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# Analysis of Socio-Economic and Environmental Sustainability of Barley Supply Chain: a Healthy Crop for Human Nutrition

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# ABSTRACT

The scope of the research is to provide evidences about the benefits, in terms of healthiness, environmental sustainability, and productive efficiency, related to barley (*Hordeum vulgare* L.), a widespread crop in the Apulia region (italy). Seeking to pursue this general goal, the aim of the research is twofold: (i) investigating consumers' perception about quality of organic food, in terms of sustainability and healthiness, and analyzing how and to what extent perceived quality of organic food is influenced by the presence of information related to quality on food products' label, and consumers' socio-demographic profile; (ii) comparing organic and conventional cultivation of barley, under favorable pedo-climatic conditions, to evaluate the potential environmental impacts related to the cultivation of barley and to identify the most suitable solution in terms of environmental sustainability and productive efficiency.

An approach based on Combination of Uniform and shifted Binomial random variables, named CUB model, was performed to analyze consumers' preference in terms of two latent components, feeling and uncertainty.

A Life Cycle Assessment (LCA) was performed alternatively using, as Functional Units (FUs), 1 ha of land involved in cultivation of barley to seek environmental sustainability and 1 kg of dry matter grains of produced barley to check productive efficiency.

Findings from CUB models highlight that the presence of specific information on food's label (e.g. environmental label, organic certification, healthy claims) contributes to perceive organic food as food of superior quality. Results also underline how consumers' socio-demographic profile plays a significant role in driving food purchasing decision mechanism.

Findings from comparative LCA show that organic barley cultivation is the most environmentally sustainable solution (but not efficient in production), vice versa conventional barley cultivation is the solution most efficient in production (but not environmentally sustainable). Efficiency in production and environmental sustainability may be balanced with methodological assumptions (choice of functional unit, allocation procedure) and qualitative elements (crop quality and adaptiveness to specific pedo-climatic conditions). A land-based FU is preferred in the analysis of the agricultural stage, while a mass-based FU is suitable for the assessment of a wider context, such as the entire supply chain.

The research seeks to fill the lack, existing in economic literature, about barley crop, which is a potential strength for Apulian farms, thanks to its sustainability and healthiness properties.

# INTRODUCTION

During last decades, the focus of international and European challenges is on increasing attention to food safety and security and on growing concerns towards socio-economic and environmental changes. To cope with these challenges, food production and consumption should combine health and environmental perspectives (Lazzarini *et al.*, 2016). Responsible production and consumption of food have become a mainstream topic (Yadav and Pathak, 2016; Dowd and Burke, 2013), because they address both health and environmental issues (Aschemann-Witzel *et al.*, 2013): responsible production and consumption allow to achieve welfare of human beings (Yadav and Pathak, 2016) and environmental sustainability (UN, 2010).

The steadily growing population shows an upward demand for food that puts high pressure on land and on inputs production. Agri-food sector contributes to human health and prosperity, but it is also responsible of great impacts (Lazzarini *et al.*, 2016; van der Werf *et al.*, 2014), and it is involved in complex socio-economic and environmental linkages (Arianfar and Sardarodiyan, 2016). Production and consumption of agri-food products are the cause of several problems for health and environment, such as for instance climate changes, resources depletion, and unhealthy diets (González-García *et al.*, 2016; Lazzarini *et al.*, 2016). An important challenge for decision-makers should be understanding the way to reduce these problems (Masuda, 2016; Korsaeth *et al.*, 2012). It is established opinion that food production must come from a more sustainable agriculture, which may combine promotion of quality for consumers with protection of environmental resources (Lamonaca *et al.*, 2016; Tricase *et al.*, 2016; Meier *et al.*, 2015). To this end the effort of agri-food sector should be to ensure a quality enhancement in products supply, in order to encourage customers confidence in supply chains and to support sustainability in production processes. All these goals should be oriented towards the logic of doing more and better with less, to achieve socio-economic and environmental quality and efficiency (Vassallo *et al.*, 2016). Adopting organic farming is a way to reduce environmental impacts, to support more sustainable agricultural practices, and to obtain food products of higher quality (Lamonaca *et al.*, 2016; Tricase *et al.*, 2016; Meier *et al.*, 2015).

At the same time, consumers tend to pay an ever increasing attention towards the relationship between nutrition and health (Mollet and Rowland, 2002; Young, 2000). The reasons of this tendency are mostly due to health scares, personalization of eating habits, as well as to demographic trends and socio-economic changes. Because consumers are even more conscious that food may contributes to improve psychophysical well-being (Menrad, 2003; Roberfroid, 2000a), they tend to consume healthy food (Kotilainen *et al.*, 2006; Roberfroid, 2000a,b). Changes in food preferences and environmental awareness highlight the needs to improve a better assessment of impacts, risks, and opportunity of food production and consumption, through life cycle approach.

It is in this context that consumers increasingly appreciate functional food. The concept of functional food was firstly introduced in Japan in the Eighties with reference to food developed specifically to promote health or reduce the risk of illness. According to the definition given at European level by the European Commission Concerted Action on Functional Food Science in Europe (FUFOSE), a food can be considered functional if it is demonstrated satisfactorily that it is able to affect in a positive way one or more functions of body in a way that is relevant and to improve health and well-being and/or reduce the risk of disease (Doyon and Labrecque, 2008; EUFIC, 2006). There are different types of functional foods and diverse approaches to obtain them: a functional food can be a natural food, in which specific components can be introduced or implemented through specific farming practices and processing (e.g. food grains, cereals, wholemeal flours, etc.) or it can be a food that has been processed using different technological, chemical or biological systems. The suitable technological approach for the development of functional food is to increase natural and wholemeal or “traditional evolved” products in a way that respects raw materials, food, needs, and preferences of the consumer (Sirò *et al.*, 2008). Among different way to obtain functional foods, cereals, that widely and frequently come in our diet and meet consumer's favor, are ideal to be used in transmitting compounds and substances with bioactive and dietary properties. In particular, barley (*Hordeum vulgare* L.) represents a valuable source of production of functional foods thanks to its characteristics (Sullivan *et al.*, 2013; Baik and Ullrich, 2008). It deserves a particular attention and has a high potential from multiple points of views.

From an economic perspective, barley is the fourth most-produced crop in the world today, it is readily available in the world and is relatively inexpensive compared with other grain. Barley involves a huge amount of resources and people working in agricultural stage for its cultivation; transportation and trade of barley grains and related products, co-products, and by-products; processing, transportation, marketing, and consumption of barley products, as well as, research and development to improve production and use of barley (Ullrich, 2011).

From a social point of view, barley has a long history of cultivation and consumption in human and animal food, feed, and nutrition; alcoholic beverage production and consumption; and in the continuing development of the biological sciences (Baik *et al.*, 2011; Ullrich, 2011). Over the time, the preponderant use of barley for feed and for brewing and distilling have de-emphasized its uses for food, because of cultural eating habits and lower preferences for barley compared to other grain. But nowadays the increasing awareness of human health benefits of consuming barley have boosted the attempts of food and crop scientists, barley industry, and food processors in an improvement of the food use of barley (Baik *et al.*, 2011). The valuable qualitative and nutritional features of barley make it a crop of niche for the functional food market.

From an environmental perspective, thanks to barley adaptability to diverse pedo-climatic conditions, it is a high self-sustainable crop: barley can be produced at higher latitudes and altitudes and further into marginal areas, due to its reduced water necessities and its short life; it can be cultivated in all kinds of farm and constant yields are obtained even in unfavorable areas (Ingvordsen *et al.*, 2015; Lamonaca and Tricase, 2015; Marinaccio *et al.*, 2015; Francia *et al.* 2011).

These considerations have pioneered the framework of this research. The scope of this research is to provide evidence about the possible strengths, in terms of healthiness and environmental sustainability and efficiency, related to barley, a widespread crop in Apulia region (Italy).

Seeking to pursue this general goal, the research consists of two phases. The first step concerns the analysis of Italian consumers' perception of healthiness and sustainability levels of organic food products, to identify which factors determine consumers' eating habits and drive their food purchasing decisions. The second step consists in the evaluation of potential environmental impacts related to barley cultivation, both in organic and conventional farming, to identify the most suitable solution in terms of environmental sustainability and productive efficiency.

The identification of determinants of Italian consumers' eating habits and food purchasing decisions is achieved adopting a Combination of Uniform and shifted Binomial random variables models, the so-called CUB models. The evaluation of potential environmental impacts related to barley cultivation is achieved performing a comparative Environmental Life Cycle Assessment (E-LCA) *from cradle to farm gate* between two production systems (organic and conventional farming) of two farms located in Apulia region.

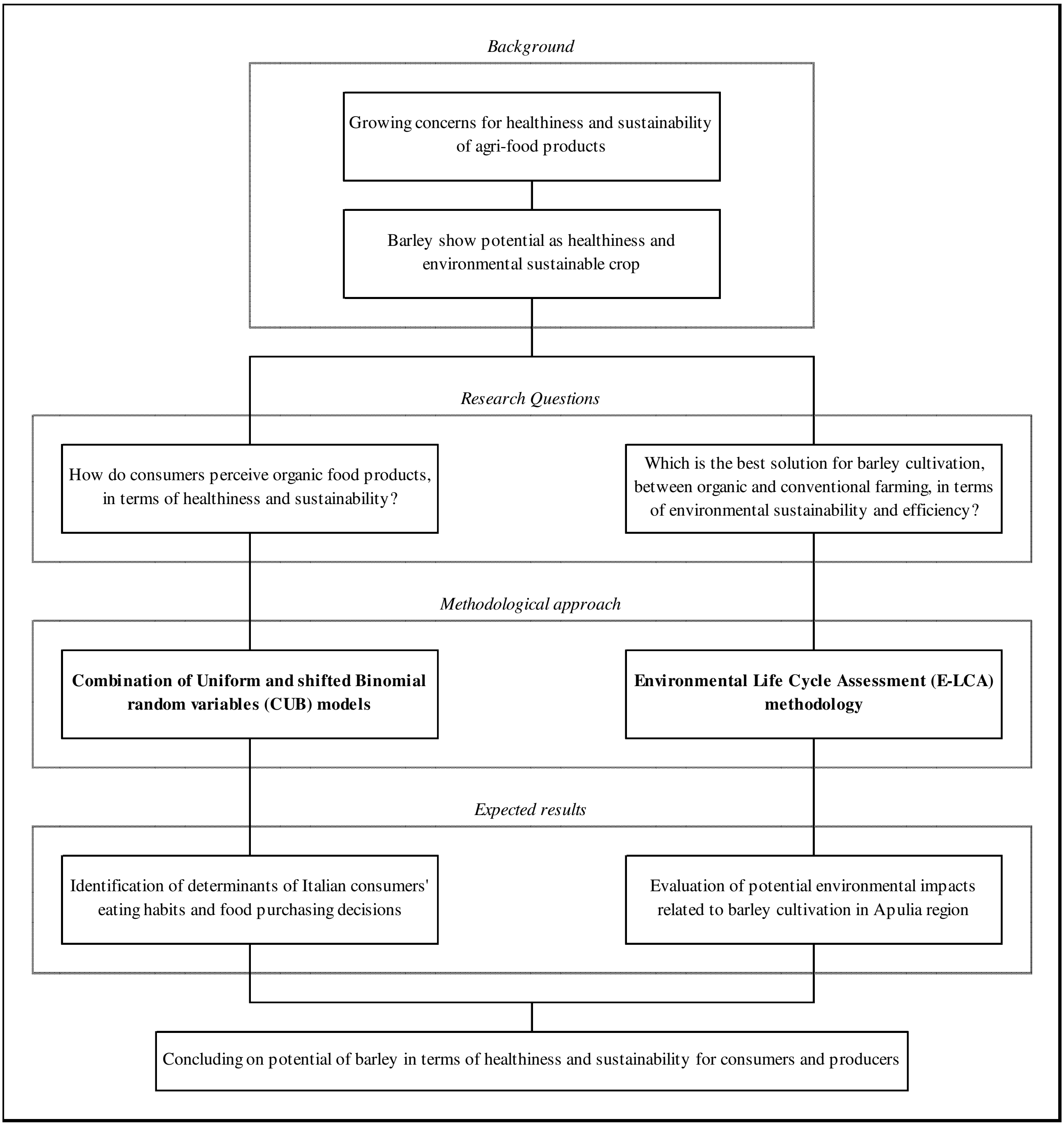


**Figure 1.** Research framework.

# Chapter 1
# BARLEY

Barley (*Hurdeum vulgare* L.) is an ancient and important grain crop, grown and used worldwide (Sullivan *et al.*, 2013; Baik and Ullrich, 2008). Its prominence is due essentially to the role that has played in several field, such as in the human development of agriculture, civilizations, and cultures, or in the sciences of agronomy, physiology, genetics, breeding, malting, and brewing (Ullrich, 2011).

The genus name of barley, *Hordeum*, derives from Roman gladiators, who were defined “hordearii” or “barley men” at their time, because they were used to consume barley to assume strength and stamina (Percival, 1921).

Barley was one of the first agricultural domesticates (Sullivan *et al.*, 2013; Baik and Ullrich, 2008), playing a significant role at least 10,000 years ago, during the human transition from hunting to agrarian lifestyle in the Fertile Crescent of the Near East. (Ullrich, 2011). In thousands of years of domestication, barley has progressively accumulated features that facilitated agricultural production, thanks to results of environmental selection or human choice (von Bothmer and Komatsuda, 2011).

## 1.1. Botanical and agronomic characteristics of barley

Barley (*Hordeum vulgare* L.) belongs to Triticeae, a tribe in the grass family, Poaceae (Table 1) (USDA NRCS, 2016). Triticeae, which is one of the economically most important plant groups in the world, includes the major temperate grain, such as several species of wheat, rye, and barley (von Bothmer and Komatsuda, 2011).

**Table 1.** Classification report of barley.

| Rank | Scientific name | Common name |
|---|---|---|
| Kingdom | Plantae | Plants |
| Subkingdom | Tracheobionta | Vascular plants |
| Superdivision | Spermatophyta | Seed plants |
| Division | Magnoliophyta | Flowering plants |
| Class | Liliopsida | Monocotyledons |
| Subclass | Commelinidae | - |
| Order | Cyperales | - |
| Family | Poaceae/Gramineae | Grass family |
| Genus | *Hordeum* L. | Barley |
| Species | *Hordeum vulgare* L. | Common barley |

Source: elaboration on USDA NRCS (2016).

According to Sullivan *et al.* (2013), barley can be classified as:

- spring or winter barley;
- two-row barley, where only the central spikelet is fertile, or six-row barley, where both central and lateral spikelets are fertile;
- hulled barley, which present an outer husk attached to the grain, or hull-less barley, which does not present an outer husk attached to the grain;
- malting barley or feed barley, depending on end-use.

Species of genus *Hordeum* are characterized by few basic botanical features. Typically, each rachis node has a triplet, which are three one-flowered (one seeded) spikelets. Non domesticated species of *Hordeum* have lateral spikelets always stalked, while *Hordeum vulgare* have lateral spikelets sessile. In the triplets lateral spikelets may be fertile and seed setting as in six-rowed barley, but they are sterile in two-rowed barley. An important feature is the large plasticity in morphological traits. Under unfavorable stress conditions caused by drought, heat, salinity, or flooding, the plants may be slender with a single, short culm with a minute spike, with a low but secured seed set. Under favorable conditions, the same genotype may be luxuriant with a height of 1 m, with several culms and large spikes and florets (von Bothmer and Komatsuda, 2011).

