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Barley production in Spain and Italy: Environmental comparison between different cultivation practices

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Abstract

In Europe, around 12 million ha are cultivated with barley and Spain and Italy are two important producers' countries.

This study aims to compare the cultivation of barley of two different contexts, Spain and Italy, evaluating the related environmental performances; this is carried out considering the similar latitude and climatic conditions of the two countries, but taking into account the different average mechanisation solutions that differentiate considerably the two production frameworks. Inventory data about barley cultivation were gathered mainly by questionnaires with farmers and technical expert interviews. To quantify the environmental performances of barley production in the two Countries, the Life Cycle Assessment approach was applied and 1 ton of grain at the commercial moisture was selected as reference unit and 12 impact categories were evaluated.

The outcomes of the impact assessment highlight how for 7 of the 12 evaluated impact categories, barley production in Spain shows a higher impact respect to the Italian production (from +7% for photochemical oxidant formation to +120% for freshwater ecotoxicity) mainly due to the lower grain yield and to the higher consumption of mineral fertilisers. For the other evaluated environmental effects, the Spanish production performs better than the Italian one, mostly because of the lower emissions of ammonia into the air. Yield is the main driver of the environmental effects. Additionally, due to mechanisation of field operations and to fertilisations, wide differences on the environmental side emerge from the comparison.

There is a trade-off between the Spanish production, where the use of mineral fertilisers reduces all the environmental effects related to ammonia volatilisation, and the Italian barley cultivation, where the use of animal slurry improves the results on the impact categories affected by the fertiliser production but worsens those affected by the nitrogen emissions.

Keywords:

Life Cycle Assessment, cereal, field mechanisation, system expansion

1 Introduction

The estimation of a population growth and a consequent increase in demand for food are the major drivers to consider for future agricultural productions. Hence, environmental, social, technological and economic sustainability assessments result fundamental, requiring that the technological progress helps producers and that the models adopted for the sustainability assessments result accurate and reliable (Lovarelli et al., 2017a; Schmidt Rivera et al., 2016).

In Europe 28-countries, the area dedicated to barley cultivation is settled to around 12,000,000 ha, of which about 20% of the total area is located in Spain. Italy is the tenth European country in terms of area dedicated to barley cultivation, representing about 2% of the total area (EUROSTAT, 2019). However, the geographical conformation of the country makes difficult to have wide areas for cropping, contrarily to other countries such as Spain. Moreover, although geographical characteristics such as latitude are the same, yield is quite different in the two countries and, generally, prevision studies under climate change result in different yield responses in the different countries (Cammarano et al., 2019; Niero et al., 2015). One of the most important issues that emerge from modelling future yields regards the change in rainfall events and in peak temperatures, which seem affecting Spanish and southern Italian productions more than those in northern Italy. In fact, cases with extreme events are those with the widest yield variation (Cammarano et al., 2019).

To make food production more sustainable, the assessment of the environmental impact of agro-food products is gaining wide importance worldwide (Bacenetti and Fiala, 2015; Springmann et al., 2018). To this scope, the Life Cycle Assessment (LCA) method is one of the most adopted tools for the evaluation of the environmental sustainability of products and or processes as it considers their whole life cycle. In more details, studies about the cultivation of different crops such as maize and rice (Fusi et al., 2014; Noya et al., 2015), olive oil (Bernardi et al., 2018) and wine (Fusi et al., 2014)show that mechanisation, together with emissions from fertilisation play the main role on the environmental profile of crops cultivation. For this reason, the mechanisation of barley production is evaluated in order to identify the possible mitigation strategies for its cultivation in Mediterranean countries and understand which system results more sustainable.

Other studies were carried out on barley production evaluating the environmental perspective. In particular, Tricase et al. (2018) compared organic and conventional barley cultivation investigating the environmental performances with two functional units (FUs); studying 1 ha as FU showed that organic farming is more sustainable due to the more reduced use of inputs respect to the conventional farming; however, respect to the FU of 1 t of barley grain, the conventional farming resulted more productive. This brings to the need of identifying a trade-off among the different needs and requirements of society. As shown in Cavaliere and Ventura (2018), the role of the consumer and of his willingness to pay is of deep importance as the market is one of the main drivers towards effective productive improvements.

In this study, the aim is to compare the cultivation of barley between two different contexts, Spain and Italy, evaluating the related environmental performances; this is carried out considering the similar latitude and climatic conditions of the two countries, but taking into account the different average mechanisation solutions that differentiate considerably the two production frameworks.

2 Materials and methods

The environmental impact of barley production was quantified by means of the LCA method in accordance with ISO 14040/44 recommendations (ISO, 2006). The main methodological steps that are carried out in the next paragraphs include the definition of goal and scope, functional unit and system boundary, the collection of inventory data, the assessment of environmental impacts with a set of environmental impact categories and the interpretation of results.

The approach applied was the attributional one, according to which the current cultivation practice is studied without considering external effects such as those deriving from market choices (United Nations Environment Programme, 2011). In addition, mass allocation is performed splitting the environmental impact between the product that is barley grain and the co-product that is barley straw. It is also investigated a scenario in which allocation is avoided and instead system expansion is applied for the attribution of the environmental impact result.

2.1 Goal and scope definition

The goal of this study is to quantify the environmental load associated with the cultivation of conventional barley in Italy and Spain, focusing on the most widely adopted solutions for field mechanisation in both countries.

The evidence is that Spanish and Italian contexts show wide differences in terms of preferred mechanisation solutions, and in this study is investigated the environmental impact of both options to understand which is the more sustainable system and to propose improvements to the single countries keeping into consideration their site-specific conditions.

The research questions in this study are:

- How much is the environmental impact related to the production of 1 t of barley grain in Italy and in Spain?
- What are the environmental hotspots (i.e., processes mainly responsible for this impact)?
- How does the impact vary between Italy and Spain where the cultivation practice involves different mechanisation levels and different yield?
- How could be reduced the environmental impact of barley cultivation?

The outcomes of the study can be useful for technicians and farmers' associations that are interested in identifying the most critical steps (field operations, production factors consumed or emissions sources) from an environmental point of view.

2.2 Description of crop cultivation

Barley has a quite straightforward cultivation practice, characterised by a low request of inputs. Generally, manure and slurry are applied on field when they are locally available; otherwise, mineral fertilisers are used for the supply of nutrients to soil. Moreover, irrigation is not supplied to this crop. Although the latitude and climatic conditions are quite similar between Spain and Italy, wide differences can be identified. The main differences are summarised in **Table 1**.

