often relying on family labour to carry out agricultural activities. These small-scale farmers or producers***

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typically own or operate their farms independently, producing crops or raising livestock for their livelihood.

Table 36 presents the answer of the living labs to the questions 6.1 and 6.2 and this already provides insights in the varying perceptions among them. Reported farm sizes range from 11-371 ha. Thresholds of small and large farm sizes also vary, depending on data availability and context. Though, generally, farms below 1 or 2 ha are considered small, and farms larger than 3 or 5 ha are considered large (SHDB, 2019). This would mean none of the living lab farms classifies as a smallholder when only looking at farm size, in hectares (ha). Interestingly, a farmer with 11 ha does not consider him/herself a smallholder, whereas a farmer with more than 356 ha does. This clearly indicates that farm size only is not sufficient to evaluate smallholders. Given the available data, another option is to also consider access to services. Table 37 indicates whether living lab farms have access to credit, capital, farm land, irrigation water, quality seeds or other inputs.

Table 36 Farm sizes of the living labs

Living Lab	How many hectares does your farm have?	Does the farm concern a smallholders farm? See definition above.
Greece	7.9	Yes
Poland	80	Yes
Spain	356,22	Yes
Czech Republic	371	No
Germany 1	88	Yes
Germany 2	195	Yes
Denmark	11	No
Sweden	100 plants/ day	No
Hungary	n.a.	No
France	n.a.	No
Italy 1	120	Yes
Italy 2	40	No
Italy 3	20	Yes

Table 37 Access to services by the different living labs

Living Lab	*Credit*	*Capital*	*Farm land*	*Irriga-tion water*	*Quality seeds*	*Fertilizers*	*Other inputs*	Total services
Greece	Yes	No	Yes	Yes	No	Yes	Yes	5

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Poland	Yes	No	Yes	No	Yes	Yes	N/A	4
Spain	No	No	No	No	No	No	No	0
Czech Republic	Yes	Yes	Yes	No	Yes	Yes	Yes	6
Germany 1	N/A	N/A	Yes	N/A	Yes	Yes	Yes	4
Germany 2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7
Denmark	N/A	Yes	Yes	N/A	Yes	Yes	Yes	5
Sweden								n.a.
Hungary								n.a.
France								n.a.
Italy 1	Yes	Yes	No	No	Yes	Yes	Yes	5
Italy 2	Yes	Yes	No	No	Yes	Yes	Yes	5
Italy 3	Yes	Yes	No	No	Yes	Yes	Yes	5

One Living lab indicated not to have access to any services. The other living labs that provided information have access to at least four services. Water for irrigation seems the most limited resource, followed by access to capital.

Furthermore, four living labs indicated that they and/or family members are members of any farmers' organizations, cooperatives, or associations. The same four respondents indicated that being part of a cooperative or farmers' group helped to access better resources, training, or market opportunities. However, these characteristics are difficult to use as clear guidelines for defining who qualifies as a smallholder, since their relevance and impact vary greatly across contexts.

Integration into Social LCA

Including smallholder farms into Social LCA is important when considering the social impacts of agriculture. Smallholders contribute substantially to food security, economic growth, and poverty reduction. However, on farms where the share of family labor is high, household vulnerability to shocks and changes in economic and climate conditions is generally also higher. Vulnerability also increases when farm resources are relatively low and/or farm size is limited.

Because the definition of smallholders is multifaceted, it is very difficult to standardize the indicators. In SHDB, *smallholders vs. commercial farms* is an existing subcategory. Two different indicators are used in this reference scale, namely farm size and the percentage of family and commercial labor. Although it is known, from the living lab survey, who is considered to be the main decision maker on the farm, the share of family labor relative to commercial labor has not been indicated.

Conclusion

In terms of performance of the living labs, the picture is mixed. None of the living labs classify as smallholders by farm size, yet several still show vulnerabilities

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typically associated with smallholder status. Access to irrigation water and capital was limited across much of the sample, and one living lab reported no access to any service at all. Where farmers were part of a cooperative or farmers' organization, this seemed to help with access to resources, training, and markets, though this wasn't the case everywhere. So while the living labs generally operate at a larger scale, a number of them still face the kind of structural constraints that smallholder focused interventions are meant to address.

This also says something about how we define and assess smallholder status more broadly. Farm size on its own did not match how farmers saw themselves, and it did not reflect their actual access to services either. That gap suggests smallholder status is less about size and more about access and structural vulnerability, which is why looking at multiple indicators together gives a more accurate picture than relying on a single threshold.

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5. Contribution to economic development

Introduction

This subcategory assess the extent to which a product or organization (farm) contributes to economic development. The rationale is that generating sufficient wealth is beneficial for human well-being. Contribution to economic development can be generated through creating revenue or jobs, providing education and training and making investments (UNEP, 2021).

Background and statistics

In 2023, the share of GDP contributed by the agriculture, forestry and fishing sectors was 1.65%. There are however substantial differences between EU member states. For example, in Germany the contribution to GDP accounted for less than 0.9% whereas the share was more than 4.5% in Hungary (see also Table 38).