**Figure 2.** *Hordeum vulgare* L.
Source: USDA-NRCS PLANTS Database - Hitchcock, A.S. (rev. A. Chase) (1950), *Manual of the grasses of the United States*, USDA Miscellaneous Publication No. 200, Washington, DC.

In general the composition of wholegrain barley consists of approximately 70% starch, 10-20% protein, 5-10% β-glucan, 2-3% free lipids and approximately 2.5% minerals, with total dietary fiber ranging from 11 to 34% and soluble dietary fiber being within 3-20% (Sullivan *et al.*, 2013).

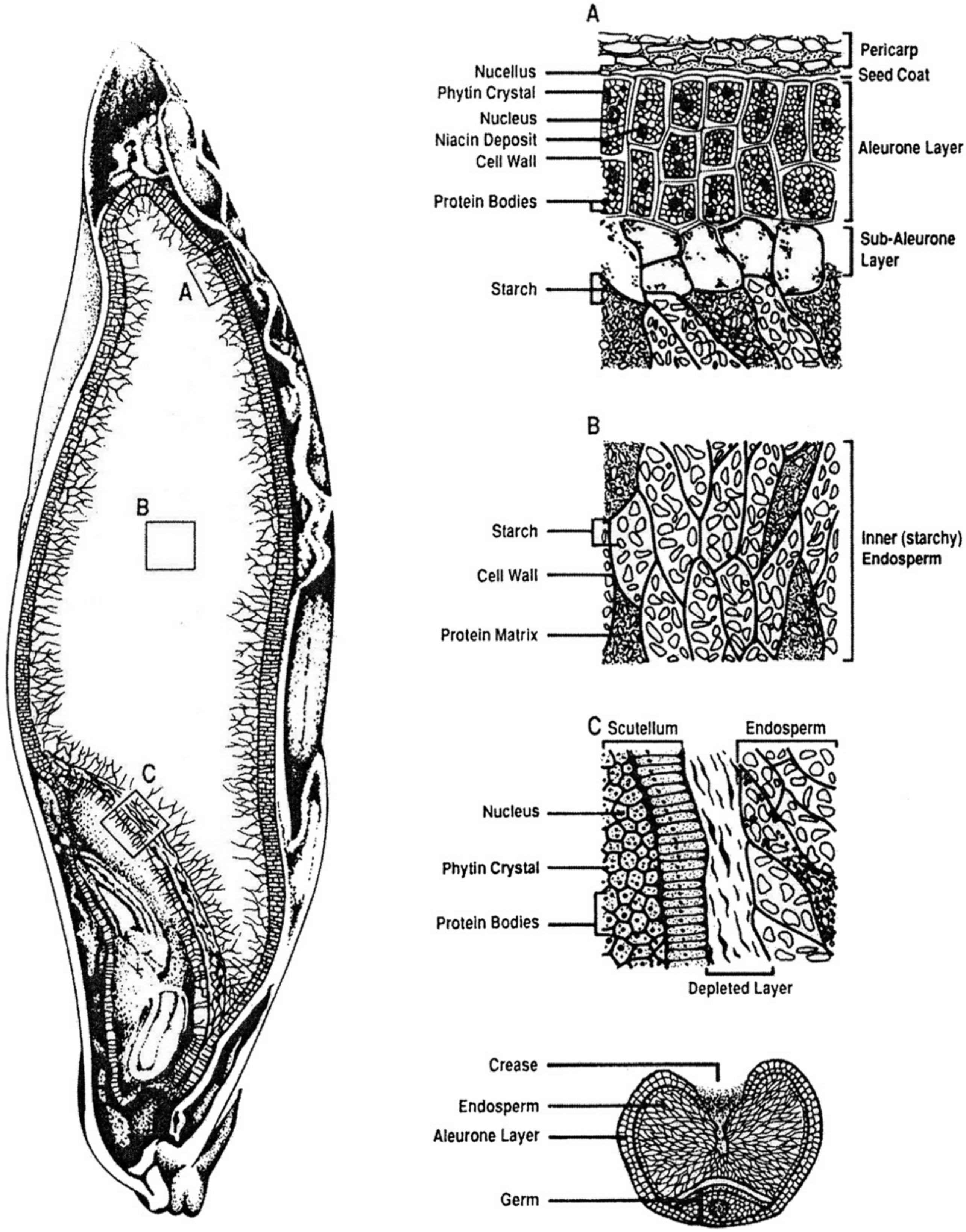


**Figure 3.** Barley grain and cross section.
Source: Sullivan, P., Arendt, E., and Gallagher, E. (2013), "The increasing use of barley and barley by-products in the production of healthier baked goods", *Trends in food science & technology*, Vol. 29 No. 2, pp. 124-134.

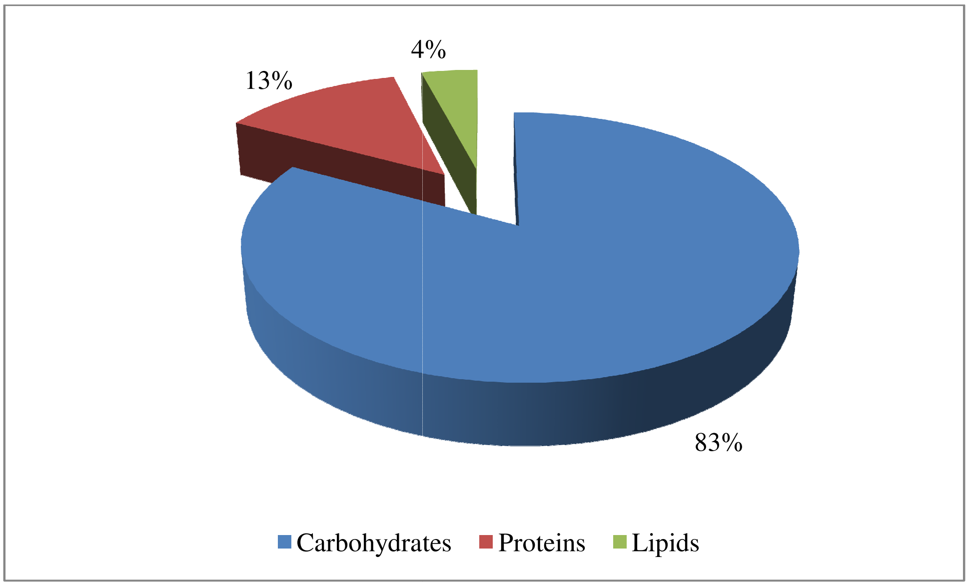


**Figure 4.** Percentage al location of energy in barley grain.
Source: elaboration on CREA (2016).

**Table 2.** Chemical composition and energy value for 100g of edible barley grain.

| Chemical composition | Unit | Value for 100 g |
|---|---|---|
| Edible part | % | 100.00 |
| Water | g | 12.20 |
| Proteins | g | 10.40 |
| Lipids | mg | 1.40 |
| Cholesterol | g | 0.00 |
| Available carbohydrates | g | 70.50 |
| Starch | g | 64.10 |
| Soluble sugars | g | 0.00 |
| Fiber (total) | g | 9.20 |
| Soluble fiber | g | 4.41 |
| Insoluble fiber | g | 4.83 |
| Alcohol | g | 0.00 |
| Energy | kcal | 319.00 |
| Energy | kJ | 1,333.00 |
| Sodium | mg | 3.00 |
| Potassium | mg | 120.00 |
| Iron | mg | 0.70 |
| Calcium | mg | 14.00 |
| Phosphorus | mg | 189.00 |
| Thiamine | mg | 0.09 |
| Riboflavin | mg | 0.08 |
| Niacin | mg | 3.10 |
| Vitamin A - retinol equivalent | µg | 0.00 |
| Vitamin C | mg | 0.00 |

Source: elaboration on CREA (2016).

Barley is the most widely adapted grain: it may be cultivated in vast and also marginal areas with relatively low yields and low management intensities (Ingvordsen *et al.*, 2015; Lamonaca and Tricase, 2015; Marinaccio *et al.*, 2015; Tondelli et al., 2015; Francia *et al.* 2011), while it does not produce acceptable yields under well-drained loam soils, at moderate rainfall (400-800 mm) or under irrigation, and at moderate temperature regimes (15-30 °C), because it is a rain-fed cereal (Ullrich, 2011). Barley is characterized by a good tolerance to drought, cold, and salt, although it does not tolerate highly humid warm climates (Ullrich, 2011). Typically, barley is grown in the cooler temperate zones where moisture levels are adequate for both autumn and spring planting and are adequate during the early summer months to enable grain to grow and fully mature. (Garstang and Spink, 2011; Ullrich, 2011).

## 1.2. Crop management

The worldwide adaptation of barley has encouraged research and development of best management practices for barley production (Ullrich, 2011). Unlike other regions of the world, the EU operate within the framework of Common Agricultural Policy (CAP), which support payments to farmers in compliance with Council Regulation 1782/2003 (European Commission, 2003), in order to achieve environmental and plant health as well as good agricultural and environmental conditions (e.g. avoidance of erosion, preservation of soil organic matter, etc.). The EU supports main cultural practices related to local growing conditions and intended to the progressive improvement of barley yields. Crop management practices thus aim at reducing variation of yields per hectare between years, depending on the effect of different types of climate, as well as to produce high and profitable yields (Garstang and Spink, 2011).

### *1.2.1.Tillage practices*

Used tillage techniques for barley were essentially based on ploughing in seedbed preparation (Briggs, 1978), while recently it is common moves towards a minimum cultivation technique (min-till) to rapidly prepare seedbed and sow the crop in a few number of operations (Garstang and Spink, 2011). But min-till is not able to provide the same weeds control achievable by ploughing. The majority of crops are drilled using drills to put seeds into a range of seedbeds from min-tilled soil to a fully pre-prepared seedbed. Given seed rates ranging from about 100 to 250 kg/ha for light seeds, barley crop is able to start the period of rapid growth with enough healthy plants ready to respond to fertilization (Garstang and Spink, 2011).

### *1.2.2.Weeds and Weed Control*

Weeds in cereals may be broad-leafed, which could be easily removed at the seedling stage, and grass, which are the most difficult to control. The main method of weed control in barley is the usage of herbicide, possibly during pre-emergence or early post-emergence: the first chemical ones were developed to remove broad-leafed weeds from cereals over 60 years ago. The increasing weeds resistance to herbicide as well as concerns about pesticide safety highlight the need to integrate the usage of herbicide with other control measures, such as crop rotation and cultivation techniques (Garstang and Spink, 2011).

### *1.2.3.Fertility*

According to Ministry of Agriculture Fisheries and Food (MAFF) (2000) and De Clercq *et al.* (2001), an efficient management of nutrient requirements of barley has to take into account total nutrient input, total nutrient derived by barley crop, and supply of nutrients already in the soil at the start of the growing season. Barley mainly requires nitrogen, phosphate, and potassium; in addition, it requires sulfur more routinely where atmospheric deposition rates have fallen and soil supplies are inadequate. Applying phosphorus and nitrogen to barley in low rainfall areas improve water use efficiency. For the fertilization, *in primis* available nitrogen and variation in the mineralization of soil organic nitrogen supplies during the growing period have to take into account; in second instance in addition to soil supply organic fertilizer (e.g. slurry, higher dry matter manures, etc.) needs to be considered; finally inorganic fertilizer can be applied to support anticipated production and to improve grain yield (Garstang and Spink, 2011).

*1.2.4.Water management*

Barley grown in the EU is mainly rain-fed and well adapted to drier conditions. Earlier maturation and harvest of barley may minimize its exposure to hotter weather conditions. To trigger germination in dry seedbeds, it is sufficient to provide water with showers. A return of drought conditions may determine significant seedling loss through desiccation: in these cases irrigation may be useful (Garstang and Spink, 2011).

*1.2.5.Harvest*

At harvest time, excessive moisture not always is advantageous. In general barley grain needs to have a content of moisture about 14% for safe storage at less than 15 °C, although the moisture requirement changes in accordance with ambient temperature and specific risk factor: storage temperature below 4-5 °C requires around 19-20% of moisture in barley grains, while storage temperatures above 30 °C requires around 12% of moisture in barley grains. Storage below 15 °C is essential to avoid insect damage (Garstang and Spink, 2011).

## 1.3. An overview of grain sector from a market perspective

Although on global markets grain are mainly considered as commodities, they represent the most relevant source of world's food energy consumption (Tadesse *et al.*, 2014; Serra and Gil, 2012; Wright, 2011), and a strategic sector for both producers and policymaker.

Global demand of grain is growing gradually at 1.8% per year. Nowadays, only few countries are responsible for the most of the total cereals production: China, the United States (US), the European Union (EU) and India together account for over 70% of global grain production; but new players are emerging also in South-Eastern Europe (e.g. Ukraine and Turkey) and in South America (e.g. Mexico, Argentina, Brazil). In general, the greatest producers are also the major consumers: the US and the EU are key consumers of grain, respectively with 15% and 12% of world total consumption, but in recent times also the emerging economies, such as China, India, Brazil and Russia, have become greater grain consumers. Regarding the traded volumes for cereal, they tripled in the last decade, although grain trade remains dependent on a small number of key export centers, such as the Northern and the Southern America and the Black Sea basin (USDA FAS, 2016; FAO - FAOSTAT, 2016).

At European level, in the last decades grain sector has reached a well-established development, thanks to the favorable conditions of the market and to the great support schemes provided by CAP. These factors allow grain sector to achieve high levels of technical, productive and organizational efficiency. Remarkable improvements have been gained in terms of productivity, with increases in yields and acreages; several market organizations have been created, with the resulting upgrade of the economic network. However the growth of grain sector nowadays suffers a slowdown, characterized by a drop in profitability and an increase in competitiveness: these levels of criticality have been encouraged by the search of new economic strategies, based on higher quality levels and oriented towards the promotion of niche products (Ismea, 2016).

Within the framework of the Italian agricultural productions, grain sector plays a prominent role due to its economic importance on the overall value in the primary sector and generally in the agribusiness, and to its significance in terms of number of involved farms and processing firms and of allocated area. Grain business affects both agricultural and processing stages. Regarding the agricultural stage, cereals correspond to 18% of the overall agricultural crops (Figure 5), which value amounts to 4,691 million of Euro; while in the processing sectors cereal allow the strengthening of supply chain networks both in food and in feed industry (Ismea, 2016).

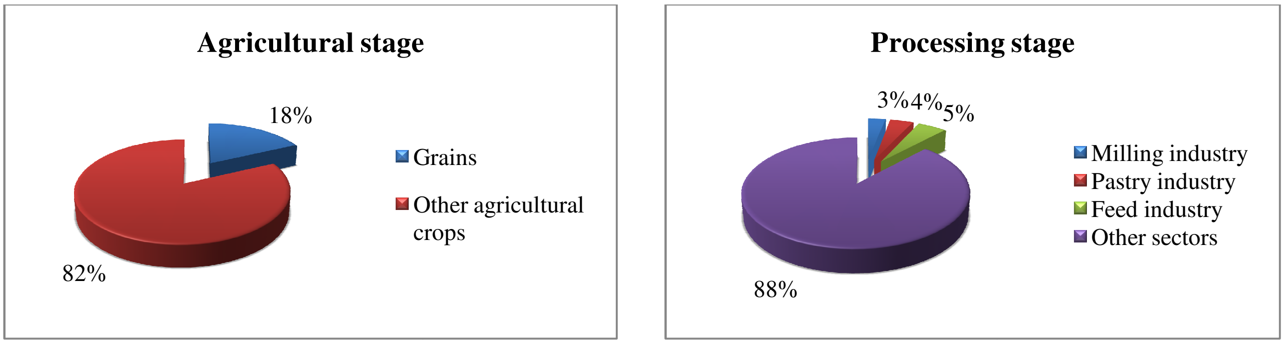


**Figure 5.** The relevance of Italian grain sector.
Source: elaboration on Ismea (2016).

In Italy, the most important and widespread grain crops are soft and durum wheat, corn and barley, which together represent 82% of the overall value of cereals (Ismea, 2015).