Table 1. Main climatic and geographic characteristics of the two studied Countries.

Characteristics	Unit	Spain	Italy
Area	km²	505,990	301,338
Average temperature	°C	12.2°C min 22.0°C max	10.9°C min 19.7°C max
Rainfall	mm	407	390-803
Peak temperatures season	-	summer	summer
Peak rainfall season	-	autumn - winter	autumn - winter
Average farm dimension	ha	230	30

2.2.1 Climatic and geographic characteristics of Spain and Italy

Spain has a total surface 40% wider than Italy (505,990 km^2 and 301,338 km^2, respectively) and cereal crops are mostly cultivated in big farms present in a wide area of Spain that includes Aragon, Castile and Andalucía. The other regions can be distinguished in 3 main groups: (i) where the climate is drier olive and wine are cultivated, (ii) where it is mild climate, pasture can be found for animal livestock breeding, and (iii) where land can be irrigated, high-value crops are cultivated. Hence, barley is cultivated on a large area in these three regions and covers about 20% of total EU area dedicated to barley.

Weather in these Regions of Spain is characterised by an average temperature ranging between 12.2°C min and 22.0°C max and rainfall equal to 407 mm. Peak temperatures are registered in summer (July and August), while peak rainfall in autumn and winter, and in spring mainly in the Aragon region.

In Italy, the average temperature ranges between 10.9°C min and 19.7°C max, with higher values found in regions in the South. Rainfall is equal on average to 803 mm in North and Central regions and to 390 mm in Southern regions. Peak temperatures are also registered in summer and peak rainfall in autumn and winter seasons.

2.2.2 Farms characteristics for barley cultivation in Spain

In the Spanish regions dedicated to barley cultivation, farms are extended and have a large Utilised Agricultural Area (UAA) for cultivation. The average farm dimension is 230 ha (INE, 2018. Encuesta sobre la estructura de las explotaciones agrícolas. Instituto Nacional de Estadística. www.ine.es/INEbase/es/).

As a matter of fact, farm dimensions affect farmers' choices respect to the mechanisation of field operations, as well as the intensity of the farming system. Therefore, to respect the restrained period available and adequate for the main practices, highly performing machinery with large working width and high field efficiency (expressed as ha/h) are fundamental. Additionally, the main characteristics are related to the common absence of organic fertilisation before tilling soils and to the fact that minimum tillage is widely adopted.

Finally, given the unfavourable climate, no double cropping is normally performed.

2.2.3 Farms characteristics for barley cultivation in Italy

Italian barley cultivation occurs mainly in the northern plain regions of Po Valley and in the hilly regions in central and southern Italy, where the average farm dimension is deeply smaller respect to Spain (on average 30 ha).

Given this conformation, mechanisation solutions are much different from the Spanish ones; in particular, minimum tillage is still limited to a quite small area and machinery are characterised by reduced working width in order to allow working on fields commonly small and irregularly shaped. In addition, thanks to the more favourable climate, in some of the regions dedicated to barley cultivation, a double cropping system characterised by sowing a summer crop (maize, soybean, etc.) after harvesting barley is a common practice.

2.3 Functional unit

The selection of the functional unit (FU) is a fundamental step to allow fair comparison among different studies. In fact, the FU is the unit to which all results refer, and its choice can affect the subsequent phases of the study (Reap et al., 2008). Therefore, taking into account the function of the analysed system and that commonly for crops' cultivation the FU is 1 ha or 1 t of grain at 13% moisture is chosen, in this case 1 t of barley grain at 13% moisture is used as FU.

Among the previous studies on the environmental impact of crop cultivation, the FU is equal to 1 t of grain at 14% moisture in Schmidt Rivera et al. (2017), Tricase et al. (2018), Bacenetti et al. (2018) hence there are wide possibilities to compare results.

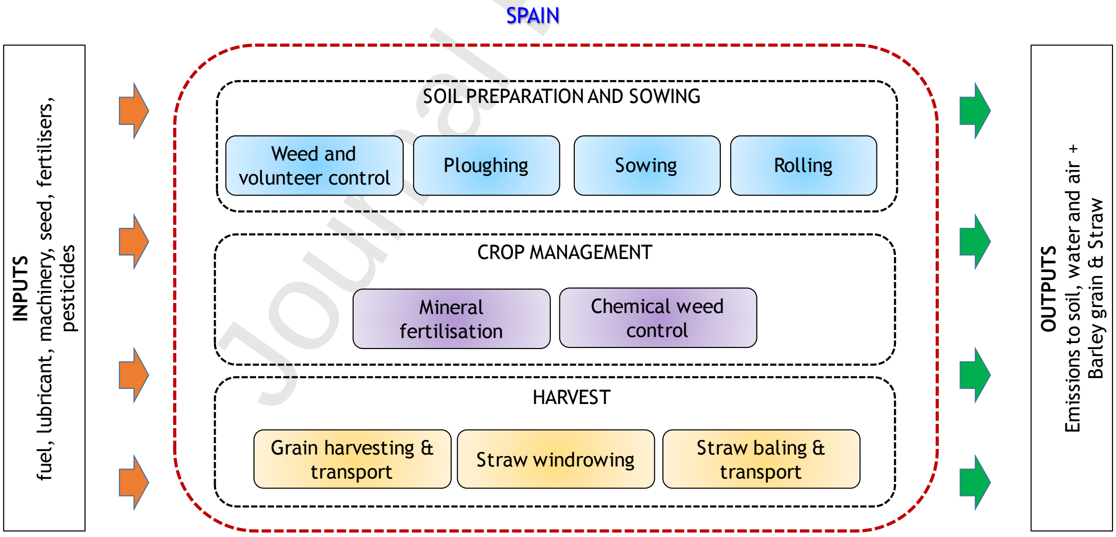
2.4 System boundary

The system boundary of barley production is reported in **Figure 1**. On the top figure is shown the Spanish production system, while below the Italian one.

The perspective adopted is the "from cradle to farm gate", from which the life cycle of every agricultural process was included within the system boundary. Barley straw production is also included in the system and is considered as a co-product due to its role in livestock farms as feed and bedding as well as to its economic value.

The following activities were included: raw materials extraction (e.g., fuels, metals and minerals), manufacturing of the different production factors (e.g., seeds, fertilizers, plant protection products, equipment, tractors and infrastructures), use of agricultural inputs and related emissions to the environment (N and P compounds emissions related to fertiliser application, emissions of pollutants from diesel combustion and tire abrasion emissions), maintenance and final disposal of tractors, operative machines and infrastructures.