Table 38 Agriculture, forestry, and fishing, value added (% of GDP) (World Bank, 2025)

LL country	2020	2021	2022	2023
Greece	3,92	3,53	3,75	3,34
Poland	2,57	2,25	2,81	2,75
Spain	2,78	2,77	2,31	2,50
Czechia	1,94	1,76	2,08	1,73
Germany	0,73	0,74	1,00	0,84
Denmark	1,34	0,99	0,79	0,76
Italy	1,93	1,83	1,89	1,86
France	1,46	1,46	1,76	1,74
Hungary	3,39	3,46	3,11	4,69
Sweden	1,20	1,11	1,04	0,99

In 2024, the total output of the EU's agricultural sector was estimated at €532.4 billion. The 'big four' accounted for 57.8% of this total, ann consisted of: France (€89.4 billion), Germany (€75.5 billion), Italy (€75.4 billion), and Spain (€67.5

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billion). They were followed by the Netherlands (€41.2 billion), Poland (€37.8 billion), and Romania (€20.5 billion) (Eurostat, 2025).

The economic contribution of agriculture can be assessed on country-level, or based in product type. Half of the estimated value of total agriultural output came from crops (Figure 30) (Eurostat, 2025).

Figure 1: Output of the agricultural industry
(% of total output, EU, 2024)

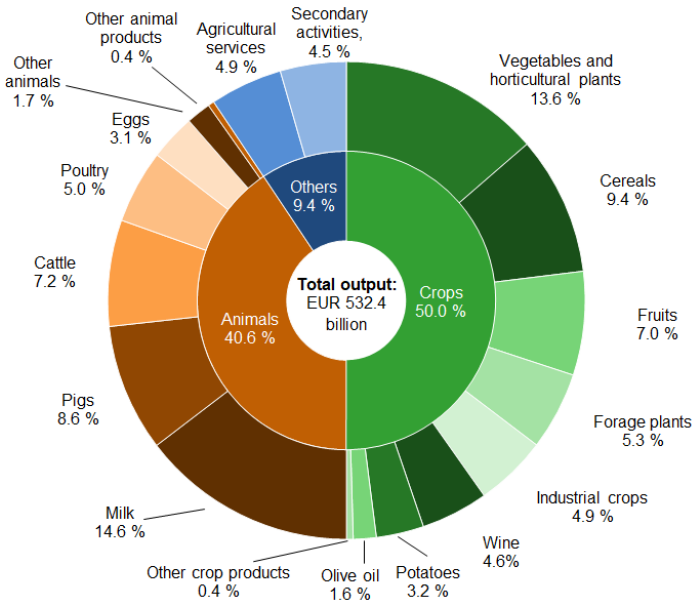

Figure 30 The share of products as percentage of total agricultural output in 2024

Data collection and analysis

Table 39 presents the indicators that were collected in the survey to measure living lab contribution to economic development.

Table 39 Indicators collected for contribution to economic development

8,1	Employment generation	*Roughly how many full-time and part-time jobs have been created as a result of producing and distributing this agricultural product?*	#
8,2		*Roughly how many indirect jobs have been supported in related sectors (e.g., transportation, packaging, retail)?*	#
8,3		*Do you have a policy on stimulating job creation in the local community, by hiring new staff, working with local suppliers or sub-contractors?*	Yes / No / N/A

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8,4	Skill development	*Have you (or your employees) received any farming-related training or learned new techniques from producing this product? If yes, please elaborate.*	Open question
8,5	~~Income and profitability~~	~~*Has your income from producing this product increased since your started growing this crop?*~~	Yes / No / N/A
8,6	Community investment and development	*Has the production of this product led to any improvements in your community (such as better roads, schools, jobs)?*	Yes / No / N/A
8,7		*If yes; how did it contribute to improvements in your community?*	Open question
8,8	General	*How do you think the production of this product is contributing to economic development?*	Open question

Nine living labs indicated that new part-time or full-time jobs have been created. Five living labs also indicated that indirect jobs have been created, though this information seems not to be known/available to the other living labs. Moreover, five living labs indicated that they have policies on stimulating job creation.

Regarding skill development, all nine living labs indicated that there is some form of training available. The type of training differs, ranging from learning from peers or supervisors, seminars, participation in field days, to safety at work trainings and training on vertical farming.

Only one living lab indicated that the production of the crop contributed to community investment and development, by providing opportunities to learn new skills to under-skilled workers. Lastly, there is not always a clear idea how to production of a specific crop contributes to (general) economic development. Some examples provided include development through the creation of jobs and contribution to a healthy lifestyle by increased vitamin intake.

Integration into Social LCA

Because economic contributions can be made in various forms, it is difficult to define the most suitable indicator(s) (UNEP, 2021). In PSILCA, contribution to economic development is evaluated by the indicators: contribution of the economic sector to economic development (as percentage of GDP), public expenditure on education, illiteracy rates and embodied value-added total (the difference between the sales price and production costs for $1 of output, per sector). Evidently, these indicators would need to be measured at meso- or macro level, rather than at the level of individual living labs. Contrary to most other subcategories, this subcategory provides an opportunity score, rather than risk score.

In the SHDB, the subcategories Contributions to Value Added and Other Socioeconomic Impacts are mentioned, which are likely related to Contribution to Economic Development. However, no indicators are defined in the SHDB.

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One indicator that has relatively often been stated in literature is 'job creation'. This can refer to the number of persons employed, the share of employees hired per year, the local workforce compared to the total workforce, etc. (Luthin et al., 2023; Siebert et al., 2018). However, determining the level of assessment can be difficult. For example, an increase in job creation in one region may imply a decrease in available jobs in another region. It may also impact both workers, local communities and larger society.