*1.3.1.The trend of barley market*

1.3.1.1.International market of barley

Barley crop is the fourth most important cereal in the world, after wheat, corn and rice (Sullivan *et al.*, 2013; Ullrich, 2011; Baik and Ullrich 2008). Market fundamentals are able to describe the operating principles of market of barley. In this regard, considering a period of 55 years, Figure 6 shows the world trend of stored quantities at the end of market year; levels of consumption; export and import flows; production level of barley. The latter, in its turn, depends on harvested area and yields (Figure 7).

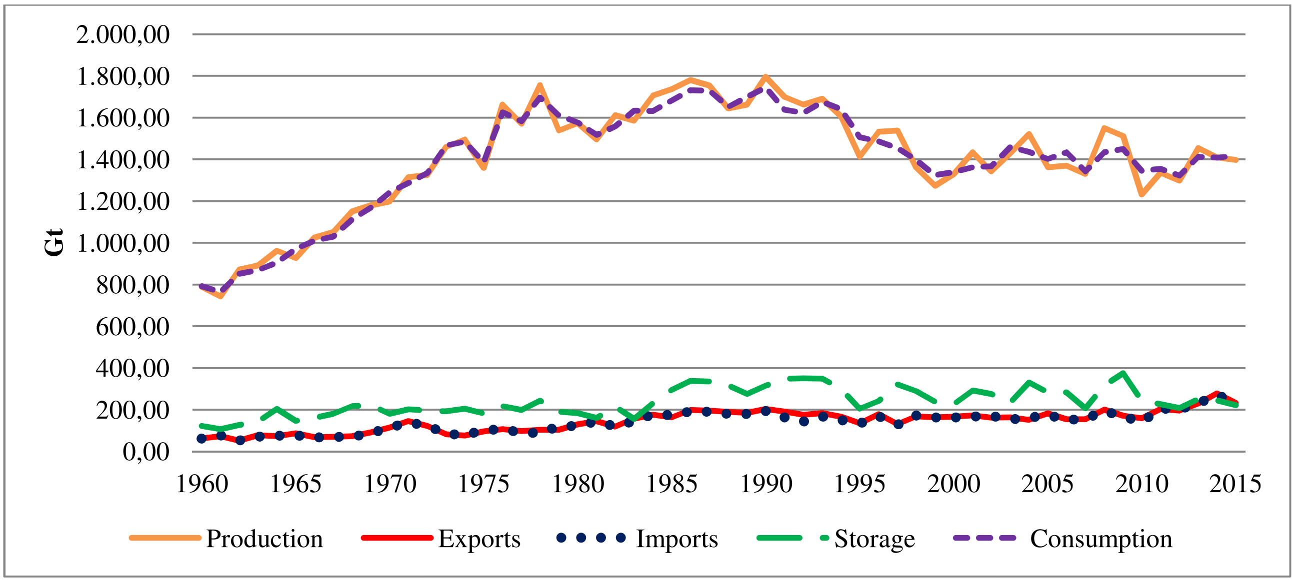


**Figure 6.** Global trend of market fundamentals of barley during the period 1960-2015.
Source: elaboration on USDA FAS PSDO (2016).

In general, barley producers utilize the bulk of their production domestically (Ullrich, 2011). As Figure 6 shows, domestic consumption absorbs almost the entire production: they share a common tendency, fluctuating wildly around a stagnant trend since 1975. While trade flows (i.e. imports and exports) rose gradually with sporadic peaks of low intensity and frequency, storage levels swing dramatically whit a slow upward trend (Figure 6). Barley is one of the most cultivated cereals, globally: production levels, harvested area, and yield have been relatively stable and growing over the period 1960-1995, but barley has decreased by about 12% in overall production in the past 20 years. Yield averages, hectare intended to barley cultivation, and total production generally reflect relative growing conditions, in particular precipitation, and management technology, such as for instance soil fertility and pest management (Ullrich, 2011). Although area of barley suffers a decrease with respect to the period from 1975 to 1990, its yields, except for a setback in 1997-2000, is steadily growing thanks to improvements in technical and productive efficiency (Figure 7). During the last period of fifty years, the tendency of barley world production shows an increase until the mid-Seventies, followed by an irregular curve trend. In contrast, barley world export and storage have a constant evolution during the same period (Figure 6). There is considerable trade of barley: FAO estimated that barley grain, typically exported and imported annually, this century have generated globally about 3 billion US$ per year (FAO - FAOSTAT, 2016).

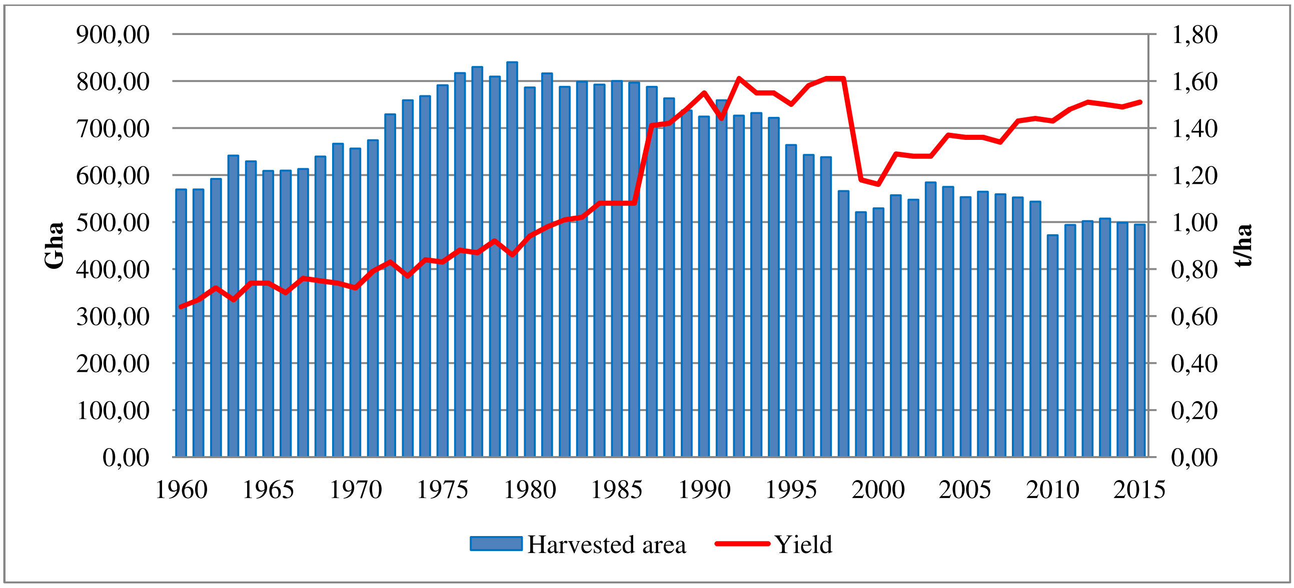


**Figure 7.** Global harvested area and yields of barley during the period 1960-2015.
Source: elaboration on USDA FAS PSDO (2016).

Current world production is approximately 1.400 Gt (USDA FAS PSDO, 2016). By far the leading barley producer[1] is the EU (586.8 Gt), followed by Russian Federation (165 Gt) and Australia (86 Gt): the EU and Russian Federation jointly account for more than 60% of the world' s barley production (Figure 8) (USDA FAS PSDO, 2016). The widespread regional distribution of barley production over the globe highlights the high adaptability of this grain (Ullrich, 2011).

[1] The major producers of barley for the last 55 years were identified by calculating their share of production with respect to the total production of barley over the last 55 years.

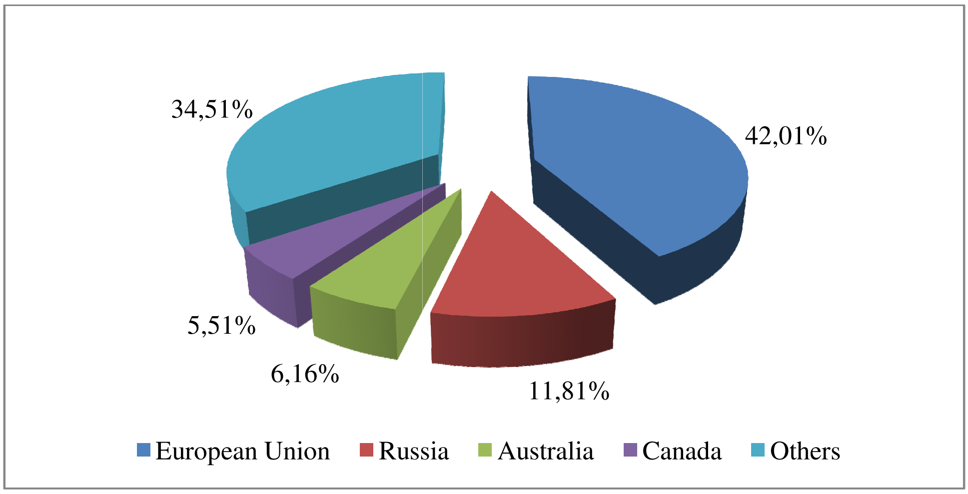


**Figure 8.** Leading world producers of barley in 2015.
Source: elaboration on USDA FAS PSDO (2016).

1.3.1.2. European market of barley

As far as the EU is concerned, considering a period of 55 years, Figure 9 shows the world trend of stored quantities at the end of market year; levels of consumption; export and import flows; production level of barley. Figure 10 shows the trend of area intended to barley cultivation and relative yields, over the past decades. Trend of production and consumption of barley in the EU reflects, while imports is almost null since the mid-Eighties (Figure 9).

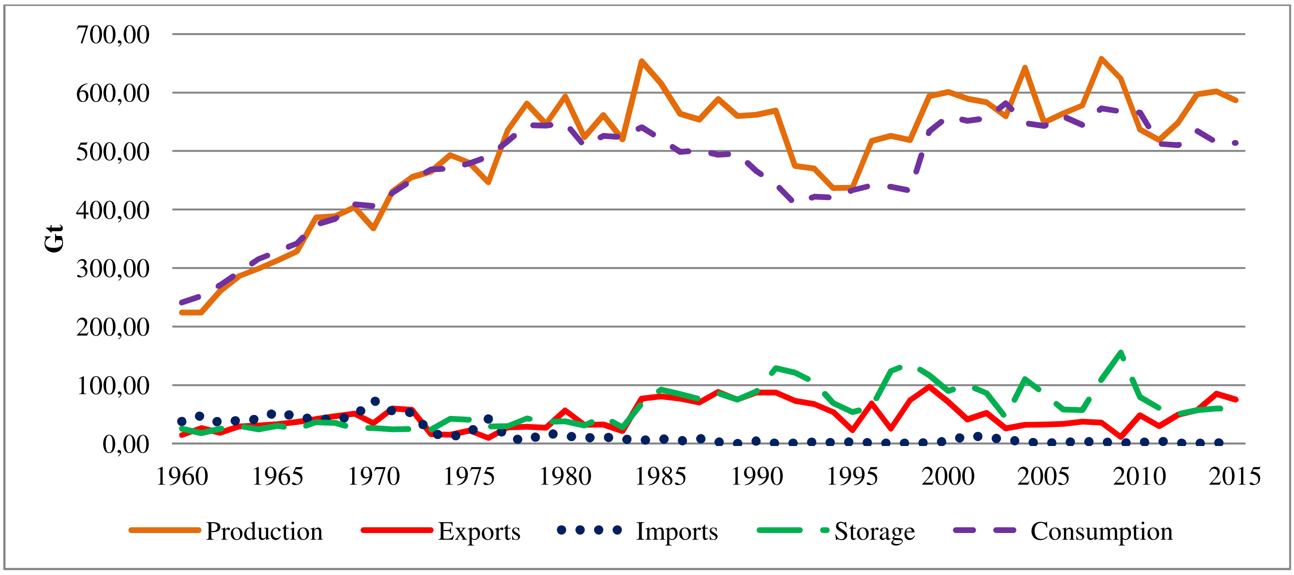


**Figure 9.** European trend of market fundamentals of barley during the period 1960-2015[2].
Source: elaboration on USDA FAS PSDO (2016).

Current production of barley in the EU is approximately 586.8 Gt, which accounts for more than 40% of the barley crop produced in the world (Figure 9). The 586.8 Gt of barley from the EU was produced from 124.2 Gha, giving an average yield of 0.05 t/ha (Figure 10) (USDA FAS PSDO, 2016). Over the last 55 years, yields have increased, with sporadic but severe peaks (Figure 10): in particular, the drop in yields in 1992

[2] Data about market fundamentals of barley, collected from USDA FAS PSDO's database, refer to EU-15 from 1960 to 1998 and to European Union from 1999 to 2015.

was caused, according to Garstang and Spink (2011), by unfavorable weather conditions across much of the EU countries. During the last decade, barley yields have been characterized by slower rate of growth, except for the upward spikes in 2004, 2008 and 2013-2014: also yields of other grain showed the same tendency from the mid-Nineties (Legg, 2005).

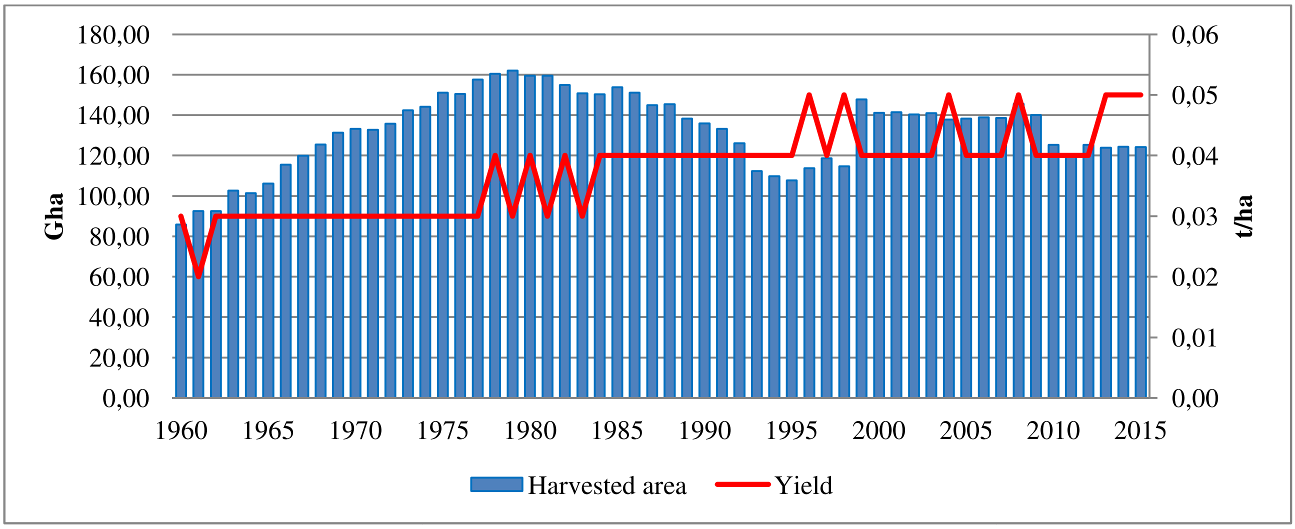


**Figure 10.** European harvested area and yields of barley during the period 1960-2015[3].
Source: elaboration on USDA FAS PSDO (2016).