No changes in the soil organic matter content were taken into account considering that, both in Spain than in Italy, the soil is cultivated with the same practices from several decades and, consequently, the soil organic matter reached the equilibrium.



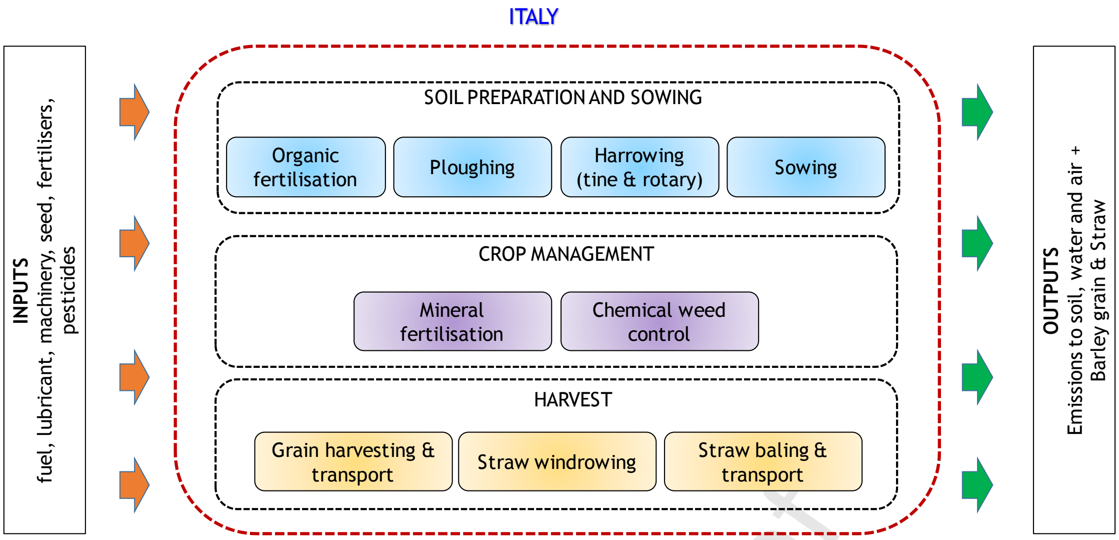


Figure 1 – System boundary of barley production. On the top: the one referred to Spain; on the bottom: the one referred to Italy.

2.5 Life Cycle Inventory

Information to recognise the most widely adopted cultivation practices for barley were collected from literature, questionnaires and technical experts interviews.

The average dimension of the farms sampled in Spain is 500 ha UAA, with single cropping and all field operations carried out by contractors, while in Italy the average dimension is 60 ha UAA, with double cropping and mostly all field operations carried out by farmers (commonly, only the harvesting phases are carried out by contractors). Contractors usually have big machines and powerful tractors that allow achieving a higher field efficiency than farmers' fleet (Lovarelli et al., 2017b, Bacenetti et al., 2019). This is commonly due to the fact they can amortise machinery more easily than farmers, due to the higher annual use and worked area. Therefore, the Spanish barley cultivation practice, totally carried out by contractors, shows high field efficiency. Moreover, the soil tillage preparation is characterised by a disc plough at 15 cm depth, which is widely different in terms of field efficiency and fuel consumption from the ploughing at 25 cm depth carried out in the Italian farm. It can be stated that one system is characterised by minimum tillage and big machinery, whereas the other system is characterised by a conventional soil tillage preparation with small-medium sized machinery. However, yield in the Spanish farm averaged 3.3 t/ha, while in the Italian one it was 6.1 t/ha. Straw yield averaged 3.3 t/ha and 5.8 t/ha, respectively.

Specifically, a data sheet for the questionnaire was developed, which includes the following sections:

- Section 1 – Cultivation practice: includes information about timing and number of repetitions of the field operations;
- Section 2 – Field operations: includes, for each field operation, information about operative machines (size, mass, length and width, required power, age, annual average working time, life span) and tractors (power, mass, exhaust gases emissions stage, age, annual working time, life span);
- Section 3 – Inputs: includes information about the production factors consumed (fuel, pesticides, fertilisers, etc.). Diesel fuel consumption was directly measured with the "full-tank method" (Lovarelli et al., 2017) during surveys on fields.

Table 1 and **Table 2** report the main inventory data adopted in the analysis for Spain and Italy, respectively. In more detail, for every operation is reported data about mass, lifespan, machine and fuel consumptions and the field efficiency.

An index named "double cropping index" is introduced in order to quantify the yearly usage of machinery depending on the cultivated UAA and the possible double cropping. This index is quantified as the number of repetitions of the single operation for every cropping system, increased in the case of presence of double cropping.

Table 1 – Inventory data for barley cultivation in Spain

Field Operation	Repetitions	Equipment			Tractor		Fuel Consumption	Field capacity	Machine width	Working speed	Input/not4	
		Machine	Duration economic &physical	Mass Kg	kW	Mass kg	kg ha^{-1}	ha h^{-1}	m	km h^{-1}	Product	Amount
Weed and Volunteer control	1	Towed Sprayer	6 years 1500 h	3800	160	9200	1.3	16.7	24.0	10	Non selective herbicide (Glyphosate)	1.53 kg a.i ha^{-1}
Ploughing	1	Tandem disk harrow	10 years 2000 h	5520	160	9200	7.1	4.2	5.5	9	Depth[b]	15 cm
Sowing	1	Direct drilling drill	8 years 1500 h	5400	160	9200	6.7	4.5	8.0	8	Seed	200 kg ha^{-1}
Rolling	1	Roller	10 year 2000 hs	5400	160	9200	4.2	7.7	10.0	9	n/n	
Fertilisation	1	Fertiliser spreades	8 years 1500 h	3500	160	9200	1.3	11.1	15.0	11	20-8-8	300 kg ha^{-1}
Weed control	1	Towed sprayer	6 years 1500 h	3800	160	9200	1.3	16.7	24.0	10	Selective herbicide (Biathlon 4D)	54 g ha^{-1} a.i.
Harvesting[a]	1	Combine harvester	10 years 3000 h	15500	265	n/a	12.5	2.7	7.7	5	n/n	3.0 t ha^{-1}
Transport	2	Farm trailer	15 years 2000 h	1500	160 90	9200 5050	15.5	0.85	n/a	n/a	n/n	3.0 t ha^{-1}
Straw windrowing	1	Windrower	10 years 3000 h	700	160	9200	1.7	4.8	6.0	10	n/n	3.3 t ha^{-1}
Straw baling	1	Baler	8 years 3000 h	9300	160	9200	2.5	5.9	9.0	8	n/n	3.3 t ha^{-1}
Transport	1	Farm trailer	15 years 2000 h	1500	160	9200	10.1	2.0	n/a	n/a	n/n	3.3 t ha^{-1}