We propose a 3-level reference scale (Table 40) to categorize Living labs based on their reported contribution to economic development:

Table 40 Reference scale for contribution to economic development

Score	Description
+1	Jobs are created, there is policy on job creation and/or there are trainings available to employees
0	Jobs are created but there is no training or policy on job creation
-1	There is no policy on job creation or there are no trainings available to employees

Based on this reference scale, the living labs can be assessed and scored accordingly:

Table 41 Opportunity score indications per living lab, for contribution to economic development

Living Lab	Score	Justification
Greece	-1	Tomato cultivation has declined in the region, with fewer farmers involved, and there is no policy on job creation nor any training opportunities, with no reported improvements for local employment.
Poland	0	Only 1 job created, no policy. The available training is on plant protection products and operating combines, which seems to be a minimal safety requirement.
Spain	-1	No policy and no specific trainings available ('continuing training')
Czech Republic	1	Multiple jobs created and there is a policy, plus participation in field days
Germany	0	Only 1 job created, no policy. The available training is on safety, which seems to be a minimal requirement.
Germany 2	-1	Job creation is reported as N/A and there are no policies stimulating job creation, aside from the general health and safety trainings.

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Denmark	1	Multiple jobs created and there is policy, unclear if specific training is available (they mention 'constant training')
Sweden	1	Many jobs created though there is no policy, unclear if specific training is available ('yes')
Hungary	1	Some jobs created, there is policy on job creation and there is training on vertical farming.
France	1	Multiple jobs created and there is policy, unclear if specific training includes more than learning from colleagues.
Italy 1	1	Multiple jobs created, there is policy on job creation and there are seminar and training courses (topics unknown).
Italy 2	1	Multiple jobs created, there is policy on job creation and there are seminar and training courses (topics unknown).
Italy 3	1	Multiple jobs created, there is policy on job creation and there are seminar and training courses (topics unknown).

Conclusion

The contribution of individual farms to economic development is relatively difficult to capture. All living labs created jobs, some even supported the creation of indirect jobs. Also all living labs provide some form of training, although some seem minimal requirement to prevent safety hazards, rather than leading to economic benefits/growth. The impact of the production of the living labs on their surrounding community and economic development in general, however, is not very evident. Standardized indicators are few, and benchmarking them remains therefore challenging.

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6. Fair salary

Introduction

According to PSILCA, a fair salary is defined as a salary that is in line with the value of product or service provided. When assessing this, three types of standards are considered: the legal minimum wage, the prevailing local sectoral wage and the living wage[2]. As such, also three indicators are defined by PSILCA.

In the SHDB, a wage assessment is also included. Here, country-specific sector average wages are compared to similar thresholds: the minimum wage, living wage and sweat-free wage[3]. For the minimum wage indicator, the average wage is compared to the minimum wage. Apart from that there are also indicators that compare the sweat-free wage and the average wage.

Background and statistics

The most recent data about minimum wages in 22 out of 27 EU countries is summarized in the table below. This represents the national gross monthly minimum wages as of 1 January 2025. Denmark, Italy, Austria, Finland, and Sweden don not have a statutory minimum wage. Wages are often set through collective bargaining between trade unions and employer associations within each industry or sector.

Table 42 National minimum wages for 22 out of 27 EU countries (European Commission, n.d.)

Above €1 500 per month	Luxembourg, Ireland, the Netherlands, Germany, Belgium and France	Wages ranged from €1802 in France to €2638 in Luxembourg.
From €1 000 to €1 500 per month	Spain, Slovenia, Poland, Lithuania, Portugal and Cyprus	Wages were between €1000 in Cyprus and €1381 in Spain
Below €1 000 per month	Croatia, Greece, Malta, Estonia, Czechia, Slovakia, Romania, Latvia, Hungary and Bulgaria	National minimum wages ranged from €551 in Bulgaria to €970 in Croatia.

Corrected for price level differences (purchasing power parity), the minimum wages in European countries rank as follows in Figure 31.

[2] Living wage can be defined as: "The wage level that is necessary to afford a decent standard of living for workers and their families, taking into account the country circumstances and calculated for the work performed during the normal hours of work" (ILO, n.d.).

[3] Sweatfree wages are based on San Francisco Admin Code Section 12U.3(b). It requires that (sub-) contractors pay a wage that is comparable to 11.99$ USD (for 2018), adjusted to reflect the country's level of economic development by using the World Bank's most recent Gross National Income per capita Purchasing Power Parity Index. It is a conservative estimate of a fair wage (SHDB, 2019).

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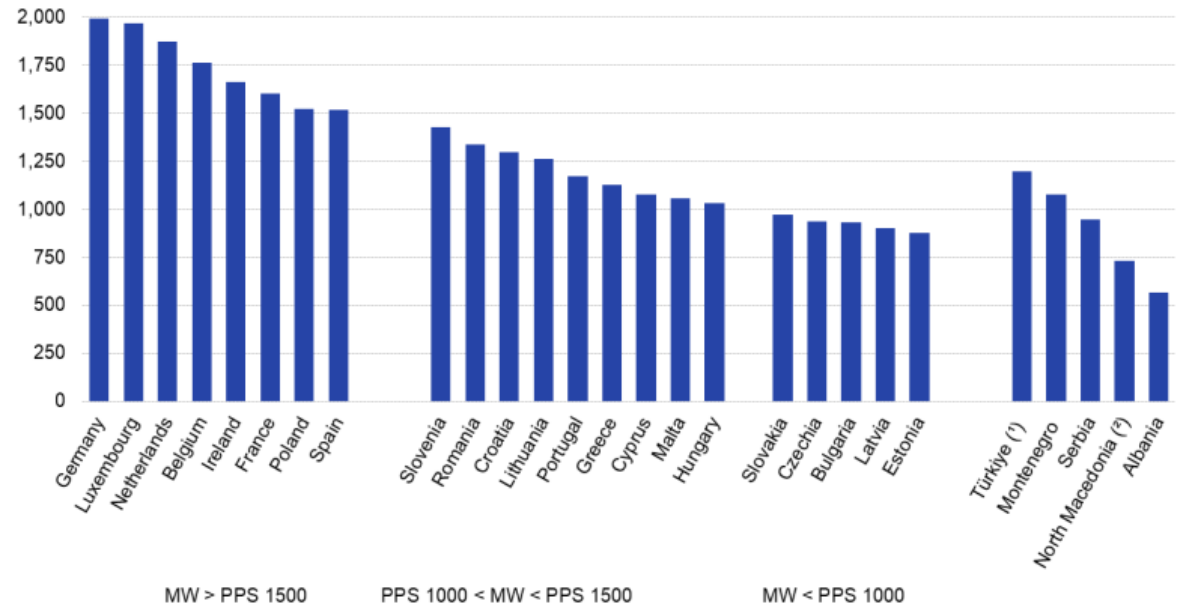