Countries of the EU produce over 40% of barley world production: by far the leading producers are Germany (17,26%), France (17,21%), Spain (16,78%), and United Kingdom (11.83%) (Figure 11) (FAO - FAOSTAT, 2016), which are amongst the top 10 countries that have the greater share of barley production in the world (Ullrich, 2011).

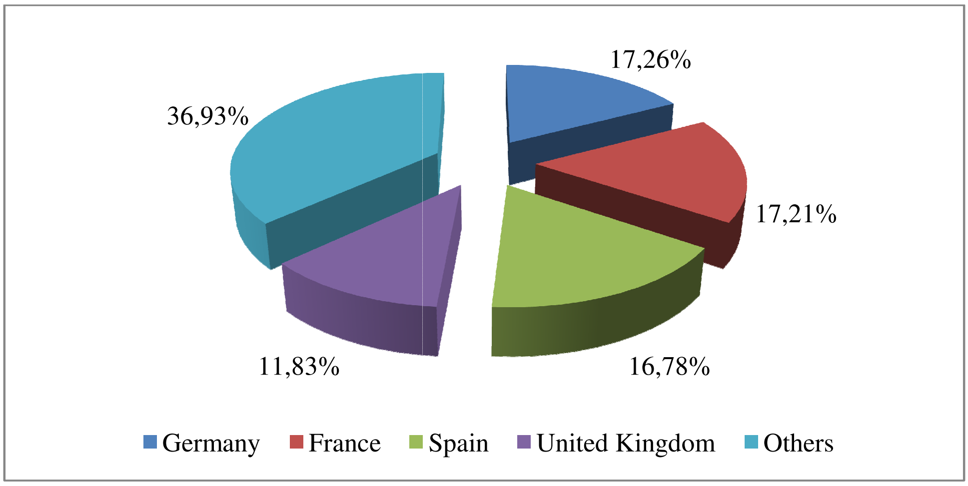


**Figure 11.** Leading European producers of barley in 2013.
Source: elaboration on FAO - FAOSTAT (2016).

Among the EU countries, Italy is the thirteenth with a production equal to 846,142 t in 2014[4] (FAO - FAOSTAT, 2016).

[3] Data about yields and harvested area of barley, collected from USDA FAS PSDO's database, refer to EU-15 from 1960 to 1998 and to European Union from 1999 to 2015.
[4] FAOSTAT's database provides country-level data updated until 2014.

1.3.1.3. Italian market of barley

In Italy, barley is equally distributed throughout the territory: regions of Northern Italy are the most productive ones, followed by Southern Italy and, in a lesser percentage, by region of Central Italy (Figure 12) (INEA, 2016).

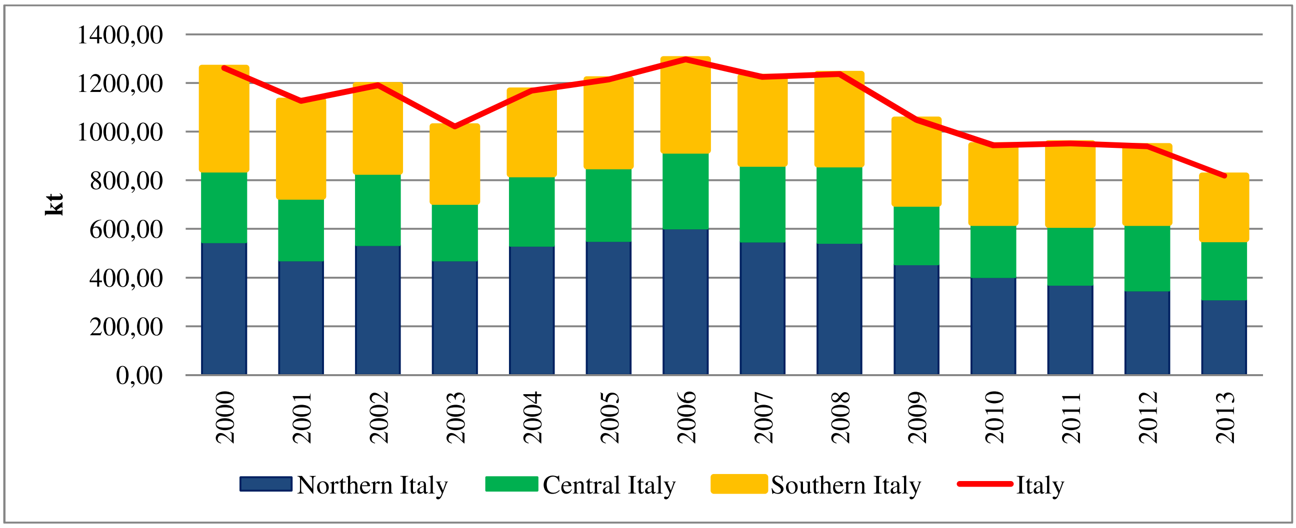


**Figure 12.** Italian production of barley, classified by geographical area, during the period 2000-2013.
Source: elaboration on INEA (2016).

Among Italian regions, Emilia Romagna is the major producer of barley, with an annual production of 106.80 kt and a corresponding value of 21,335.50 thousand € in 2013[5], followed by Umbria and Lombardy (Figure 13) (INEA, 2016).

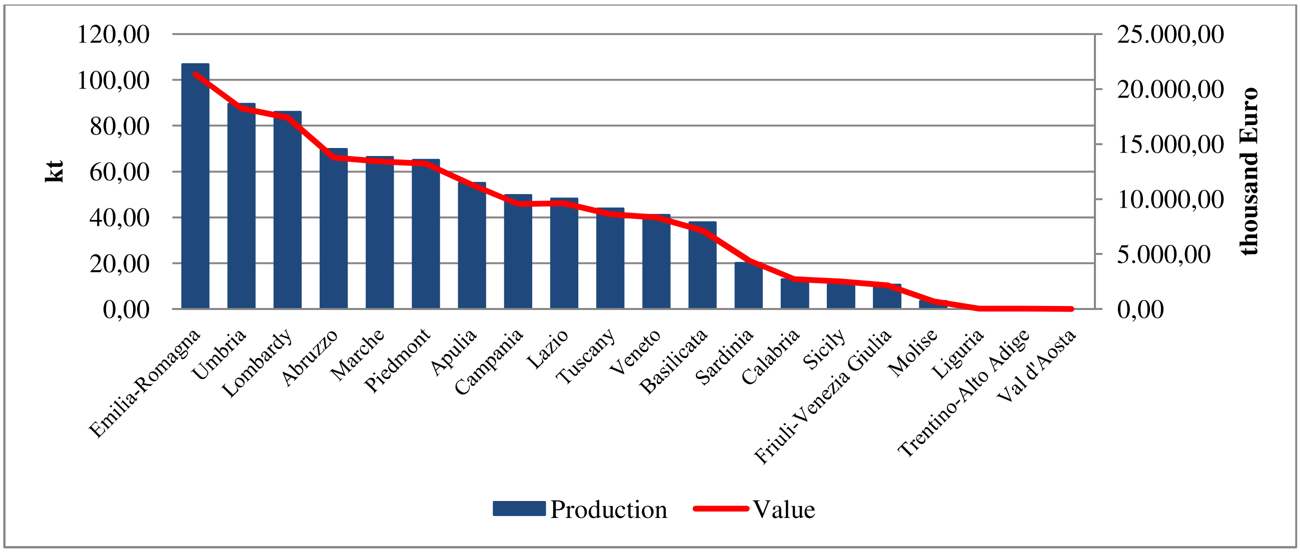


**Figure 13.** Italian produced quantity and value of production of barley in 2013.
Source: elaboration on INEA (2016).

[5] INEA's database provides regional-level data updated until 2013.

#### 1.3.1.3.1. Market of barley in Apulia region

In the Southern Italy regions barley is broadly cultivated and is efficient in production, thanks to favorable pedo-climatic conditions which are typical of those areas. Climate of Southern Italy is mostly Mediterranean with wet, mild winters and hot, dry summers (Lamonaca *et al.*, 2016).
Amongst Southern regions of Italy, Apulia is the major producer, with an annual production of 55.10 kt and a corresponding value of 31,301.39 thousand € in 2013 (Figure 14) (INEA, 2016).

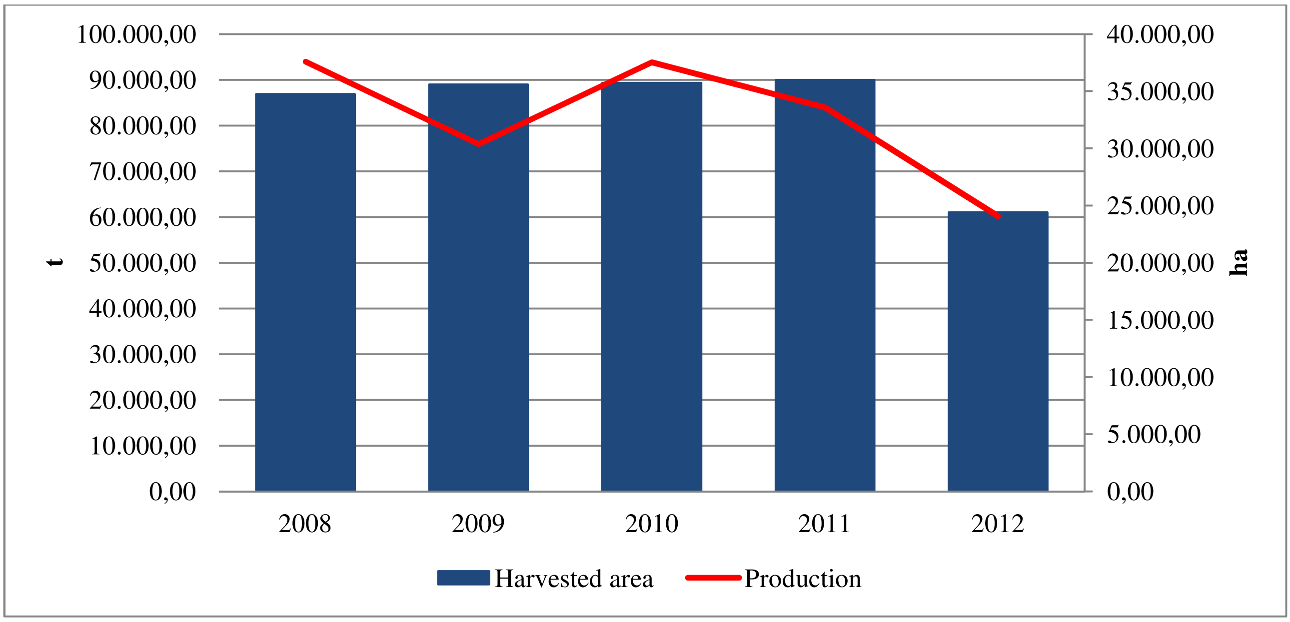


**Figure 14.** Apulian area intended to barley cultivation and produced quantity of barley during the period 2008-2012. Source: elaboration on Ismea (2016).

According to the last data provided by Ismea (2016), after a period of stable data referred to land intended to cultivation of barley (from 2008 to 2011), in 2012 barley harvested area suffered a severe reduction of about 32%. This is one of the reason also of the reduction in production of barley in Apulia region: from 2010 to 2012 barley production decreased of about 36% (Figure 14) (Ismea, 2016).

### *1.3.2. Barley supply chain in Italy*

Barley crop has a considerable role by three points of view: economic, productive and environmental. From an economic perspective, barley production allows to boost some of major agro-industrial supply chains, such as milling and pastry industry, starch factory for both human nutrition and industrial applications, and feed industry. About the productive point of view, its availability on a specific area permits to foster domestic and international competitiveness of related supply chains. In environmental terms, barley helps to improve a well-balanced agro-soil profile of a particular territory.
Barley national supply strongly affects domestic barley availability (Figure 15). Domestic supply is equal to 0.9 million t of barley grain. In general, approximately 30% of domestic production is intended to consumption needs of the producing farms. Although annual production suffers of structural fluctuations, it is necessary to confide in significant amount of foreign raw material, which on average represents the 60% of the total barley supply. Imports essentially follow two channels: feed industry directly absorbs nearly 50% of imported quantities, while private traders import the remaining half (Ismea, 2015).
Grain production and distribution component is constituted of barley producers (farms) and their diverse aggregation forms, which support basic production and operate a first commercialization of the agricultural basic product. Agricultural consortia (AC), Cooperatives (Coops) and Producers Organizations (POs) take

care of the commercialization of 60% of domestic barley grain, which they sell to feed industry. Private traders, which can use own storage centers or work as intermediary between farm and industry, spread approximately 30% of domestic supply, almost entirely addressed to feed industry (99% of the total) and to export only in a residual way (1% of the total). The remaining 10% of domestic production straight restock the feed industry (Ismea, 2016). All things considered, almost the entire domestic production of barley serves livestock farming, throughout feed industry.

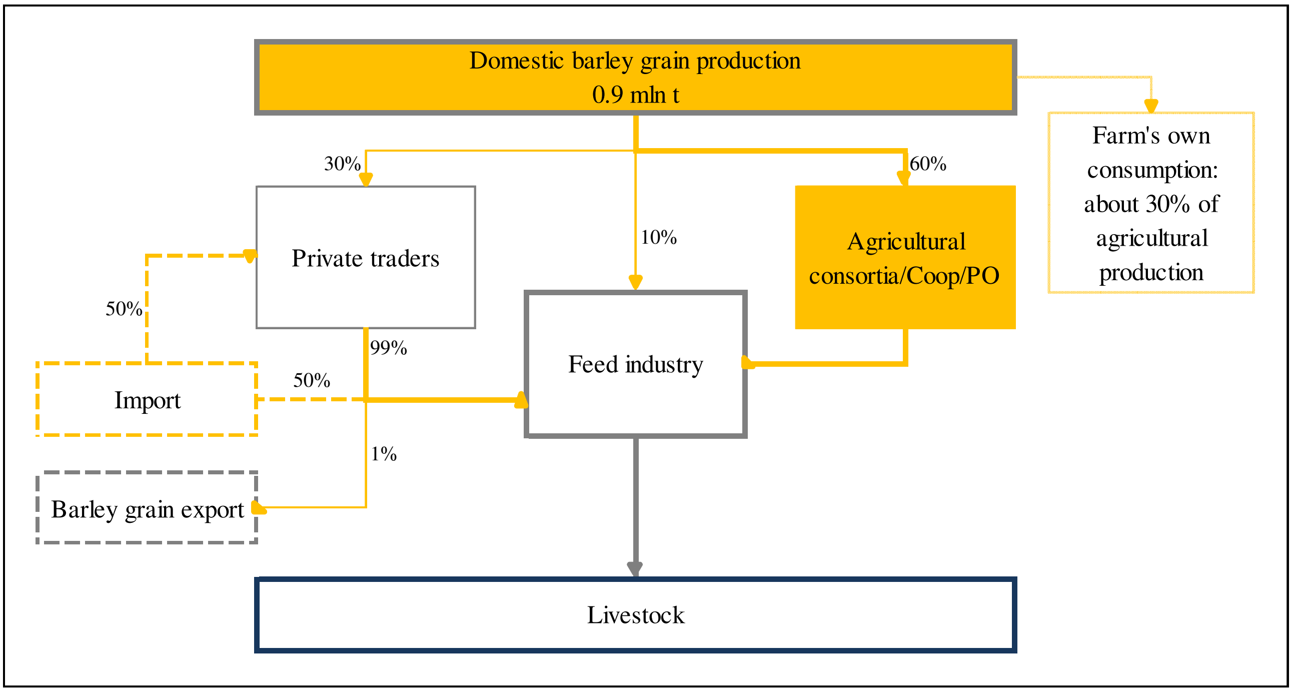


**Figure 15.** Quantitative flows along barley supply chain.
Source: elaboration on Ismea (2015).

The stakeholders involved in the whole barley supply chain are numerous. Barley supply chain, characterized by the existing structural dichotomy between agricultural and processing stages, encompasses barley grain production and its commercialization, production of flours, bakery products, by-products, and animal feeds (Figure 16).