[a] Barley is harvested with 10% moisture content. No need to dry. [b] Soil type: cambisol of silty-clay-loam texture

Table 2 – Inventory data for barley cultivation in Italy

Field Operation	Repetitions	Equipment			Tractor		Fuel Consumption	Field capacity	Machine width	Working speed	Input/Note	
		Machine	Duration economic &physical	Mass Kg	kW	Mass kg	kg ha^{-1}	ha h^{-1}	m	km h^{-1}	Product	Amount
Slurry spreading	1	Slurry tanker 20 m^3	10 years 2500 h		130	7080	44.5	0.39	0.33	5.5	Pig slurry	45 kg N ha^{-1}
Ploughing	1	3-furrow plough	8 years 2000 h	1000	90	5050	24.9	0.60	0.9	7.0	Depth	25 cm
Harrowing	1	Rotary harrow	8 years 1500 h		74	4000	20.2	1.00	2.4	5.5	Depth	10 cm
Harrowing	1	Spring tine harrow	8 years 2000 h	400	74	4000	9.8	2.00	4.0	10.0	Depth	5 cm
Sowing	1	Sowing machine	8 years 1500 h	550	74	4000	8.4	2.00	2.0	8.5	Seed	190 kg ha^{-1}
Fertilisation	1	Fertiliser spreader	8 years 1500 h	350	63	4900	3.0	2.00	12.0	10.0	33.5% N	70 kg N ha^{-1}
Weed control	2	Sprayer	6 years 1500 h	400	63	4900	3.3	3.60	15.0	10.0	Selective herbicide (Tribenuron-methyl, Difensulfuron, Bromoxinil, 2,4)	585 g ha^{-1} a.i.
Harvesting	1	Combine harvester	10 years 3000 h	11500	n/a	n/a	42.0	0.80	5.5	5.0	n/n	5.05 t ha^{-1}
Transport	2	Farm trailer	15 years 2000 h	1500	90	5050	15.1	0.80	n/a	n/a	n/n	5.05 t ha^{-1}
Straw windrowing	1	Windrower	10 years 3000 h	3000	74	4000	8.8	1.00	4.0	15.0	n/n	4.21 t ha^{-1}
Straw baling	1	Baler	8 years 3000 h	600	74	4000	12.1	1.00	4.0	6.0	n/n	4.21 t ha^{-1}
Transport	1	Farm trailer	15 years 2000 h	1500	74	4000	12.1	2.0	n/a	n/a	n/n	4.21 t ha^{-1}

Concerning the emissions related to crop cultivation, different emission sources were considered: those from N and P compounds that are related to ammonia volatilisation, denitrification, nitrogen leaching and runoff, as well as emissions related to fuel combustion.

In both Spain and Italy, emissions of nitrogen (ammonia due to volatilisation, nitrate leaching and dinitrogen monoxide due to denitrification) and phosphorous (phosphate due to soil run-off) compounds were quantified adopting models by Brentrup et al. (2000) and Prahstun et al., 2007.

The emissions related to fertiliser applications (nitrate leaching, ammonia volatilisation and nitrous oxide from denitrification) were evaluated according to Brentrup et al. (2000) and Prahsun (2006). More in detail, following Brentrup et al. (2000) NH_3 volatilisation, emissions of N_2O and NO_3 leaching were assessed considering soil characteristics (texture, pH, cation-exchange capacity), climate (temperature, wind, precipitation) and type of fertilisers. Phosphate emissions were calculated considering leaching to groundwater (assessed with a factor of 0.06 kg $P \cdot ha^{1} \cdot year^{-1}$) and runoff to surface water (evaluated considering 0.175 kg $P \cdot ha^{-1} \cdot year^{-1}$ as emission factor) (Prahsun, 2006). Due to the presence of herbaceous cover on the soil, phosphate emissions through erosion to surface waters were considered negligible (Zuazo et al., 2009).

Background data about the production of seeds, diesel fuel, urea, pesticides, tractors and agricultural machines was retrieved from the Ecoinvent Database v.3.5 (Weidema et al., 2013) using country-specific datasets.

2.6 Allocation

Both in Italy than in Spain, besides the grain also the straw is sold. Therefore, to solve the multifunctionality of the studied production system allocation is carried out.

A mass allocation is performed to quantify the environmental impact on both product (barley grain) and co-product (straw). This choice is made considering that mass allocation is the primarily suggested option when allocation cannot be avoided (PCR for arable crops, Environdec, 2016). Moreover, it permits to analyse the system avoiding market variations as could occur with economic allocation.

Mass allocation is evaluated considering the relative mass of barley and straw produced on farm, hence 54.3% and 54.5% of the impact is attributed to grain and the remaining 45.7% and 45.5% to straw, for the Spanish and the Italian scenario, respectively.

In the sensitivity analysis section (see section 3.3), allocation was avoided by introducing a system expansion. Hence, the avoided production of other bedding material is considered as a consequence of the production of straw; therefore, its environmental impact is subtracted by the one of barley grain production.

The choice of performing both mass allocation and system expansion is related to the need of underlying the different achievable results. Moreover, system expansion is adopted because the use of straw is very important in livestock farms and plays a role on other production systems.

2.7 Life Cycle Impact Assessment (LCIA)

The collected inventory data are transformed into potential environmental impacts using the characterisation factors defined by ILCD (International Reference Life Cycle Data System) midpoint method (ILCD, 2011). This method is endorsed by the European Commission. For this study, 12 impact categories are evaluated using the characterisation factors proposed by the ILCD LCIA method (EC-JRC, 2012):

- Climate Change (CC, kg CO_2 eq),
- Ozone Depletion (OD, kg CFC-11 eq),
- Particulate Matter Formation (PM, kg PM2.5 eq),
- Human Toxicity–No Cancer Effect (HTnoc, CTUh),
- Human Toxicity–Cancer Effect (HTC, CTUh),
- Photochemical Ozone Formation (POF, kg NMVOC eq),
- Terrestrial Acidification (TA, molc H+ eq),

- Terrestrial Eutrophication (TE, molc N eq),
- Freshwater Eutrophication (FE, kg P eq),
- Marine Eutrophication (ME, kg N eq),
- Freshwater Ecotoxicity (FEx, CTUe),
- Mineral, Fossil and Renewable Resource Depletion (MFRD, kg Sb eq).