Figure 31 Minimum wages per month in European countries, corrected for price levels (PPP) (European Commission, n.d.)

For average wages in agriculture, less recent data is available. In 2021, the average farm income per worker in the EU was €28 800. In that year, at the top 10% of farms with the highest income, workers earned about €61 500 per year, while at the bottom 10% the average payment was less than €800 per worker on average (European Commission, 2023). Generally, incomes are higher in the north-western part of the EU (Denmark, north-west Germany, the Netherlands and Northern France). In the eastern part (including Romania, Slovenia, Croatia and Eastern Poland) the lowest incomes were recorded.

Overall, all agricultural sectors registered an increase in income, compared to 2020, with the exception of pigs and poultry (-11.3%). Nevertheless, the income at pigs and poultry farms remained among the highest per worker, compared to other agricultural sectors. Moreover, the income in the horticulture, field crops, wine and dairy sectors are also above average in the EU average in 2021 (European Commission, 2023).

Data collection and analysis

A survey was conducted among nine agricultural Living labs to assess wage-related indicators. Table 43 presents the indicators that were collected in the survey.

Table 43 Indicators collected for fair salary

4,1	Minimum wage	*What is the national minimum wage (or collectively agreed)?*	LCU[4] / month
4,2		*Are all workers paid above the minimum wage?*	Yes / No / N/A

[4] LCU = payment expressed in local currency

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4,3	Sectoral wage	*What is the sectoral minimum wage by law or by collective agreement?*	LCU / month
4,4		*Are all workers paid above the sectoral wage?*	Yes / No / N/A
4,5	Job type & salary	*Please specify the most common pay per employee type:*	
			EUR/month
			EUR/month
			EUR/month
4,6	Regular payment	*Are workers paid regularly (e.g., weekly, biweekly)?*	Yes / No / N/A
4,7	Documented payment	*Is the payment to workers documented?*	Yes / No / N/A
4,8	Salary reductions	*Have there been salary reductions for any worker?*	Yes / No / N/A
4,9		*Were the salary deductions made for a clear reason that is understood by the workers?*	Yes / No / N/A

In most countries, the reported minimum wage equals the sectoral minimum wage. In France, the sectoral minimum wage is higher (by 49 euro per month) than the general minimum wage. The Danish Living lab indicated that in their country, there is no general minimum wage; this depends fully on the sector and usually reached through collective bargaining. (This is also the case in Italy and Sweden, so it is assumed that the living labs from those counties reported sectoral minimum wages as general minimum wages.) Minimum reported sectoral wage ranges from 750 to 2124 euro per month[5].

In all living labs, employees receive regular payments. This payment is equal to or above minimum wage. Documentation is common practice in 8 living labs. In one living lab, payments are not documented and salary reductions occur.

Integration into Social LCA

Integrating fair salary in social LCA involves assessment of existing policies on minimum wages in specific countries. Sometimes such policies exist on national level, and/or in other cases minimum wages are negotiated on sectoral level. Part-time and full-timing working agreements also need to be taken into account. Moreover, the reported wages are specified either per hour/day/week/month. The number of hours worked per time unit needs to be calculated first, in order to make fair comparisons between countries and cases.

[5] *In one LL, the sectoral wage is reported in local currency and would amount to 438 euro. This number is assumed to be too low to be realistic.*

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An additional difficulty is that employees within one organization, company or farm may ear different wages. There is no standardized method of aggregating the assessed risks on organizational level.

We integrate Fair Salary into Social LCA by developing a scoring scale ranging from +2 to -2 in Table 44, based on average wages and minimum wages. In our assessment we defined a point risk scale, using SHDB[6] as a basis. The medium risk level (score 0) is defined as an average which is (approximately) equal to, but not lower than, the minimum wage.

Table 44 Reference scale fair salary

Score	Description
+2	Average wage ≥125% * minimum wage
+1	Average wage = 110-125% * minimum wage
0	Average wage = 100-110% * minimum wage
-1	Average wage ≤ minimum wage by 0-25%
-2	Average wage ≤ minimum wage by ≥25%

Because of differences in reported data (different time units in combination with unknown number of working hours per week or month; differences between function types; and the lack of national minimum wages in some countries), it was not possible to assign scores for the Fair Salary indicator. Table 45 briefly outlines the reported information.

Table 45 Risk score indications per LL, for fair salary

Living Lab	Justification
Greece	Average wages are around €880 per month, with not all workers earning above the minimum or sectoral wage, although payments are made regularly and properly documented.
Poland	Although it was reported that all workers are paid above the minimum wage (1011,76 Euro/month), this is not reflected in the presented wages per function type. It is furthermore reported that payments are not documented, and that salary reductions occur at times.