Farms are the keystone of barley supply chain. Farmers consider barley as basic crop for the achievement of their economic aims and, in some pedo-climatic conditions, it is often the unique productive solution. Barley supply chain involves numerous farms, with lots of hectares intended to barley cultivation and a strongly pulverized supply of unstable quantity and quality. Farms production would be intended in part to primary processing industries and for the remaining share to mediators in aggregation forms (e.g. private traders, AC, Coops, and POs) and to feed industries. The former is essentially constituted by milling industry, while the agents in aggregation forms export barley grain as it is or serve milling and feed industries. Feed industry provides raw materials to domestic livestock or exports barley as animal feed (Ismea, 2016).

Barley supply chain encompasses also several processing industries, that have strengthened their network and supply relationships during the last years. Both primary and secondary processing industries are more concentrated in territorial and in productive terms. Processing stages need a steady procurement of barley grain, in qualitative and in quantitative terms. Primary processing sector is composed by milling industry sector, which provides to transformation of barley grain in flours. As by-products of this process, barley bran is essentially intended to animal feeds. Barley flours is addressed partially to the export and for the major part to the secondary processing industry (Ismea, 2016). Secondary processing is characterized by high productive variability and it includes barley-based bakery products, which in general are bread substitutes, pastry, confectionery, handmade and industrial bread-making industries. The productive fabric of bakery sector is characterized by a thick network of handcrafted workshops, which also make direct sale or, in some cases, they operate as manufacturing suppliers to Mass Retail Channel. Secondary processing sector addresses its productions on both foreign markets and domestic market, through several networks of wholesalers and intermediaries. The growth of exports and of domestic consumption supports an increasing national production of secondary industry (Ismea, 2016).

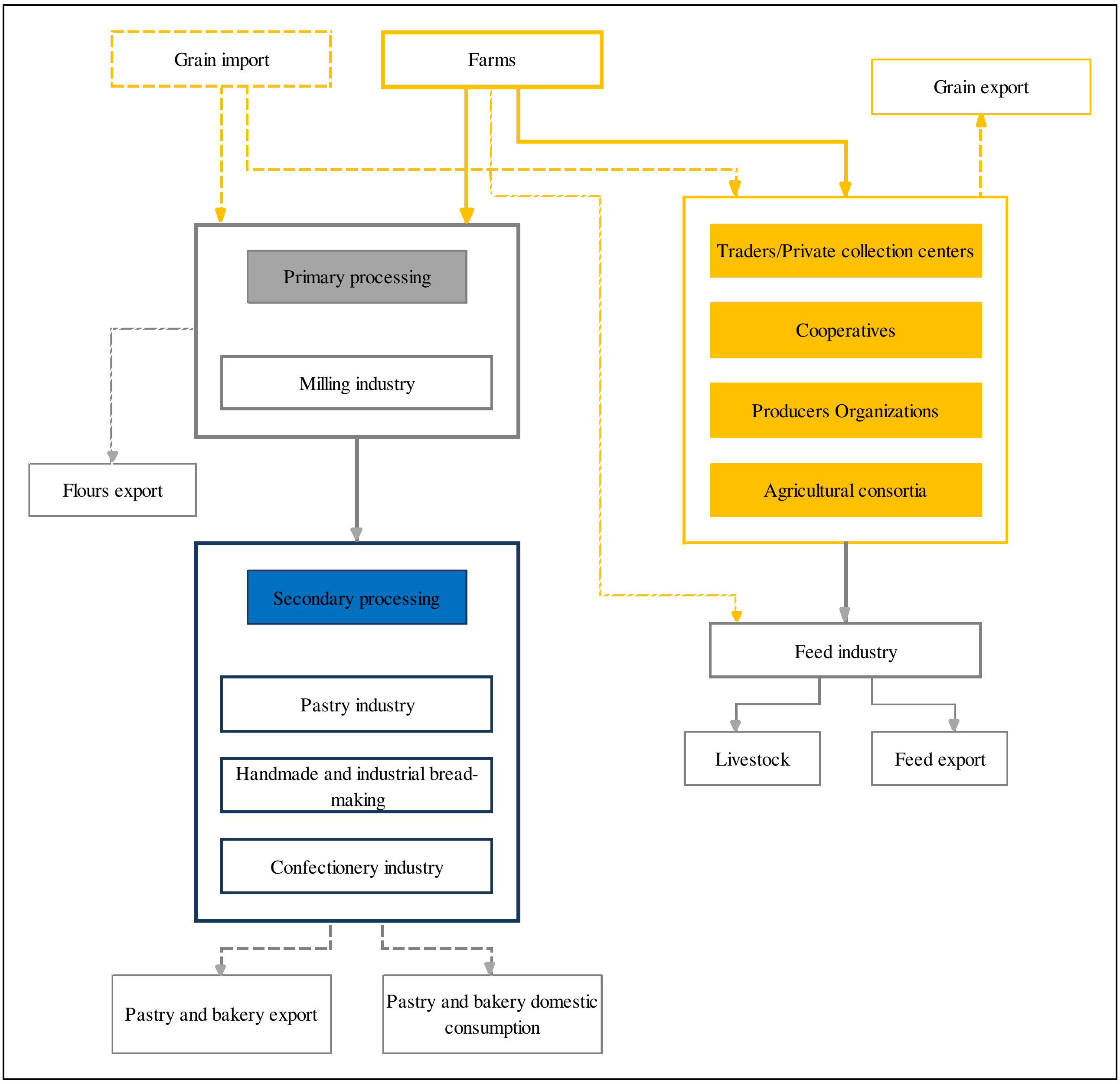


**Figure 16.** The main stakeholders of barley supply chain.
Source: elaboration on Ismea (2015).

## 1.4. Intended uses of barley

Barley is a versatile crop, able to provide annual forage, grain for livestock, grain high in soluble fiber for human food, and grain suitable for malting (Blake *et al.*, 2011). Most probably, *in primis* it was used as

human food, to then evolve into a feed, malting, brewing, and distilling grain, for which is best known worldwide (Ullrich, 2011).
According to the last data of FAO - FAOSTAT (2016), recently more than 70% of barley crop has been used for feed; about 21% has been intended to malting, brewing, and distilling industries; lesser than 6% has been consumed as human food; in addition, a growing interest in renewable energy has led to modest use of barley grain for production of fuel ethanol (Figure 17). The prominence of barley as food grain was due in part to a substitution effect with grain more suitable for human consumption, such as wheat and rice.

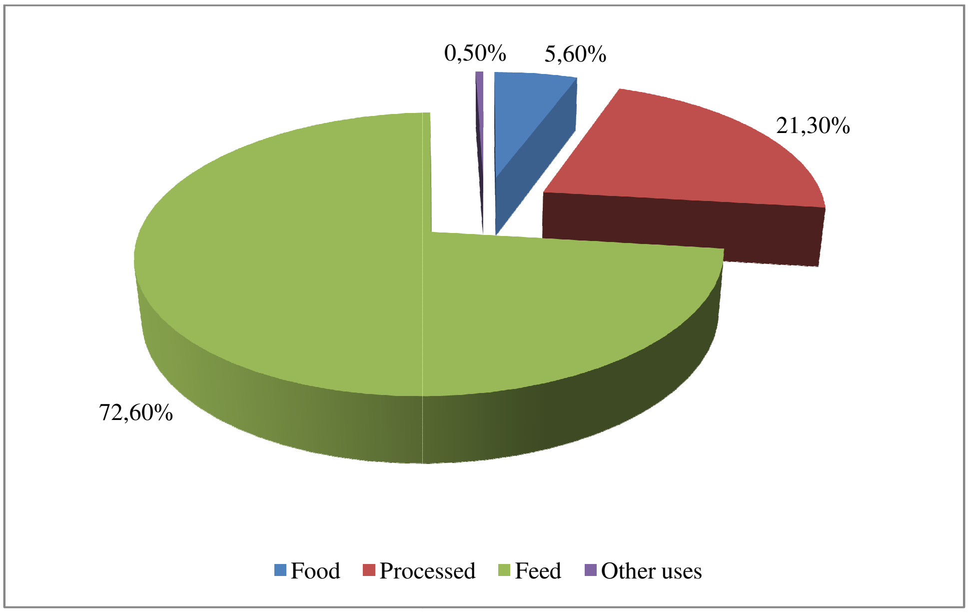


**Figure 17.** Intended uses of barley world production in 2011.
Source: elaboration on FAO - FAOSTAT (2016).

### *1.4.1.Barley for feed*

Barley is a versatile, high-quality feed grain, commonly used as a feed grain for livestock species, especially in diets of ruminant and non-ruminant livestock, poultry, and fish, although it competes with corn, sorghum, and wheat as a feed grain (Blake *et al.*, 2011; Ullrich, 2011). However, given a greater adaptation of barley with respect to corn, barley plays a relevant role for food in areas where corn is not produced, especially where the climate is cool and/or dry (Ullrich, 2011). Traditionally, barley is dry rolled or ground and thus intended to beef cattle rations. Also prize animals are often fed with barley soaked for 12 hours and then rolled (Blake *et al.*, 2011). Barley is a traditional grain for swine and poultry, although the presence of a fibrous hull on its grain creates inconvenient (Blake *et al.*, 2011; Ullrich, 2011). For poultry feed β-glucans are added after ground during feed composition (Kellems and Church, 2002), while Bregitzer *et al.* (2007) developed specific cultivar suited for commercial fish feed.

### *1.4.2.Barley for malt*

The barley use that produces the largest value added is the production of malt, because it is associated to the production of beer and to the production of distilled alcoholic beverages. The history of alcoholic drinks including beer goes back thousands of years: in particular, the use of barley for beer dates from archeological evidence to at least 8000 years ago in the Middle East and in Egypt (Schwarz and Li, 2011; Ullrich, 2011). Malt is also used for food applications in baking, cereal, confectionary, and distilled alcohol industries, as well as it is used as a source of flavor, aroma, and amylase activity, but in a small amount. Globally, barley accounts for the most part of malt production, although any grain can be used to produce malt. Malting is a process of controlled germination followed by drying (Schwarz and Li, 2011; Ullrich, 2011).

### *1.4.3.Barley for food*

Barley's versatility as food grain in human nourishment across the globe is historically acknowledge. As a food grain, barley may be blended into many food products at various levels, adding texture, flavor, aroma, and nutritional value to products (Baik *et al.*, 2011). Since desirability and acceptance of a food is usually related to culture and social status of the consuming population, the increasing use of wheat, rice and corn as a food source for human nutrition has led to a drastic decrease in barley consumption for human needs (Figure 19) (Sullivan *et al.*, 2013; Baik *et al.*, 2011; Baik and Ullrich, 2008). Although barley has remained a major food source for some cultures in Asia and northern Africa (Ullrich, 2011; Newman and Newman, 2006), it may be considered relatively under-utilized with regard to its potential use as an ingredient in processed human foods.

For food uses, barley grain is first abraded to produce pot or pearled barley, and may be further processed into grits, flakes and flour. Pearled barley, grits or flour have been used in the preparation of many traditional dishes (Chatterjee and Abrol, 1977). Barley flour, prepared from pearled grain through hammer milling or roller milling, can easily be used to produce bread, cakes, cookies, noodles and extruded snack foods (Baik *et al.*, 2011; Ullrich, 2011; Newman and Newman, 1991) (Figure 18).

**Figure 18.** Whole grain, pearled grain, rolled grain, and flake of barley.
Source: Ullrich, S.E. (2011), *Barley: Production, improvement, and uses*, Wiley-Blackwell, Oxford, UK.

Approximately the 80% of the current international consumption of barley, intended to human nutrition, is divided between barley grain as it is and barley processed into grits, flakes, flour, and so forth (FAO - FAOSTAT, 2016).

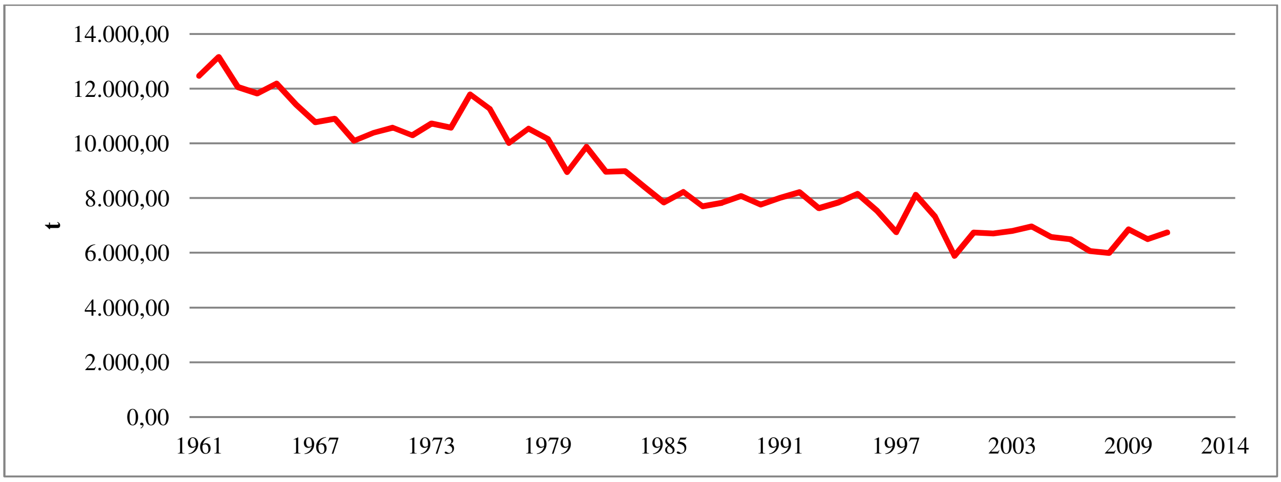


**Figure 19.** Trend of barley for food use during the period 1961-2011.
Source: elaboration on FAO - FAOSTAT (2016).

Since 2000 the use of barley for human nutrition seems to increase again (Figure 19), because of the fact that this grain has valuable qualitative and nutritional features, that make it a crop of niche for the functional food market. Over the last decade, the development of novel barley-based foods that are healthy has become a priority as a response to increased consumer awareness and demand (Sullivan *et al.*, 2013). For this, there has been little improvement in food processing and product development of barley (Baik and Ullrich, 2008). The discussion of increasing healthiness of consumers by changing eating habits or incorporating ingredients with health benefits has raised quickly. Today more than 6,700 t of produced barley is used for human consumption (FAO - FAOSTAT, 2016).