The achieved results for the different evaluated impact categories were tested by sensitivity and uncertainty analyses. Uncertainty analysis was carried out using the Montecarlo method.

3 Results and Discussion

3.1 Relative contribution

Figure 2 identifies the environmental hotspots for the Italian production while **Figure 3** shows those related to the Spanish one. Each column can be read as a cake graph and reports for each impact category the relative contribution of inputs (consumed production factors), field operations and outputs (emissions).

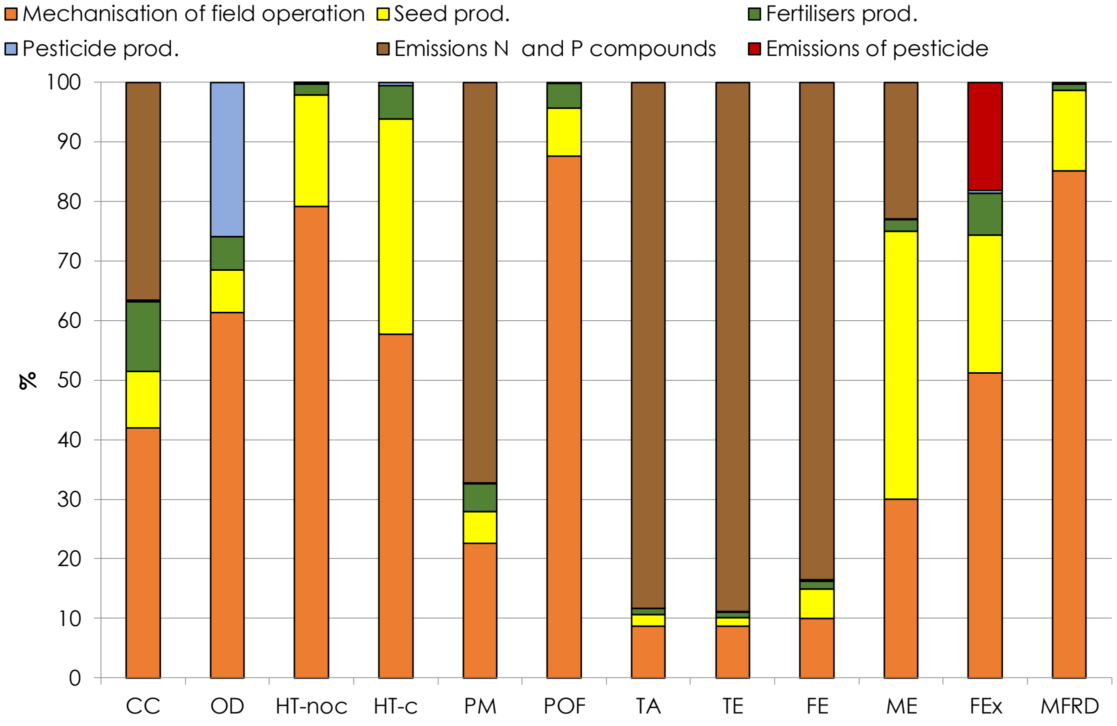


Figure 2 – Hotspots identification for Italian barley grain production

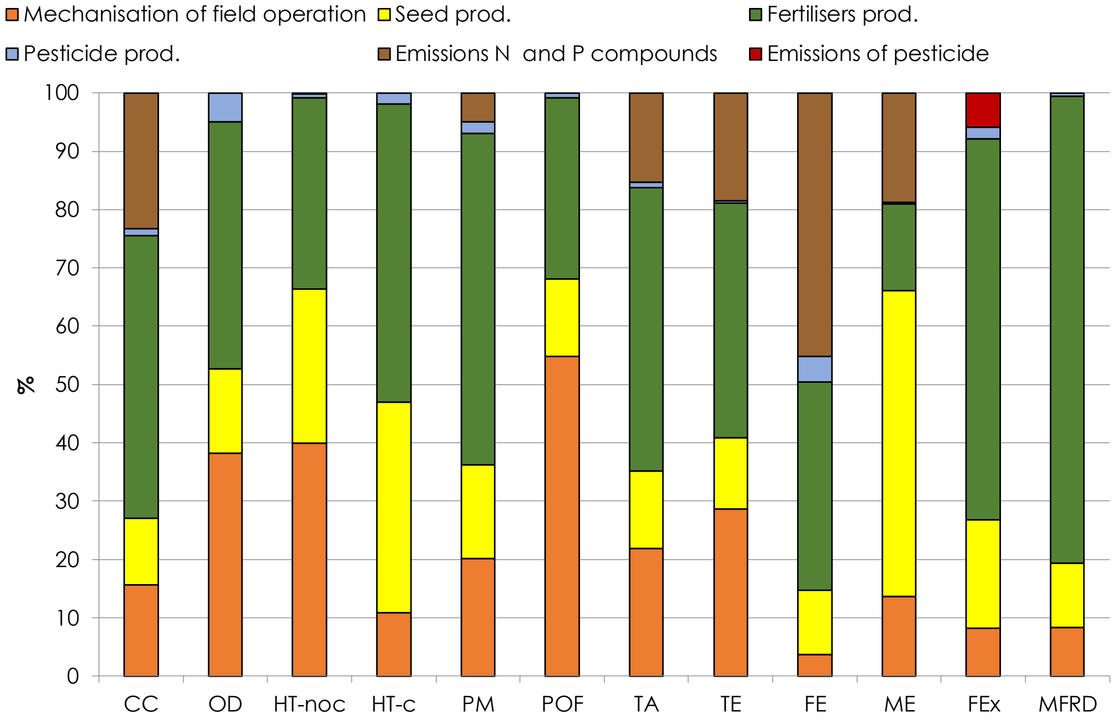


Figure 3 – Hotspots identification for Spanish barley grain production

Between the two scenarios (Spanish and Italian cultivation) different hotspots can be identified that originate mainly from the different fertilisation scheme. This operation in Italy is carried out using (mainly) organic fertilisers and in Spain with mineral ones. In particular, in Italy the application of animal slurry involves a negligible impact related to the manufacturing of fertilisers (i.e. the animal slurry has no environmental impact since it is a waste of the livestock activity and the mineral fertiliser is applied only in a small quantity of urea); however, the emissions of N and P compounds related to the fertilisation are the main responsible of PM, TA and TE (67%, 88% and 89%, mainly due to ammonia volatilisation during and after application) and FE (83% due to the phosphorus run-off). Regarding CC, 26% of the impact is related to the emission of dinitrogen oxide. Differently, in Spain the main hotspot is the production of mineral fertilisers (above all the nitrogen ones whose production is highly energy intensive) (from 80% for MFRD to 15% for ME) while the related emissions are responsible for a lower share of the environmental impact (from 45% for FE to 5% for PM) respect to the other scenario. Tidåker et al. (2016) studied the nitrogen efficiency related to different applications of fertilisers and reported the benefits on the environmental point of view when improved nitrogen uptake occurs. Similarly, Bacenetti et al. (2016) compared different techniques for slurry spreading and highlighted the environmental differences that emerge from these solutions, both regarding the aspects related to mechanisation (e.g., fuel consumption and related exhaust gases emissions) and to emissions from the fertilisers spreading.

In this study, the mechanisation of the different field operations represents more than 50% of the environmental impact for 6 evaluated impact categories (OD, HT-noc, HT-c, POF, FEx and MFRD) in Italy and only for one (POF) in Spain. The higher relative contribution of mechanisation highlighted for the Italian cultivation is, firstly, due to the lower impact related to the fertiliser consumption and, secondarily, to the higher absolute impact (from +45% for ME to +378% for MFRD). In particular, for CC, mechanisation is responsible of 77 kg CO_2 eq/FU in Italy and 42 kg CO_2 eq/FU in Spain. The higher impact due to mechanisation for the Italian scenario is motivated by:

- a different cultivation practice that, especially for soil tillage, is more energy demanding as it involves a ploughing operation at 25 cm depth and soil refinement with a rotary and tine harrows (instead of the minimum tillage carried out in Spain); environmental impact results with differences dependent on the soil tillage operations were studied by Lovarelli et al. (2017), Lovarelli and Bacenetti (2017b) and Tidåker et al. (2016),