[6] SHDB: compares the average wages (AW) to minimum wages (MW) and defines the following thresholds: also uses accident data but defines different thresholds: very high risk (MW>AW by >25%), high (MW>AW by 0-25%), medium (MW<AW), and low (MW<AW by >25%).

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Spain	Wages of both workers are equal to the minimum wage (1300 euro/month)
Czech Republic	Based on the reported daily wages (ranging, all function types exceed the minimum wage when converted to a monthly equivalent. Assuming a full time workload of approximately 20–22 working days per month, the estimated monthly income is about €1,280–€1,408 for roles paid €64 per day and €1,600–€1,760 for the farm manager (€80 per day). These values are substantially above the reported minimum wage of €750 per month.
Germany 1	N/A (No data reported apart from a minimum wage of 12 eurore/hour).
Germany 2	All workers are paid above the minimum wage of 12 euro/hour and are paid regularly. However it is not specified per employee type, so it is hard to verify.
Denmark	There is no minimum wage defined by Danish legislation. Wages are agreed through collective bargaining by workers' unions and employers' associations. According to the LL, a minimum wage for agricultural workers (over 18 years, without vocational training) is almost 2700 euro per month.
Sweden	There is no national minimum wage defined by Swedish legislation. Wages are agreed through collective bargaining by workers' unions and employers' associations. According to the LL, a minimum wage for agricultural workers is about 2110 euro per month.
Hungary	Unknown. The reported national minimum wage is lower than the minimum wages reported by other sources[7]
France	The reported sectoral minimum wage (€1,807.90 per month) is slightly higher than the national reference value in France (€1,766.92 per month). Wage levels vary substantially across job functions. Minimum wage definitions also differ, in some cases being state regulated, standardized across the agricultural sector, and based on full time equivalent employment (e.g. 35 hour work week).
Italy 1	There is no national minimum wage defined by Italian legislation. Wages are agreed through collective bargaining by workers' unions and employers' associations. Reported wages are expressed in various time units (e.g. 100 euro per month versus 70 euro per day).
Italy 2	There is no national minimum wage defined by Italian legislation. Wages are agreed through collective bargaining by workers' unions

[7] For example: https://bpion.com/minimum-wage-in-hungary-2025/

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	and employers' associations. Reported wages are expressed in various time units (e.g. 100 euro per month versus 70 euro per day).
Italy 3	There is no national minimum wage defined by Italian legislation. Wages are agreed through collective bargaining by workers' unions and employers' associations. Reported wages are expressed in various time units (e.g. 100 euro per month versus 70 euro per day).

Conclusion

In most countries, the reported minimum wage matches the sectoral minimum wage, except in France where it is slightly higher. Denmark, Italy, and Sweden lack a national minimum wage, relying on sectoral agreements instead, reached through collective bargaining. Inconsistencies in reported data prevented scoring the Fair Salary indicator.

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Chapter 4: Reflection of workshop “Future farming scenarios- exploration of the social impacts”



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Methodology

The workshop aimed to explore the potential social impacts of future farming scenarios towards 2050, focusing on how AI, automation, and broader socio-environmental changes may transform farming systems, labour structures, and rural communities. The insights contribute directly to WP5 by sharpening the scenario narratives and informing the analysis of social impacts. They also help identify key challenges and opportunities across farming systems, supporting the development of more nuanced transition pathways and guiding policy discussions.

While quantitative projections or simulations can provide valuable insights, they are often constrained by uncertainty, context dependency, and the difficulty of capturing qualitative dimensions such as skills, fairness, and rural life. To complement these approaches, the workshop adopted an exploratory, participatory format. This method emphasizes identifying pathways, interconnections, and potential social consequences to support resilience, anticipate trade-offs, and prepare for multiple possible futures. The workshop was attended mainly by Living lab representatives, complemented by a few knowledgeable conference participants from additional countries and crop sectors. Living lab participants contributed from the perspective of their own country and focus crop, while the other participants reflected on their country and selected a focus crop that aligned with their main expertise.

The living labs had developed five scenarios in D1.4 to capture a range of possible futures. The first two, and in some cases three, represented more extreme or middle-ground conditions, including business-as-usual and severe climate impacts, linking directly to the first breakout session, which explored the Rocky Road scenario and its potential social implications for changes in farming and the agricultural sector more broadly. The remaining two or three scenarios focused on a mix of opportunities and interventions, providing mitigation options that formed the basis for the second breakout session. These intervention scenarios were clustered into five overarching themes for Seeds of Change, representing thematic areas addressed by the living labs: Promotion of Climate-Smart Agriculture, Regenerative Land Stewardship, Shifting Consumer Demand Towards Sustainable Products, Clean Technology Solutions, and Social Equity and Community Resilience. This clustering provided a structured framework for participants to explore potential social and environmental impacts of intervention-focused futures.

To help participants think beyond their local contexts and consider how global systems might evolve, the scene was set by presenting simulation results of the MAGNET model based on the Shared Socioeconomic Pathways (SSPs). The middle road, Rocky Road, and Green Road scenarios illustrated how changes in population, land productivity, food prices, and labour and capital availability could unfold under different global conditions. Participants were encouraged to reflect on questions such as how climate impacts, food affordability, and infrastructure resilience could vary depending on societal, economic, and environmental conditions. This stage provided context for imagining alternative futures without prescribing specific

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outcomes and helped participants frame their scenario explorations within broader, world-scale dynamics.