1.4.3.1. Health benefits of barley food

Since research on based-barley foods have shown health benefits and suitability for barley inclusion in food products (Newman and Newman, 1991), there have been minor changes in increased usage of barley as a food grain, also thanks to the efforts of scientists, nutritionists, and grower-supported organizations (Baik *et al.*, 2011; Ullrich, 2011): due to its high soluble fiber content and nutritional significance, it has once again become a desirable food source (Sullivan *et al.*, 2010). The current appreciation of barley as a food source is due to its potential health benefits (Sullivan et al., 2013). Barley kernels naturally contain many bioactive compounds localized in different parts of the kernel, including β-glucans, lignans, tocotrienols, folate, fructans, phytosterols, polyphenols, policosanol, phytates, pentosans, arabinoxylans which play numerous biological activities (prebiotic, probiotic, antioxidant, hypoglycemic, hypocholesterolemic, reduction of cardiovascular disease, colon cancer and neural tube defects), that can be used as ingredients for the development of functional foods (Table 3) (Marconi, 2012).

**Table 3.** Compounds with biological activity in barley caryopsis

| Compound | Location | Activity |
|---|---|---|
| Beta-Glucan | endosperm/aleuronic layer | cholesterol-lowering/hypoglycemic |
| Tocopherols | germ/aleuronic layer | antioxidant/cholesterol-lowering |
| Tocotrienols | germ/aleuronic layer | antioxidant/cholesterol-lowering |
| Folate | aleuronic layer/germ | reduction of neural tube's defects/reduction of cardiovascular conditions and of colon cancer |
| Phytosterols | germ/aleuronic layer | cholesterol-lowering |
| Polyphenols | pericarp | antioxidant |
| Phytates | pericarp | reduction of colon cancer |
| Policosanol | pericarp | cholesterol-lowering |
| Pentosans | pericarp | cholesterol-lowering |
| Arabinoxylans | pericarp | cholesterol-lowering |
| Lignans | pericarp/aleuronic layer | reduction of cardiovascular conditions/reduction of malignancies |
| Alkylresorcinols | pericarp | antioxidant |

Source: elaboration on Marconi (2012).

Among these compounds, barley contains a high percentage of β-glucan, a soluble fiber. Nutritional studies into barley β-glucan have shown a link between its regular consumption and a number of health benefits, including a decrease in the risk of chronic heart disease by lowering blood cholesterol (Önning, 2007; Braaten, *et al.*, 1994) and an increased insulin response in diabetics (Poutanen *et al.*, 2007; Wood *et al.*, 1994). In addition, in 2006, the US Food and Drug Administration (FDA) issued a health benefit endorsement for barley, based on β-glucan effects on lowering blood cholesterol with implications for heart health as well as on lowering blood glucose levels (glycemic index) with implications for diabetes (Baik *et al.*, 2011; Ullrich, 2011; Baik and Ullrich, 2008).

# Chapter 2
# METHODOLOGICAL APPROACH

## 2.1. Combination of Uniform and shifted Binomial variables models[6]

The use of ordinal variables as outcomes is common in a wide range of disciplines especially in the social sciences where they generally represent respondents' answers to questions in questionnaires. The handling of such variables requires a proper modeling approach which takes into account their discrete and ordered nature. Several models have been proposed with the aim of interpreting and fitting ordinal responses (Agresti, 2010). In particular, Piccolo (2003) and D'Elia and Piccolo (2005) introduced a suitable modeling tool based on a Combination of Uniform and shifted Binomial random variables, named CUB model, for analyzing preference/evaluation data sets in several contexts. Over the past years, the interest in CUB models is increasing especially for the evaluation of customer satisfaction surveys, consumer tests, market segmentation and product positioning (Cafarelli *et al.*, 2015; Iannario and Piccolo, 2013; Corduas *et al.*, 2013). The use of these models involves the possibility of mutating subjects' opinions on certain topics, expressed as integer numbers via hedonic scale (Likert scale), into quantitative variables allowing a feasible formulation of the probability distributions for ordinal responses.

D'Elia and Piccolo (2005) provided a simplified representation of the evaluation process where the formulation of subject's judgment about a product/service can be summarized by means of two latent components: a personal *feeling* for an item under judgment and an inherent *uncertainty* of answers in traducing perceptions into a hedonic scale (ordinal value). *Feeling* may be seen as the degree of liking/disliking about an item under judgment, whereas *uncertainty* mostly depends on circumstances that drive the elicitation process (e.g. indecision associated with knowledge, background, partial understanding of item, apathy, laziness, etc.). Piccolo (2006) suggests to model *feeling* using a shifted Binomial random variable and *uncertainty* with a discrete Uniform random variable. The ordinal response (rating), $r$, is thus the realization of a discrete random variable, $R$, with probability function specified as:

$$\Pr(R = r) = \pi \binom{m-1}{r-1} \xi^{m-r}(1-\xi)^{r-1} + (1-\pi)\left(\frac{1}{m}\right) \qquad r = 1,2,\dots,m \tag{1}$$

where $r$ is the rating, $m$ is the number of rates of the evaluation scale, $\xi$ is the parameter related to latent component of *feeling*, $\pi$ is the parameter related to latent component of *uncertainty*.

The CUB model in equation (1) is fully identifiable for any $m > 3$, as discussed in Iannario and Piccolo (2012), and it is defined for $\xi \in (0,1]$ and $\pi \in (0,1]$.

Parameters $\xi$ and $\pi$ influence differently the probability distribution of $R$. Parameter $\xi$ affects both location and skewness of $R$: when $\xi < 0.5 (> 0.5)$ the probability distribution of $R$ is negatively (positively) skewed, with respect to the midpoint $\frac{(m+1)}{2}$, suggesting that respondents choose their ratings from the end (beginning) of the evaluation scale (Iannario *et al.*, 2012). In this study, the best positive judgment corresponds to $m$, so values of $\xi$ lower than 0.5 represent the respondents' awareness toward the perception about quality of organic food in terms of healthiness and sustainability[7].

Parameter $\pi$ is inversely related to the weight of uncertainty component $(1-\pi)$: when $\pi \to 0$ the inclination towards a completely random choice increases and the random variable $R$ tends to behave as a Uniform

[6] The description of methodological approach related to Combination of Uniform and shifted Binomial random variables models is part of the section *Materials and Method* of a paper entitled "Analysis of consumers' perception about quality of organic food", written by Emilia Lamonaca, Barbara Cafarelli, Crescenza Calculli, and Caterina Tricase, and currently under review at Journal of Cleaner Production.

[7] For more details see paragraph 3.1. CUB models for the analysis of consumers' perception.

distribution; when $\pi \to 1$, $R$ tends to behave as a shifted Binomial distribution suggesting a completely thoughtful choice (Iannario and Piccolo, 2013; D'Elia and Piccolo, 2005).
Covariates related to respondents, such as socio-demographic characteristics or behavior habits, might influence the evaluation process. Covariates may be quantitative (e.g. age, family income, etc.) or qualitative, coded as dichotomous or polytomous variables (e.g. gender, marital status, etc.). It is also possible to consider objective covariates in order to capture potential different reactions of respondents in decision making process, depending on the characteristics of the item they are evaluating.
This premise leads to a more general class of mixture models that directly consider the relation among *feeling* and/or *uncertainty* parameters and features of respondents, through logistic functions. For $r = 1,2,\dots,m$ and for any $i$-th subject, these so-called CUB models with $p$ and $q$ covariates, CUB(*p,q*), are defined by:

· a stochastic component:

$$\Pr(R_i = r|\boldsymbol{y}_i;\boldsymbol{w}_i) = \pi_i \binom{m-1}{r-1} \xi_i^{m-r}(1-\xi_i)^{r-1} + (1-\pi_i)\left(\frac{1}{m}\right) \qquad i = 1,2,..,n \tag{2}$$

· two systematic components:

$$\pi_i = \pi_i(\boldsymbol{\beta}) = \frac{1}{1+e^{-y_i\beta}} \qquad \xi_i = \xi_i(\boldsymbol{\gamma}) = \frac{1}{1+e^{-w_i\gamma}} \qquad i = 1,2,\dots,n \tag{3}$$

where $\boldsymbol{y}_i = (1, x_{i1}, \dots, x_{1p})'$ is the vector of respondents' covariates related to *feeling*, $\xi$, and $w_i = (1, w_{i1}, \dots, w_{iq})'$ is the vector of respondents' covariates related to *uncertainty*, $\pi$; $r$ is the rating, $m$ is the number of rates of the evaluation scale; $\beta$ and $\gamma$ are parameters referred to *uncertainty* and *feeling* respectively.
The probability distribution of a CUB(*p,q*) model is:

$$\Pr(R_i = r|\boldsymbol{y}_i;\boldsymbol{w}_i) = \frac{1}{1+e^{-y_i\beta}}\left[\binom{m-1}{\boldsymbol{y}_i-1}\frac{(e^{-w_i\gamma})^{y_i-1}}{(1+e^{-w_i\gamma})^{m-1}} - \frac{1}{m}\right] + \frac{1}{m} \qquad r = 1,2,\dots,m;\ i = 1,2,\dots,n \tag{4}$$

A stepwise procedure allows to select covariates: *in primis*, covariates are introduced one by one in equation (4) both for *feeling* and/or *uncertainty* components, then they are chosen according to their significance levels. The interpretation of the effects of this covariates on *feeling* and *uncertainty* follows equations in (3) where, for $k$ that varies from 1 to the number of the categories, if $w_k$ ($y_k$) increases positively, there is an increase in *feeling* (*uncertainty*) if $\gamma_k < 0$ ($\beta_k < 0$); *vice versa* there is a decrease in *feeling* (*uncertainty*), if $\gamma_k > 0$ ($\beta_k > 0$) (Iannario and Piccolo, 2012). The goodness of fit for each estimated model is also assessed using dissimilarity index, $Diss$, (D'Elia and Piccolo, 2005), which compares the $f_r$ observed frequencies and the expected probabilities $\hat{p}_r = p_r(\hat{\xi},\hat{\pi})$. The measure, normalized in $[0,1]$ , is:

$$Diss = \frac{1}{2}\sum_{r=1}^{m} |f_r - p_r(\hat{\xi},\hat{\pi})| \tag{5}$$

that indicates the proportion of respondents to move in order to achieve a perfect fitting. The dissimilarity index is often computed as a benchmark for judging the adequacy of the model: values of $Diss < 0.1$ are considered as compatible with a good fitting (Iannario, 2009).
The interpretation of the results is eased representing the estimated parameters of *feeling* and *uncertainty*, in the parameter space (unit square). The parameters coordinates are directly related to the latent component of feeling $(1-\xi)$, in vertical axis, and of uncertainty $(1-\pi)$, in the horizontal one. As a consequence, values of $(1-\hat{\xi})$ close to 1 indicate a high degree of liking with respect to the analyzed item, whereas values of $(1-\hat{\pi})$ close to 1 suggest a propensity of respondents to make a random choice.

## 2.2. Life Cycle Assessment

The growing concerns over the negative environmental impacts related to products life cycle has led to the development of techniques intended to comprehend and consequently reduce these impacts. Among them, Life Cycle Assessment (LCA) attempts to address these issue (ISO, 2006a).

### *2.2.1. General definition*

LCA is an internationally standardized methodology and a management tool. This comprehensive technique normally refers to Environmental Life Cycle Assessment (E-LCA) and it aims at addressing the environmental aspects of a product[8] and at quantifying the potential environmental impacts, related to all inputs and outputs, throughout its life cycle. LCA operates in the perspective of *from cradle to grave*, involving all stages of a product system, from raw material acquisition or natural resource extraction, through production, use, and recycling, up to the disposal of the remaining waste (ILCD handbook, 2010; ISO, 2006a,b).

According to the abovementioned definition, LCA is based on three pillars:

- environmental impacts;
- sustainable development;
- Life Cycle Thinking (LCT).

The environmental impacts include emissions, consumed resources, human health, and ecological consequences: LCA allows their definition, qualification, quantification, and weighing (ILCD handbook, 2010; ISO, 2006a,b). The maximization of environmental sustainability entails the reduction of environmental impacts related to a product's life cycle: LCA of impacts allows the identification of improvement solutions and the selection of relevant indicators of environmental performance and sustainable development (ISO, 2006a). LCT perspective encourages development, implementation, and monitoring of environmental improvement policies, as well as support for strategic decisions (ILCD handbook, 2010).

### *2.2.2. LCA phases*

According to the recommendations of the International Standards (ISO, 2006a,b), the implementation of an LCA shall include essentially the following four phases (Figure 20):

1. Goal and Scope definition;
2. Life Cycle Inventory (LCI);
3. Life Cycle Impact Assessment (LCIA);
4. Life Cycle Interpretation.

[8] The term "product" not only refers to product systems but may also include service systems (ISO 2006a).

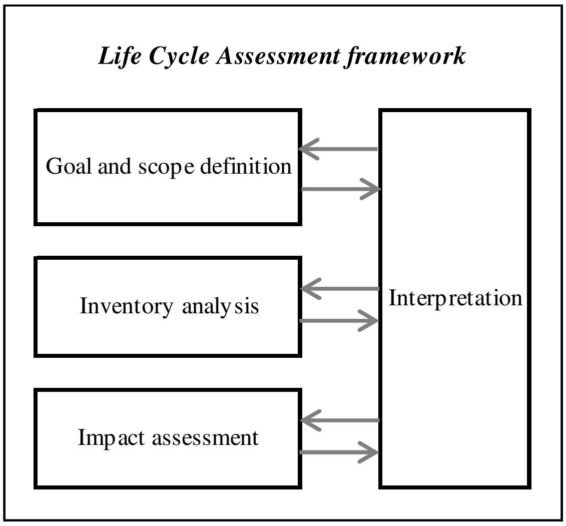


**Figure 20.** LCA phases
Source: elaboration on ISO 14040 (2006a).

The level of detail of an LCA study depends on its goal and scope. The scope of an LCA study has to be unequivocally defined and consistent with the intended application, thus to be compatible and adequate to address the stated goal. It involves the definition of the product system under analysis, the Functional Unit (FU), the system boundary, the allocation procedure (ISO, 2006a). According to the International Standards (ISO, 2006a,b), the FU of the system being studied has to be chosen accurately on the base of the scope of the LCA study. From a theoretical point of view, a FU is defined as a measure of a system's performance (Krozer and Vis, 1998), that can be described through a collection of unit processes performing a well-defined function. A FU provides reference to which relates inputs and outputs, thus to ensure comparability among different systems, evaluated on a common basis, to the extent that it is defined and measurable. The potential adoptable FUs may be numerous, but the selected one must dependent on goal and scope of the study (ISO, 2006a). The system boundary defines the unit processes that a specific LCA study has to include for the assessment of environmental impacts. Its definition depends on several elements, such as intended application of the study, assumptions made, cut-off criteria, data constraints, and intended audience. Inputs and outputs included in the boundaries, as well as material and energy flows, shall be consistent with the goal of the study (ISO, 2006a,b). Data involved in the system boundary have to be representative and consistent in terms of time-related and geographical coverage (ISO, 2006a). An allocation procedure is necessary when the system under study involves more than a product (e.g. co-products or by-products) (ISO, 2006a).