- the use of tractors and operative machines that, respect to the Spanish ones, are less modern and characterised by lower width and field capacity (ha/h) and, consequently, involve longer working time and higher fuel consumptions; in fact, in Lovarelli et al. (2017) it was studied the effect of these variables on the environmental sustainability of field operations, but similar results related to the inventory data were obtained by Pitla et al. (2016);,
- a lower annual working time that involves higher virtual consumption of machines and tractors. As studied in Lovarelli et al. (2017), the use of machinery

affects the environmental impact results of the categories affected by the materials production and consumption.

Regarding the contribution of seed production, the two scenarios are similar. Seed production has a non-negligible impact for ME, HT-c and FEx; for these two latter toxicity-related impact categories, the impact is related mostly to the use of fungicide for seed tanning. The production of pesticides and the related emissions of the active ingredients are responsible of less than 5% of the total impact for all the evaluated impact categories, except for OD (due to the energy consumption during pesticide manufacturing) and FEx (due to the release of the active ingredient into freshwater).

3.2 Comparison between Italy and Spain

Table 3 reports the environmental absolute impact of barley grain production in the two countries while **Figure 4** shows the relative comparison between them.

Table 3 – Absolute results for the FU (1 t of barley grain at the commercial moisture) in Italy and in Spain

Impact category	Italy	Spain	Impact variation*
CC	184.89 kg CO_2 eq	271.91 kg CO_2 eq	47%
OD	2.03 x10^{-5} kg CFC-11 eq	1.78 x10^{-5} kg CFC-11 eq	-12%
HT-noc	0.0001167 CTUh	0.0001466 CTUh	26%
HT-c	6.46 x10^{-6} CTUh	1.141x10^{-5} CTUh	77%
PM	247.8 g PM2.5 eq	145.6 g PM2.5 eq	-41%
POF	1.017 kg NMVOC eq	1.088 kg NMVOC eq	7%
TA	8.545 molc H+ eq	2.144 molc H+ eq	-75%
TE	37.925 molc N eq	7.910 molc N eq	-79%
FE	0.129 kg P eq	0.104 kg P eq	-19%
ME	1.000 kg N eq	1.517 kg N eq	52%
Fex	746.7 CTUe	1644.6 CTUe	120%
MFRD	14.901 g Sb eq	31.972 g Sb eq	115%

*The variation is calculated as: [(Impact of Spain/Impact of Italy) -1] x 100

For 7 of the 12 evaluated impact categories, barley production in Spain shows a higher impact respect to the Italian production. This impact increase ranges from 7% for

POF to 120% for FEx and is mainly related to the lower grain yield and, as already discussed in the previous sub-section, to the higher consumption of mineral fertilisers. For the other evaluated environmental effects (OD, PM, TA, TE and FE) the Spanish production performs better respect to the Italian one, mostly because of the lower emissions of ammonia into the air.

The comparison between the two scenarios highlights how there is a kind of trade-off between the Spanish production, where the use of mineral fertilisers reduces all the environmental effects related to ammonia volatilisation, and the Italian barley cultivation, where the use of animal slurry improves the results on the impact categories affected by the fertiliser production but worsens those affected by the N emissions.

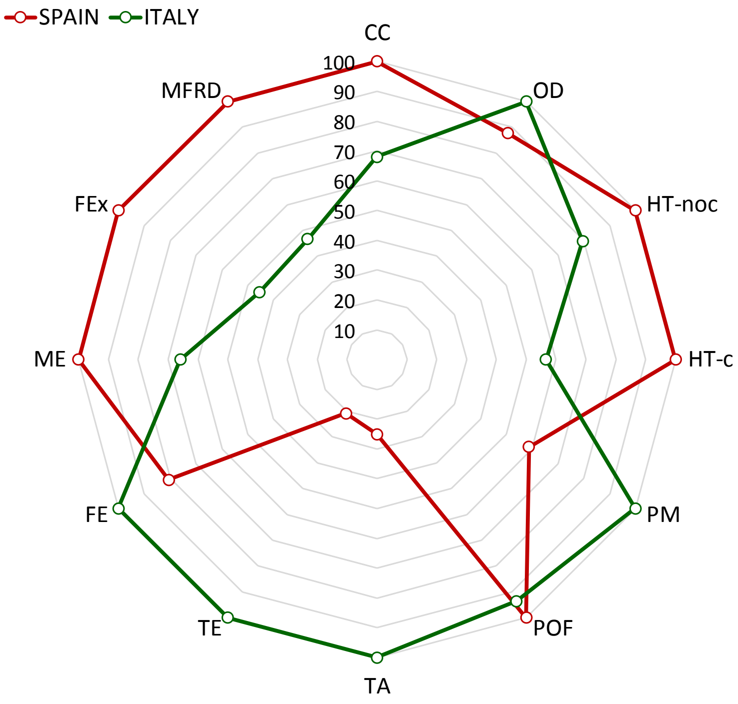


Figure 4 – Relative comparison between Spanish and Italian barley grain production.