Breakout Group Exploration

Participants engaged in two interactive breakout sessions designed to explore both risks and opportunities in future farming systems:

1. **Rocky Road Scenario**
   Each Living Lab considered how their farming systems might evolve under a challenging future with severe climate impacts. Discussions focused on three questions:

- How would your farming system look in this scenario, including inputs, technologies, scale, and processes?
- What would the required and available workforce look like, including skills, composition, and labour availability?
- How would working conditions change, including salaries, working hours, and occupational health and safety?

2. **Futures Wheel with Focus Seeds of Change**
   Participants then explored two of the five Seeds of Change:

- Promotion of Climate-Smart Agriculture
- Clean Technology Solutions

For these, they selected specific focus crops and developed concrete Seeds of Change (Table 1). Using the Futures Wheel method (Figure 1), participants mapped first- and second-order social consequences, visualizing interconnections and anticipating impacts on farmers, labour conditions, and rural communities. Figure 2 shows an example of a filled in Futures Wheel template for a milking robot.

This structured and participatory approach allowed participants to explore multiple pathways, understand potential risks and opportunities, and gain insights into how technological and social transformations may affect farming systems, labour, and rural communities in 2050.

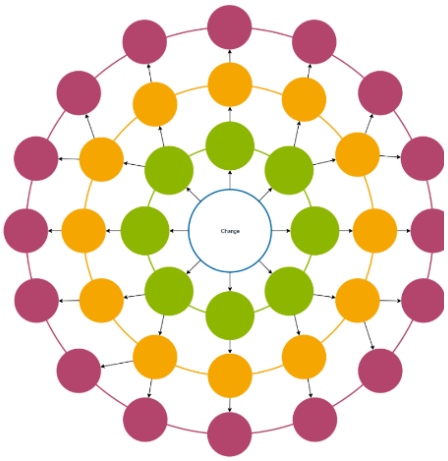

Figure 32 Futures Wheel -Seeds of change template

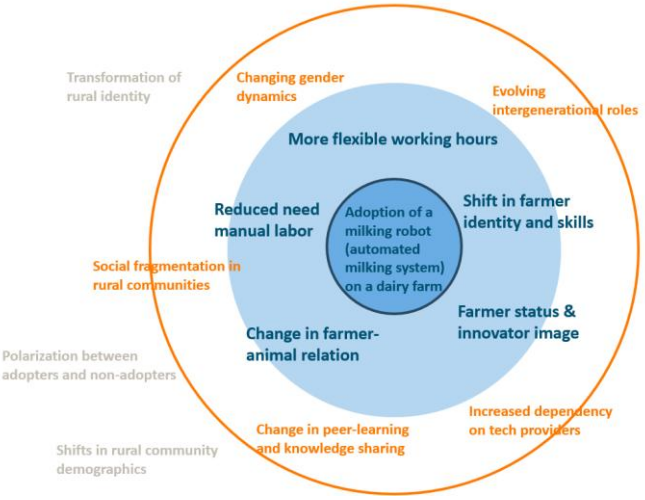

Figure 33 Example of an adoption of a milking robot as a seed of change

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\Table 46 Participants and their representing countries, products and seed of change

Country	Product	Seeds of Change
Czech Republic	Wheat	Promotion of Climate-Smart Agriculture (new drought-tolerant varieties and variable seed rate technologies)
Czech Republic	Organic wheat	Promotion of Climate-Smart Agriculture (organic breeding for new oilseed and protein crops)
UK	Sheep & goats	Promotion of Climate-Smart Agriculture (genomic selection and computational disease-resilience methods)
Italy	Tomato	Promotion of Climate-Smart Agriculture (new genomic and biotechnology techniques – NBT)
Germany	Barley	Clean Technology Solutions (soil and nutrient-demand evaluation aligned with nitrogen reduction targets)
Germany	Barley	Clean Technology Solutions (AI for pest control and fungal prediction)
Poland	Barley	Clean Technology Solutions (AI-based fertilization)
Poland	Barley	Clean Technology Solutions (robots for weed control)
General	—	Promotion of Climate-Smart Agriculture (mixed and intercropping)
Spain	Wheat	Clean Technology Solutions (autonomous tractors)
Spain	Wheat	Promotion of Climate-Smart Agriculture (recovery of ancestral wheat varieties)
Turkey	General	Clean Technology Solutions (AI to prevent waste and increase efficiency)

Results

Round 1 - Rocky Road

1. **Farming system changes**

All participants anticipated that farming systems would face stronger pressures from drought, heat, and extreme weather, making water availability the most pressing constraint. Crops with high water demands, such as tomato, were considered particularly vulnerable, pushing farmers toward smart irrigation, new breeding techniques, or shifts in crop choice. In Southern Europe, where rainfall is expected to become more erratic, farmers foresaw the need to adopt drought-tolerant varieties and smarter irrigation systems. In contrast, Central European participants focused on rising input costs, fertilizer shortages, and declining cooperation among farms, while Northern regions noted risks related to feed availability and pasture quality in livestock systems.

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Crop-specific insights reflected how differently these stressors might play out. Cereal production, such as wheat and barley in the Czech Republic, Germany, Poland, and Spain, was expected to continue but under tighter resource constraints and with higher input costs. Organic wheat systems appeared particularly fragile, as the success of legume-based crop rotations could be undermined by drought, threatening the viability of the entire production system. Livestock systems, represented by sheep and goat farms in the United Kingdom, anticipated changes in grazing patterns, heat stress, and a growing need for adaptive infrastructure such as shaded shelters or alternative feed strategies.