LCI analysis involves data collection and calculation procedures to quantify input flows related to utilization of resources and materials, consumption of energy, as well as transports, within an entire life cycle of a product, depending on the goal and scope of LCA (ISO, 2006a). Among LCA phases, LCI analysis is the most relevant one, because it is necessary to assess and reproduce several activities involved in a product's life cycle, and to collect and compute all data related to environmental impacts (Lo Giudice *et al.*, 2016; Ingrao *et al.*, 2015; Niero *et al.*, 2015a; Zhang *et al.*, 2015).

LCIA aims at evaluating the significance of potential environmental impacts related to the analyzed systems. To this end the resulting flows, quantified within inventory analysis, have to be aggregated into a limited set of damage and impact categories (De Benedetto and Klemeš, 2009; ISO, 2006a; Suh and Huppes, 2005). According to the International Standards (ISO, 2006a,b), LCIA phase may include two mandatory steps, namely classification and characterization of inventory data into damage and impact categories, and two optional steps, viz normalization and weighting of results with respect to a common reference. Normalization facilitates the interpretation of LCIA results, analyzing the respective share of each impact to the overall damage by applying normalization factors to midpoint or damage impact classes. "The normalized factor is determined by the ratio of the impact per unit of emission divided by the total impact of all substances of the specific category for which characterization factors exist, per person per year" (Jolliet *et al.*, 2003, p. 329). Weighting aggregates the four-damage oriented impact categories (HH, EQ, CC, R) for the interpretation phase of LCA (Jolliet *et al.*, 2003).

Interpretation combines together findings from LCI and LCIA, to obtain conclusions and recommendations consistent with the goal and scope of the study (ISO, 2006a).

LCA methodology allows to perform comparative assessments. To ensure the accuracy in the comparison, systems being compared have to: be corresponding; use the same FU; be based on equivalent methodological assumptions, such as performance, system boundaries, data quality, allocation procedures, decision rules on evaluating inputs and outputs and impact assessment (De Benedetto and Klemeš, 2009; ISO, 2006a).

### *2.2.3. Characterization model: Impact 2002+*

The choice of method to evaluate environmental impacts depends on the goal and scope of the study. Among characterization models[9] used in the assessment of LCIA, IMPACT 2002+ LCIA methodology proposes an approach based on a combination of midpoint impact categories and endpoint damage categories, to evaluate the environmental repercussions of a given system. This approach links the output inventory flows to four damage categories (i.e. Human Health-HH, Ecosystem Quality-EQ, Climate Changes-CC, Resources-R), throughout 14 midpoint categories which are expressed using equivalent indicators (ILCD handbook, 2010; Joillet *et al.*, 2003). In particular, the considered midpoint categories are: Human toxicity (HT), Respiratory effects (RE), Ionizing radiation (IR), and Ozone layer depletion (OLD) that refer to HH damage category; Photochemical oxidation (PO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Aquatic acidification (AA), Aquatic eutrophication (AEU), Terrestrial acidification/nutrition (TAN), and Land occupation (LO) that refer to EQ damage category; Global warming (GW) that refers to CC damage category; Non-renewable energy (NRE), and Mineral extraction (ME) that refer to R damage category (Figure 21) (ILCD handbook, 2010; Joillet *et al.*, 2003).

[9] A wide range of characterization models exists and is frequently used in the evaluation of LCIA. It includes CML 2002, Eco-Indicator 99, EDIP (1997-2003), EPS2000, Impact 2002+, LIME, LUCAS, ReCiPe, Swiss Ecoscarcity or Ecological scarcity, TRACI, MEEuP methodology (ILCD handbook, 2010).

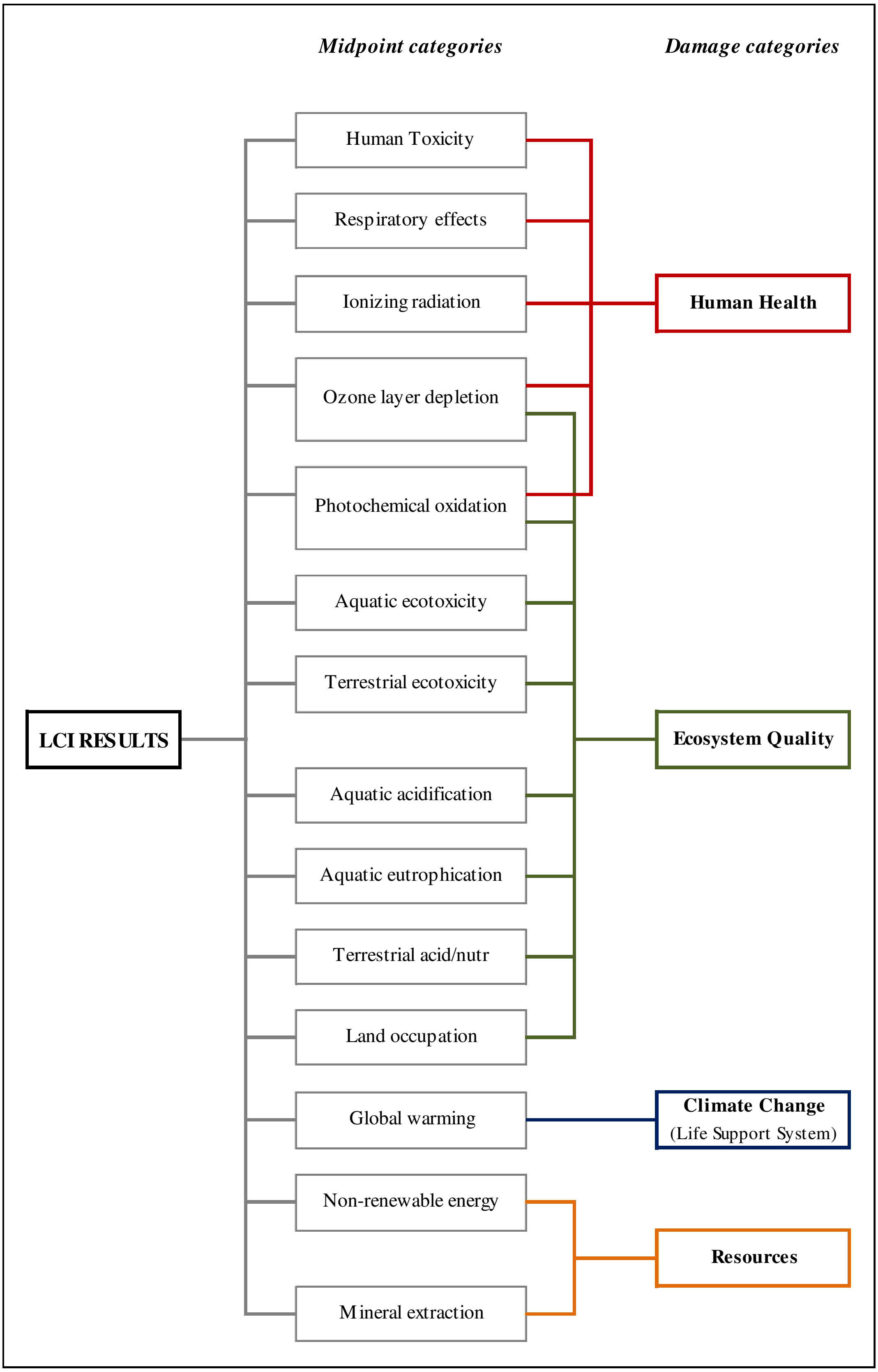


**Figure 21.** Impact categories and pathways covered by the IMPACT 2002+ methodology
Source: elaboration on ILCD handbook (2010).

### *2.2.4. LCA in agricultural researches*[10]

According to Thomassen and de Boer (2005), a variety of tools and methods can be used to assess environmental impacts of agricultural production systems at farm level (e.g. input-output accounting, ecological footprint analysis, LCA, etc.). During the last decades, LCA has been extensively applied to investigate sustainability and efficiency in agricultural sector (Tricase *et al.*, 2016; Ingrao *et al.*, 2015; Niero *et al.*, 2015a; Fedele *et al.* 2014; Tidåker *et al.*, 2014; van der Werf *et al.*, 2014), becoming an effective, systematic, and robust tool to support the design of guidelines for the implementation of more sustainable production systems (Tricase *et al.*, 2016; Ingrao *et al.*, 2015; Jeswani *et al.*, 2010).

Current and future demand for food by a growing population puts high pressure on land and inputs production. Although agriculture and food sectors contribute to human health and prosperity, they are responsible of great environmental impacts (van der Werf *et al.*, 2014; Ingrao *et al.*, 2015). Environmental impacts refer to both adverse and beneficial changes to the environment, and may derive from the interaction of an organisation with the environment. The environment is the surroundings in which the organisation operates and refers to air, water, land, natural resources, flora, fauna, humans and their interrelation (ISO, 2004). Understanding what the magnitude of environmental impacts related to food production are and how they can be reduced to achieve more sustainable agricultural systems is an important challenge for decision-makers (Masuda, 2016; Korsaeth *et al.*, 2012). There is no consensus on the definition of sustainability in agriculture. It may refer to quality of environment and resources (McIsaac, 1996), or to reduction of negative externalities caused by agricultural modernization in the 20$^{th}$ century (Aerni, 2009), as well as to the contribution of agricultural practices to depletion of natural and non-renewable resources, to increase in Greenhouse Gases (GHGs) emissions and related impact on climate change and ecosystem quality (Moss and Schmitz, 2013).

Agriculture and related sectors deeply influence a huge number of environmental impact categories (e.g. land use, non-renewable energy source exploitation, and climate change), due to its dependence upon several impacting inputs such as land, fertilisers, fossil fuels, machines, pesticides, electricity, just to name a few (González-García *et al.*, 2016; Noya *et al.*, 2015; Bacenetti *et al.*, 2014). Nowadays, it is a well-established opinion that organic farming may be one of the solutions to minimise negative externalities and to reduce agriculture's impacts on environment (Tricase *et al.*, 2016; Meier *et al.*, 2015). Those effects are achievable by the omitted usage of synthetic fertilisers and pesticides, crop diversification and the application of organic fertilisers, as the European Council Regulation on organic production requires (EC, 2007). In this regard, Meier *et al.* (2015) and Tuomisto *et al.* (2012) documented that organic farming allows to obtain the same quantity of product achievable in conventional farming, but employing larger pieces of land. This should be attributed to the yield-gap that exists between organic and conventional systems, and is so well acknowledged worldwide that has become one of the main focuses of the international debates in the field. According to several researchers working in this field such as Meier *et al.* (2015), de Ponti *et al.* (2012), and Nemecek *et al.* (2011), that gap is about 5-34%, depending upon system and site characteristics. Because yields in organic farming are lower than in conventional farming, environmental benefits of organic agriculture might be relevant (Meier *et al.*, 2015).

LCA methodology could not establish *a priori* if organic farming is the best practice to adopt, from an environmental perspective, because local dynamics, regional geo-climatic, pedo-climatic, and site-specific factors affect agricultural LCA results. A solution could be the analysis and comparison of specific case studies: because of the lack of historical data and the availability of average data different from real data, a single farm cannot base its business and strategic choices on evaluation of environmental impacts that are not

[10] Part of the description of LCA in agricultural researches is part of the *Introduction* of a paper entitled "A comparative Life Cycle Assessment between organic and conventional barley cultivation for sustainable agriculture pathways", written by Caterina Tricase, Emilia Lamonaca, Carlo Ingrao, Jacopo Baceneti, and Agata Lo Giudice, and currently under review at Journal of Cleaner Production.

case-specific (Fedele *et al.*, 2014). For this reason, rather than providing absolute dimensions of sustainability of an agricultural system, it is useful to compare various farming scenarios in order to highlight similarities and differences (Ingrao *et al.*, 2015).

LCA has been extensively used to quantify the potential environmental impacts related to agriculture and, in particular, to cereal production systems, such as in González-García *et al.* (2016), Dijkman *et al.* (2016), Boone *et al.* (2016), Masuda (2016), Tidåker *et al.* (2014), van der Werf *et al.* (2014), and Brankatschk and Finkbeiner (2014): they agree in considering LCA a useful tool to assess inventories and impacts, and to support environmental decision-making in agricultural systems. Though using different methodological approaches, Aguilera *et al.* (2015), Fedele *et al.* (2014), and Niero *et al.* (2015a,b) compared environmental impacts related to cultivation of grain in organic and conventional farming, concluding that organic farming is preferable with respect to conventional one. Despite the extended empirical literature on the issue, just a few studies refer to barley cultivation: some of them, such as Dijkman *et al.* (2016), Niero *et al.* (2015a), and Fedele *et al.* (2014), propose a comparison between conventional and organic cultivation systems for barley. However, to the best of knowledge, none of them assessed the influence that the choice of the Functional Unit (FU) plays upon the investigated system, as well as results from the comparison in terms of material and energy flows (inlet to and outlet from the system) and environmental impacts. In addition, Aguilera *et al.* (2015) and Brankatschk and Finkbeiner (2014) highlighted that frequently LCAs applied to crop products do not take into account cereal co-products, such as straw, that may have relevant economic functions and, so, should be considered as responsible for a share of the environmental impacts related to the cultivation phase. In this regard, one of the main challenges of agricultural LCAs is to ensure an adequate allocation procedure to duly compute shares of environmental burdens and to correctly attribute them between main product and the co-products (Brankatschk and Finkbeiner, 2014; Ekvall and Finnveden, 2001).

Because of the lack of comprehensive comparisons between organic and conventional management of barley production systems, which involve specific methodological assumptions (i.e. different FUs, economic allocation procedure between product and co-product), this research could make a relevant contribution in this regard. Also, it could contribute to enrich the knowledge on LCA in this field, allowing useful comparisons with equivalent products. Section 3.2.3.1 thus presents a comparative LCA between conventional and organic farming, based upon the assessment of environmental impacts related to the cultivation of barley in Southern Italy under favourable pedo-climatic conditions. For great understanding, sub-Section 3.2.3.2 and 3.2.3.3 present in detail the analysis of environmental impacts related to cultivation of barley both in organic and conventional farming, caused by each phase involved in the cultivation process. This research aims at addressing the following question:

- which is the best solution, in terms of environmental sustainability and productive efficiency, for barley cultivation between organic and conventional farming;
- how methodological assumptions, such as choice of FU and allocation procedure, influence comparative assessment of environmental impacts for barley cultivation.

To duly address the scope, the study takes into account real activities of two farms located in the Alta Murgia Park, in Apulia region (Italy): one of them produces organic barley, while the other cultivates conventional barley. They were chosen because they fall within the same geographical area: this allows to avoid affecting LCA results, because the two cultivation systems take advantage from the same pedo-climatic conditions.

# Chapter 3
# RESULTS AND DISCUSSION

## 3.1. CUB models for the analysis of consumers' perception

### *3.1.1.Research design*[11]

The empirical analysis was conducted through an online survey on consumers' eating habits, implemented in the Italian market. The research instrument was a questionnaire[12] designed to:

· investigate consumers' food purchasing decisions and their determinants;
· analyze consumers' perception about quality of organic food, in terms of healthiness and sustainability, and to evaluate the importance of these two features in choosing organic food.