Figure 4 clearly highlights the trade-off between the two cultivation practices that characterise the two Countries.

To provide better insights regarding decision-making, the ReCiPe Endpoint (H) V1.13 / Europe R LCIA method (Huijbregts et al., 2016) that is an assessment method with endpoints, was applied to assess the single score impacts when all is aggregated. The results are reported in **Figure 5**, and show how, when the single scores are aggregated the Italian cultivation performs much better than the Spanish. Analysing the three endpoint categories, the result is more evident in regard of the endpoint "ecosystems", followed by "resources".

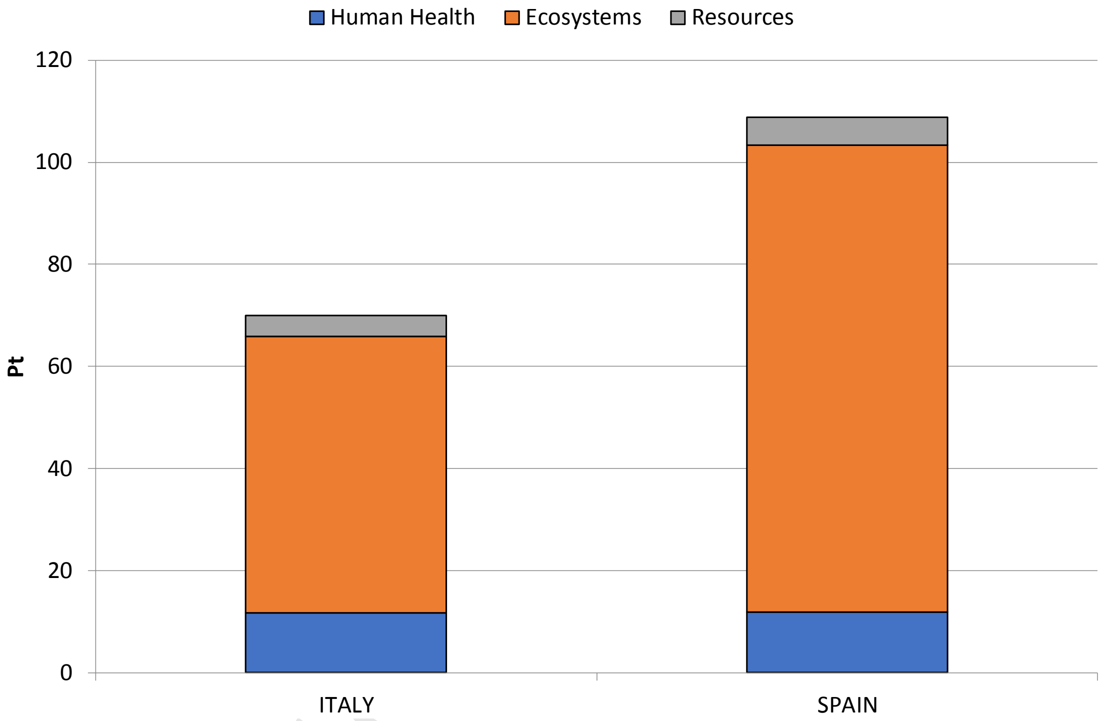


Figure 5 – Single score impact for the two barley cultivation practices.

3.3 Sensitivity and uncertainty analysis

To test the robustness of the achieved environmental results, a sensitivity analysis and an uncertainty analysis were carried out.

3.3.1 Sensitivity analysis

The sensitivity analysis was realised to investigate the effect of methodological choices regarding the solving of multifunctionality. Instead of the mass-based allocation, a system expansion was considered and the impact of barley grain was assessed subtracting to the impact of the whole production system the impact related to barley straw production (Straw {CH}| barley production, Swiss integrated production, intensive | APOS, U from the database Ecoinvent®). Even if not foreseen by the International EPD® system (Environdec, 2016), system expansion including the benefits from "avoided production" was evaluated because, similarly to the mass-based allocation, it is not affected by price variability. Economic allocation was not considered because it is affect by price variability. Even if over a 3-5 years period the price variability is reduced, in this case study the price differences between Spain and Italy would affect the environmental results making difficult to highlight the impact differences related to the prices with the ones due to the cultivation practices.

The results of the sensitivity analysis are reported in **Table 4**.

Table 4 – Results of the sensitivity analysis: Impact variation with the system expansion respect to the mass-based allocation.

Impact Category	Spain	Italy
CC	137%	161%
OD	70%	71%
HT-noc	62%	56%
HT-c	43%	11%
PM	66%	73%
POF	72%	70%
TA	59%	77%
TE	56%	77%
FE	72%	74%
ME	27%	-3%
FEx	48%	5%
MFRD	73%	59%

When system expansion is applied instead of mass-based allocation, all impact categories except for ME are deeply affected. Among them, CC increases 1.37 and 1.61 times in the Spanish and in the Italian scenario, respectively, whereas ME is the least affected by the change of multi-functionality approach. For the Spanish scenario this change involves an impact increase for ME of 27% but in the Italian one it brings to an impact reduction of 3%.

The results of the sensitivity analysis underline how the solution adopted to solve the multifunctionality deeply affects the absolute environmental impact of barley system. However, even if the results are deeply affected by this methodological choice, the overall picture does not change and the identification of the least impacting scenario (Spanish or Italian barley production) depends on the considered impact category.

3.3.2 Uncertainty analysis

Uncertainty analysis was carried out using the Monte Carlo technique (5,000 iterations and a confidence interval of 95%) to test the robustness of the results. **Figure 6** shows the outcomes of the uncertainty analysis, from which emerges that for all the evaluated impact categories the uncertainty is low. The modelling of the two systems evaluated (barley production in the two European countries) is robust, thus the results are trustworthy. Except for OD and POF, for all the other impact categories there is a reduced uncertainty level (<5%). Therefore, the uncertainty that is related to the selection of the data source, model imprecision and data variability does not significantly affect the results.