2. **Required and available workforce**

Across most contexts, participants expected the total number of workers to remain stable or decline, but the type of labour needed would change significantly. Future farming systems were seen as more dependent on skilled, adaptable, and digitally literate workers capable of managing advanced technologies and data systems. This transition was widely viewed as challenging, given that many rural areas already struggle with a lack of qualified labour and ageing farming populations. For instance, Italian and Spanish participants pointed to a shortage of young, tech-savvy workers, while Czech and German participants noted limited labour market flexibility and slow adoption of automation in smaller farms.

Differences between crop systems were also evident. Large-scale arable systems, particularly in cereals, were expected to employ fewer manual workers as automation and AI tools become more common. As advanced technologies take over tasks such as harvesting, planting and farm preparation, the traditional role of the farmer is shifting from hands-on work and a direct connection with crops or animals toward managing data, interpreting technology outputs and making strategic decisions. Roles based solely on experience are expected to disappear, and farm workers will increasingly need digital, analytical and technical skills. Conversely, organic and diversified systems could require more hands-on labour if crop rotations and soil management become more complex under climate stress. In livestock production, such as sheep and goat farming, participants foresaw a need for broader skill sets that include nutrition management, feed balancing, and infrastructure maintenance. Some participants also raised concerns about increasing reliance on migrant labour in large farms, potentially under less favourable working conditions.

3. **Working conditions**

Working conditions were expected to become more uneven, shaped by both technological change and environmental stress. Many participants foresaw longer and more flexible working hours, especially in regions facing extreme heat, where daily schedules might shift to early mornings and evenings. Southern participants, especially from Italy and Turkey, mentioned that high temperatures could reduce mid-day activity and lead to more fragmented workdays. Wage trends were also expected to diverge: while higher skills and responsibilities could justify better pay in some cases, reduced yields and profitability might push salaries down in others, particularly where production declines or low-cost labour is used.

Crop type also influenced these expectations. In highly mechanized systems such as cereals, working conditions may become more technical but also more isolated, as

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fewer workers are needed in the field. In organic systems or those with complex crop rotations, manual work may persist, potentially under tougher environmental conditions. Livestock workers, particularly in grazing systems, may need to spend more time outdoors managing herds, including providing supplemental feed and moving animals to shelters, which increases their exposure to extreme weather and physical strain. Across all systems, safety concerns were raised regarding the misuse or malfunction of new technologies, suggesting that occupational health and safety risks could increase even in technologically advanced farms.

Round 2 – Seeds of Change

Promotion of Climate-Smart Agriculture

Seeds of Change

The Seeds of Change consist of climate-smart agricultural innovations aimed at improving farm resilience, economic stability, and environmental sustainability. These include drought-tolerant wheat varieties and variable seed rates in the Czech Republic, organic breeding developments for wheat and protein/oil crops, genomics and AI tools for disease resilience in UK sheep and goat farming, and genome-edited tomatoes in Italy (Table 1). These innovations are expected to stabilise yields, reduce reliance on external inputs, improve food quality, and transform farm practices, labour, and research priorities.

First-order consequences

Looking at immediate, operational impacts, participants expect multiple benefits across crop and livestock systems. Drought-tolerant wheat in the Czech Republic could stabilise yields, reduce disease pressure, improve weed control, and decrease fuel use and manual labour for weeding. Organic wheat and protein crops may enhance farm economics, support diversification, reduce imports of protein and oil crops, and lower environmental externalities from conventional farming. In livestock, UK sheep and goat farming could see improved disease resilience, less need for vaccination, reduced virus mutations, and increased profits, while also requiring farmers to develop digital skills for early disease detection. Genome-edited tomatoes in Italy are expected to reduce fertilizer and pesticide use, improve farmer health, decrease manual interventions, and save time and money.

Across systems, general first-order consequences point to increased productivity and operational efficiency, reduced reliance on external inputs, lower physical labour, environmental benefits, improved food quality, and the need for new technical skills in areas such as AI, genomics, and biotechnology.

Second-order consequences

Over the longer term, participants anticipate broader social, economic, and environmental effects. Drought-tolerant wheat in the Czech Republic could strengthen farm economics, improve product quality, and support more stable rural livelihoods. Organic wheat systems may encourage farm diversification, motivate conversion to organic practices, deliver climate benefits, reduce stress, and lower public spending on social and health care. In livestock, UK sheep and goat farming

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could shift labour demand by reducing the need for veterinarians and increasing demand for digital expertise, while fostering investment in sustainable practices. Genome-edited tomatoes in Italy are expected to produce environmental benefits, enhance biodiversity (e.g., supporting beneficial insects), improve food quality, free farmers' time for family and community activities, and create opportunities for highly skilled research.

In general, second-order consequences suggest stronger farm economics, improved social resilience, environmental gains, and expanded research and innovation opportunities. At the same time, participants emphasised potential challenges, including GMO debates, questions of ownership and power dynamics, dependency on technology providers, and barriers for late or non-adopters. These considerations underline the importance of equitable access, training, and careful adoption strategies to ensure that the benefits of innovation are widely and fairly realised.

Clean Technology Solutions

Seeds of Change

The Seeds of Change focus on the adoption of low-impact, resource-efficient technologies to reduce emissions and support sustainable intensification. Participants explored solutions across crops such as barley, wheat, and general farm systems in multiple countries, including Germany, Poland, Spain, and Turkey. Examples include soil and nutrient monitoring to reduce nitrogen use in German barley, AI for pest and fungus prediction in German barley, AI-based fertilization and robotic weeders in Polish barley, autonomous tractors and ancestral wheat varieties in Spain, and AI-driven resource management in Turkey. In addition, nature-based solutions such as mixed cropping and intercropping were investigated to improve resilience, crop diversity, and product variety (Table 1). These Seeds of Change represent different technological approaches that aim to improve operational efficiency, reduce environmental impact, and strengthen farm sustainability.