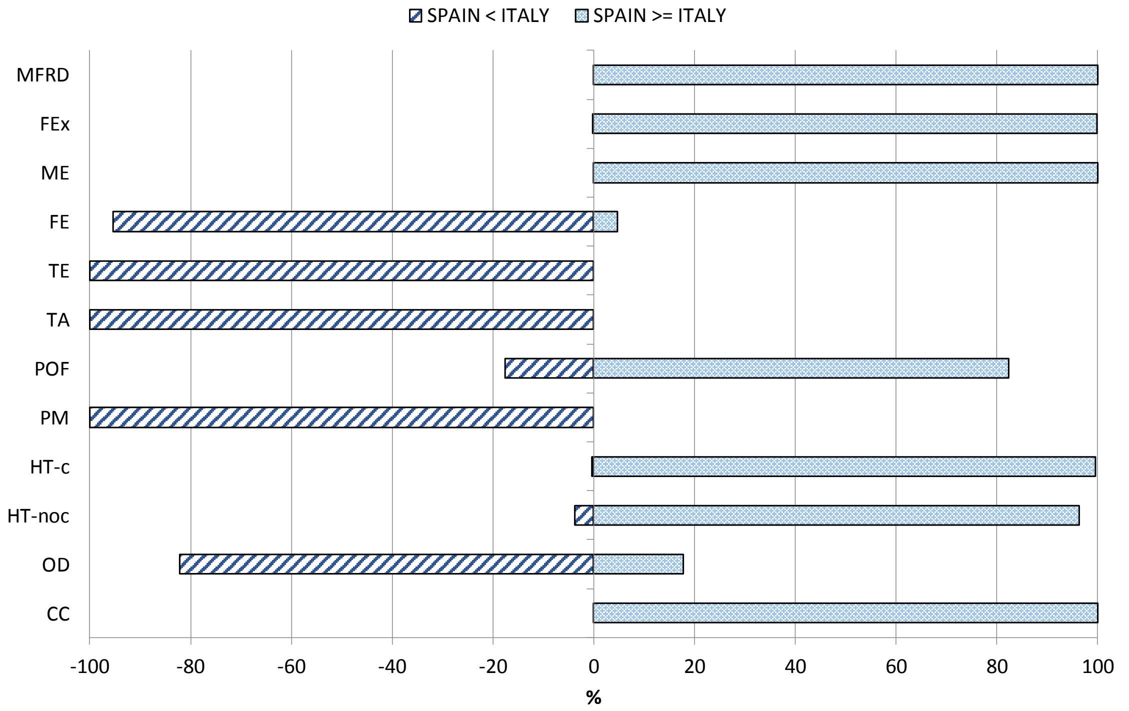


Figure 6 – Results of the uncertainty analysis. The bars on the left represent the probability that the environmental impact of Spanish production is lower than the Italian one; on the contrary, the bars on the right mean the opposite (i.e. the environmental impact of barley grain production in Spain is higher than the one in Italy).

4 Conclusions

The environmental impact of barley grain in two of the most important producer countries in Europe was evaluated using the LCA approach. Both for Spain and Italy, the most representative cultivation practices were identified through surveys, data collection and interviews carried out in the two most important barley growing areas (Aragon, Castile and Andalucía in Spain and Po Valley in Italy). Respect to the Italian one, the Spanish barley production is characterised by lower grain yield, by the use of machines with wide working width and of mineral fertilisers spread on field and by a cultivation system that occurs over big areas (300-400 ha). For these reasons, it presents the worst environmental results most of all for the impacts affected by the consumption of mineral fertilisers. On the contrary, despite the considerably higher grain yield, the

Italian production shows a higher impact for those environmental effects affected by the emissions related to the application of organic fertilisers. A trade-off between the two evaluated production systems can be identified: the Spanish system reduces some environmental loads (particulate matter formation, acidification and eutrophications) but is negatively affected by the low yields, while the Italian one, being characterised by higher yield, shows better results for the remaining impacts. When building an endpoint score, the Italian barley production results more environmentally sustainable.

From this study, it emerges that yield and efficient field activities deeply affect the systems, therefore the management practice together with high yield are the predominant processes on which focusing. In any case, the study performed in these two important barley-producing countries characterised by similar geographic conditions can help policy makers understand the wide variability occurring in European countries. Moreover, the mitigation of the most impacting processes that affect the sustainability of barley production could be helpful in reducing the negative effects of global warming in the studied regions.

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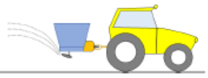
Graphical abstract

AIM

Quantify the environmental impact of barley grain production in two different European countries: **SPAIN** (no organic fertilizers and mechanisation of field operations with wide machines, **ITALY** (organic fertilisation and mechanisation of field operations with small and medium tractors and operative machines)

wide working width (m)
high working speed (km/h)
high engine power (kW)

Spain



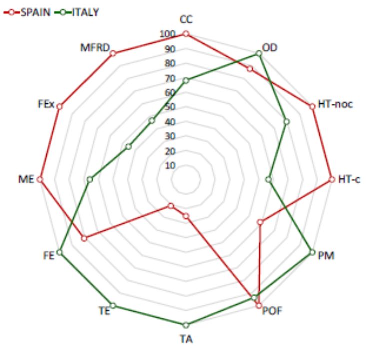
vs

small working width (m)
low-medium working speed (km/h)
low-medium engine power (kW)

Italy

+

RESULTS



Climate change (CC), Ozone depletion (OD), Particulate matter formation (PM), Human toxicity-no cancer effect (HTnoc), Human toxicity- cancer effect (HTc), Photochemical ozone formation (POF), Terrestrial acidification (TA), Terrestrial eutrophication (TE), Freshwater eutrophication (FE), Marine eutrophication (ME), Freshwater ecotoxicity (FEx), Mineral and fossil resource depletion (MFRD)

Highlights

- Environmental impact of barley cultivation in Spain and in Italy was compared
- For 7 of the 12 evaluated impact categories, Spanish production has higher impact
- Grain yield is the main driver of the environmental results
- Use of mineral fertilisers reduces all environmental effects related to ammonia volatilisation
- Use of animal slurry reduces the impacts affected by the fertiliser production