First-order consequences

Participants anticipate a range of immediate operational impacts from the Seeds of Change. The German barley Seed focusing on nitrogen reduction is expected to lower fertilizer use, reduce greenhouse gas emissions, improve nutrient management through soil analysis, and reduce operational costs. A separate German barley Seed using AI for pest and fungus prediction is expected to lower pesticide use, prevent crop loss, reduce labour demand, and increase investment capacity. In Polish barley, AI-based fertilization may reduce fertilizer use, cut labour, generate large datasets, and enable specialized tech providers to scale services, while robotic weeders are expected to reduce herbicide use, fuel consumption, and manual labour, while creating new service opportunities. In Spain, autonomous tractors for wheat production could reduce labour, improve operational efficiency, and require higher technical skills, while the recovery of ancestral wheat varieties could increase disease resilience, enhance product diversity, and improve crop quality. In Turkey, AI-based resource management systems are expected to optimize production,

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reduce waste, improve efficiency per unit area, and lower manual labour requirements. Nature-based solutions such as mixed cropping and intercropping are expected to enhance crop protection, increase product variety, and improve resilience.

In general, these Seeds of Change are expected to lead to lower input use (fertilizers, fuel) and environmental impact, reduced operational costs, less manual workload, lower stress, and improved farmer quality of life. Shared service models may reduce investment burdens for individual farmers, and the entry of specialized tech providers supports innovation and service provision. At the same time, greater reliance on IT systems, AI, and energy infrastructure may increase technological dependency across farming systems.

Second-order consequences

Longer-term impacts from the Seeds of Change are expected to vary by crop and technology. The German barley nitrogen-reduction Seed may require farmers to adapt to new approaches, stimulate demand for soil analysis services, and enable precision harvesting for differentiated grain qualities, while the AI pest/fungus prediction Seed could reduce pesticide waste, shift labour needs, and increase dependence on technology. In Polish barley, AI-based fertilization may reduce stress for farmers, raise demand for IT expertise, and improve rural quality of life, while robotic weeders may further shift labour requirements, create a need for AI-specific training, and support biodiversity. In Spain, autonomous tractors may reduce low-skilled driving jobs, enable larger farm operations, increase production, and demand technical expertise, while ancestral wheat varieties could improve disease resilience, enhance product diversity, and reduce input needs. In Turkey, AI-driven resource management is expected to lower food prices, support healthier people, and decrease carbon emissions. Nature-based solutions like mixed or intercropping are anticipated to enhance long-term crop resilience and maintain product variety.

Interpretation of these results shows that the role of the farmer is shifting from hands-on management and direct interaction with crops or animals toward a knowledge intensive role as data manager, technology operator, and strategic decision maker. Roles based purely on experience are increasingly replaced by tasks requiring digital literacy and technical expertise. These changes are expected to strengthen farm economics, resilience, and efficiency, improve environmental outcomes, and enhance quality of life for farmers and rural communities. At the same time, traditional agricultural knowledge could decline, and system failures, cyber-attacks, or energy shortages could create cascading risks affecting farm operations and related sectors. Local communities may benefit from reduced labour intensity and higher living standards, but also face challenges such as noise, privacy concerns, and increased technical demands. Additional challenges include social gaps between early adopters and late or non-adopters, increased dependence on technology providers, possible over-regulation, and the need for continuous training and skill development. These lessons highlight the importance of careful adoption strategies to ensure the benefits of innovation are widely and fairly realized.

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Overall reflection

The Rocky Road scenario highlighted how climate change and shifting market pressures could amplify inequalities both between and within European farming systems. While technological innovation and digitalization offer pathways to greater efficiency, resilience and productivity, they also risk marginalizing smaller or less capitalized farms. Regional and crop specific differences highlight that the impacts of climate and market pressures vary widely: cereal systems face challenges in resource efficiency and yield stability, horticultural systems are particularly sensitive to water availability and drought, and livestock systems are affected in terms of welfare, infrastructure and feed management. The scenario underlines that without proactive adaptation, farming systems may struggle to cope with environmental and economic stress, and inequalities in outcomes are likely to widen.

The Seeds of Change exercise illustrated how targeted innovations, ranging from drought tolerant varieties and genomic selection for disease resilience to AI driven fertilization, autonomous tractors and nature based solutions, can enhance production, reduce environmental impacts and support social outcomes. These developments also point to a changing role for farmers, who will increasingly need to manage complex technologies, interpret data and make strategic decisions, shifting from primarily manual labour to knowledge intensive work. While these innovations offer opportunities for greater efficiency and resilience, they also risk reinforcing inequalities if access to knowledge, skills and capital is uneven.

Although the perspectives gathered reflect specific regions and products rather than all European farming systems, they provide important insights into emerging challenges and opportunities. Building on these results, we will further develop the scenarios by integrating them with qualitative inputs already collected across multiple countries and production systems. This synthesis will create a richer and more nuanced picture of possible agricultural transitions, highlighting where vulnerabilities and opportunities might emerge. The results of the workshop show that water scarcity, limited availability and uneven working conditions are broad challenges across farming system. At the same time, crop- and region-specific differences highlight particular risks and adaptation needs. These findings not only guide scenario refinement but also provide a foundation for policy discussions, helping decision-makers to design approaches that are responsive to local contexts and attentive to cross-cutting concerns such as equity, skills development and occupational safety.

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