The questionnaire is based on a thorough review of the literature on the issue, considering empirical researches such as, for instance, Bryla (2016), Ghvanidze *et al.* (2016), Lazzarini *et al.* (2016), Lee and Yun (2016), Meyerding (2016), Yadavar and Pathak (2016), Hsu and Chen (2014), Aschemann-Witzel *et al.* (2013). It contained 12 questions, divided into three thematic sections. *In primis*, participants were asked to provide some socio-demographic information, such as gender, age, residential area, level of education, their financial situation, the components of family unit adults as well as their weekly spending for food. The second section of the questionnaire contained some questions, aimed at profiling respondents' food purchasing decisions, eating habits and perception about quality of organic food: because of the complexity of such questions, they were split up into different items, concerning healthiness and environmental aspects. The items derive from relevant literature and were measured using a 7 point agree/disagree Likert scale, according to respondents' preferences, where 7 indicates a positive view (essential) and 1 represents a negative view (unimportant) (Likert, 1932). Table 4 reports the questionnaire items, their source of adoption, along with the summary statistics for each item in the constructs.

**Table 4.** Questionnaire items, source of adoption, and descriptive statistics.

| Item | Scale | Source of adoption | Low (%) | Neutral (%) | High (%) | Mean | SD |
|---|---|---|---|---|---|---|---|
| *Food purchasing decisions* | | | | | | | |
| Label info | Likert (7 pt) | Ghvanidze *et al.* (2016) | 26.97 | 8.64 | 64.38 | 4.83 | 2.03 |
| Health claims | Likert (7 pt) | Ghvanidze *et al.* (2016) | 34.13 | 11.48 | 54.40 | 4.39 | 1.99 |
| Quality label | Likert (7 pt) | Lazzarini *et al.* (2016) | 26.83 | 11.92 | 61.25 | 4.69 | 1.93 |
| Organic label | Likert (7 pt) | Lazzarini *et al.* (2016) | 32.49 | 13.71 | 53.80 | 4.41 | 2.00 |
| Environmental label | Likert (7 pt) | Meyerding (2016) | 39.64 | 11.92 | 48.44 | 4.13 | 2.04 |
| *Eating habits* | | | | | | | |
| Regularity of organic food's consumption | Nominal scale | New variable | 38.90 | 16.54 | 44.56 | 3.13 | 1.20 |
| *Perception about organic food's quality* | | | | | | | |
| Organic food is healthier | Likert (7 pt) | Seegebarth *et al.* (2016) | 30.55 | 12.37 | 57.08 | 4.55 | 1.99 |
| Organic food is GMO free | Likert (7 pt) | Seegebarth *et al.* (2016) | 34.43 | 14.46 | 51.12 | 4.40 | 1.97 |
| Organic food is environmentally sustainable | Likert (7 pt) | Mohd Suki (2015) | 31.30 | 14.75 | 53.95 | 4.48 | 2.06 |

[11] The description of the research design is part of the section *Materials and Method* of a paper entitled "Analysis of consumers' perception about quality of organic food", written by Emilia Lamonaca, Barbara Cafarelli, Crescenza Calculli, and Caterina Tricase, and currently under review at Journal of Cleaner Production.
[12] See the Appendix (Section *i. Questionnaire*).

The final survey was pre-tested among 10 respondents and slight revisions to the survey were made on the basis of their recommendations. The research instrument was provided in a web-based format: a link to the survey was distributed to an online panel, which may be considered a representative sample of Italian consumers, regarding gender, age, education, and various geographical representations. The questionnaire was distributed through social media, personal contacts and several e-mail lists, to a panel of respondents who meet the specific sample criteria. The survey was conducted from May to July 2016 in Italy. The theoretical framework was analyzed using R (Project for Statistical Computing).

### *3.1.2. Description of the sample*[13]

The analyzed samples rely upon 672 observations. According to Kline (2011), this sample size is sufficient because there are much more than 10 cases per parameter, considering that the questionnaire consists of 15 items. Table 5 provides the demographic composition of the sample.

**Table 5.** Socio-demographic characteristics of the sample.

| **Socio-demographic variables** | **N** | **%** |
|---|---|---|
| *Gender* | | |
| Male | 242 | 36.0 |
| Female | 430 | 64.0 |
| *Age* | | |
| 18-25 | 128 | 19.0 |
| 26-35 | 247 | 36.8 |
| 36-45 | 149 | 22.2 |
| 46-55 | 98 | 14.6 |
| More than 55 | 50 | 7.4 |
| *Residence area* | | |
| Northern Italy | 64 | 9.5 |
| Center Italy | 64 | 9.5 |
| Southern Italy | 544 | 81.0 |
| *Educational level* | | |
| Primary school | 4 | 0.6 |
| Middle school | 31 | 4.6 |
| Upper secondary school | 210 | 31.3 |
| Bachelor/Master’s degree or equivalent | 427 | 63.5 |
| *Financial situation* | | |
| Difficult | 38 | 5.7 |
| Modest | 154 | 22.9 |
| Discreet | 290 | 43.2 |
| Good | 178 | 26.5 |
| Very good | 12 | 1.8 |
| *Weekly spending for food* | | |
| Lesser than €50 | 96 | 14.3 |
| €50-€100 | 290 | 43.2 |
| €100-€150 | 178 | 26.5 |
| €150-€200 | 73 | 10.9 |
| More than €200 | 35 | 5.2 |

[13] The description of the sample is part of the section *Materials and Method* of a paper entitled “Analysis of consumers’ perception about quality of organic food”, written by Emilia Lamonaca, Barbara Cafarelli, Crescenza Calculli, and Caterina Tricase, and currently under review at Journal of Cleaner Production.

Females constitute more than an half of respondents and the age of the sample ranges from 18 to more than 55, with an average of 30-40 years. As far as concerned educational level, 5.2% of respondents have completed primary and/or middle school, 31.3% have secondary education, and 63.5% have completed university degree. Regarding the financial situation and the weekly spending for food, the sample is very heterogeneous: on average, respondents have a discrete financial situation, with a weekly spending for food ranging between 50 and 100 Euros (Table 5).

*3.1.3.Statistical analysis*

In order to analyze data collected from the online survey, CUB models were fitted with a two-fold purpose of:

- investigating consumers' food purchasing decisions; analyzing to what extent consumers' socio-demographic profile influence their buying behavior;
- investigating consumers' perception about quality of organic food products in terms of healthiness and sustainability, analyzing how the presence of specific label influence the perceived quality, and examine to what extent consumers' socio-demographic profile contributes to their perception about quality.

In this regard, CUB models without covariates in equation (1) were fitted on items related to:

- consumers' food purchasing decisions;
- consumers' perception about healthiness and sustainability of organic food, and the awareness to avoid the consumption of GMOs buying organic food products (GMO free).

In order to evaluate the influence of aspects related to the consumer's background on their purchasing decisions and their perception about quality of organic food, CUB models with covariates in equation (4) were fitted considering socio-demographic and profile characteristics of respondents (i.e. *gender*, *educational level, financial situation* and *weekly spending for food*) as covariates that might influence consumers' perception about quality of organic food. The covariates were given as dummy variables thus; besides *gender*, other covariates were rearranged considering two levels for *educational level* (primary, middle school = 0; upper secondary school, bachelor/master's degree = 1), *financial situation* (difficult, modest, discreet = 0; good, very good = 1) and *weekly spending for food* (<150 € = 0; >150 € = 1).
In order to stress which factors drive consumers' perception about quality of organic food, CUB models with covariates in equation (4) were fitted considering as covariates items related to consumers buying behavior about food (i.e. presence of detailed information on label (*label info*), *health claims*, *quality label*, *organic label*, and *environmental label*). To this end, because these items were measured on a 7 points Likert scale, rates attributed to the items were rearranged as dichotomous variables, considering two level of importance: scores which attribute less importance to items (from 1 to 4 of Likert scale points) were categorized as *low importance*, and scores which assign great importance to items (from 5 to 7 of Likert scale points) were categorized as *high importance*.
For each item, CUB($p$,0) and CUB(0,$q$) models, with $p$=1 or $q$=1 respectively, were implemented in order to select significant covariates for *feeling* and *uncertainty*. For fitted CUB models, the parameters estimate, $\hat{\xi}$ and $\hat{\pi}$, were obtained by means of maximum likelihood estimation (ML), via Expectation-Maximization (EM) algorithm. Inferential issues are fully specified in Piccolo (2006) and they were implemented in package CUB 3.0, available in R environment (Iannario *et al.*, 2016).

*3.1.4.Analysis of consumers' food purchasing decisions*

3.1.4.1.CUB models without covariates

Models in equation (1) are estimated for each item related to consumers' food purchasing decisions, reported in Table 4. Table 6 shows results from fitting CUB(0,0) models on items label info, health claims, quality label, organic label, environmental label.

**Table 6.** Estimated CUB(0,0) models parameters for groups of items.

| Item | $\hat{\xi}$ | $\hat{\pi}$ | *Diss.* |
|---|---|---|---|
| Label info | 0.011* | 0.372* | 0.049 |
| Health claims | 0.192* | 0.208* | 0.054 |
| Quality label | 0.189* | 0.354* | 0.065 |
| Organic label | 0.204* | 0.202* | 0.082 |
| Environmental label | 0.189* | 0.078 | 0.057 |

Note: * indicates *p-values* <0.05.

Estimated values of $\hat{\xi}$ are quite small for all analyzed items, suggesting high levels of *feeling* in responses. In particular, consumers consider the presence of detailed information on products' label as an important attribute, able to drive their food purchasing decisions. Conversely, estimated values of $\hat{\pi}$ suggest a moderate level of *uncertainty* in responses. For each fitted model, values of dissimilarity index are always lower than 0.1, indicating a good fit for estimated CUB(0,0) models (Table 6). As shown in Figure 22, the representation in the parametric space of results in terms of latent component $(1-\xi)$ and $(1-\pi)$ highlights high levels of *feeling/liking* for items related to consumers' food purchasing decisions, as discussed.

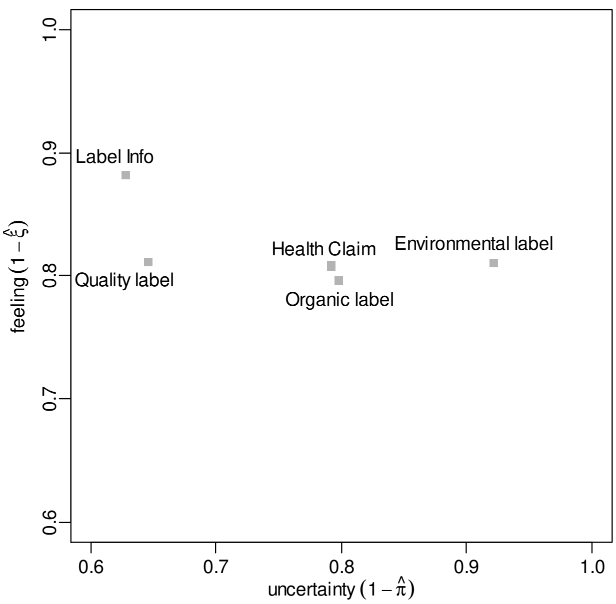


**Figure 22.** Representation in the parametric space of estimated *feeling* and *uncertainty* for groups of items related to *Food purchasing decisions* (left panel) and to *Perception about organic food's quality* (right panel).

As regard items related to consumers' food purchasing decisions, CUB(0,0) models estimate similar levels of *feeling* for almost all attributes, except for the presence of detailed information on label that is the item with the highest *feeling* and the lower *uncertainty* (Figure 22). The other items (i.e. health claims, quality label, organic label, and environmental label) share higher levels of *uncertainty* than item related to the presence of detailed information on label: in particular, the item related to environmental label has the highest level of *uncertainty*, although it does not reach the statistical significance (Table 6). These findings clearly highlight that consumers perceive the presence of detailed information on label of food products more important than the presence of environmental information about food production and of health claims: this may be due to the fact that consumers are more familiar with information on food labels, while it is not common to find environmental labels which are not a legal obligation (Ghvanidze *et al.*, 2016). In addition, the higher *uncertainty* that, *ceteris paribus*, characterizes the presence of environmental label with respect to the presence of health claims, may depend on the fact that health concerns and the consequent decision to consume healthier food products are directly related to health condition of individuals, whereas environmental concerns are impersonal drivers which depend on the degree of awareness of respondents (Ghvanidze *et al.*, 2016).

3.1.4.2. CUB model with socio-demographic variables as covariates

Using four socio-demographic variables as covariates (i.e. *gender*, *educational level*, *financial situation*, and *weekly spending for food*), 20 CUB models concerning respondents' food purchasing decisions were estimated. Table 7 shows only the significant relationships, pointed out by the estimated CUB(1,0) and CUB(0,1) models. Covariate *gender* is significant with respect to $\xi$ for all the items: this indicates that males and females behave differently in scoring the degree of *feeling/liking* of considered attributes. Covariates *educational level* and *financial situation* are significant only for items related to the influence of organic label and environmental label in food purchasing decisions (Table 7). Since covariates under evaluation are significant only for a few aspects with respect to $\pi$ (i.e. label info with covariate *gender*), final CUB models do not take into account them. Besides, non significant effects of the *weekly spending for food* has been found in estimated CUB models for both $\xi$ and $\pi$.

**Table 7.** Results from estimated CUB(1,0) and CUB(0,1) models parameters for groups of items.

| **Item** | **Gender** | | **Educational level** | | **Financial situation** | |
|---|---|---|---|---|---|---|
| | $\xi$ | $\pi$ | $\xi$ | $\pi$ | $\xi$ | $\pi$ |
| Label info | X | X | | | | |
| Health claims | X | | | | | |
| Quality label | | | | | | |
| Organic label | X | | X | | | |
| Environmental label | | | X | | X | |

Note: X indicates a significant covariate effect.

Results from Table 7 highlight that consumers' food purchasing decisions are related to their socio-demographic characteristics, in particular indicating significant differences with reference to *gender* and, although to a lesser degree, to *educational level* and *financial situation*. In this regard, Table 8 shows results of estimated CUB(0,1) models considering only significant covariates.

**Table 8.** Estimated CUB(0,1) models parameters for groups of items, with significant covariates.

| **Item** | **Covariate** | $\hat{\pi}$ | $\hat{\gamma}_0$ | $\hat{\gamma}_1$ |
|---|---|---|---|---|
| Label info | *Gender* | 0.398* | -1.278* | -0.969* |
| Health claims | *Gender* | 0.218* | -0.849* | -1.053* |
| Organic label | *Gender* | 0.210* | -0.648* | -1.319* |
| Organic label | *Educational level* | 0.224* | 5.633* | -3.411* |
| Environmental label | *Educational level* | 0.101* | 5.551* | -3.359* |
| Environmental label | *Financial situation* | 0.096* | 5.340* | -3.335* |

Note: * indicates *p-values* <0.05.

Considering covariate *gender*, negative values of estimated $\hat{\gamma}_1$ suggest increasing *feeling* for females (gender=1) compared with males (gender=0). This evidence is clear in Figure 23, where the estimated distributions for males (solid line) and females (dashed line) respondents are plotted: females' distributions are mainly shifted on the right for any considered items. Females generally confer a greater importance than males in scoring attributes related to food purchasing decisions. In particular males respondents are less health conscious than females respondents, confirming previous findings from Ghvanidze *et al.* (2016).

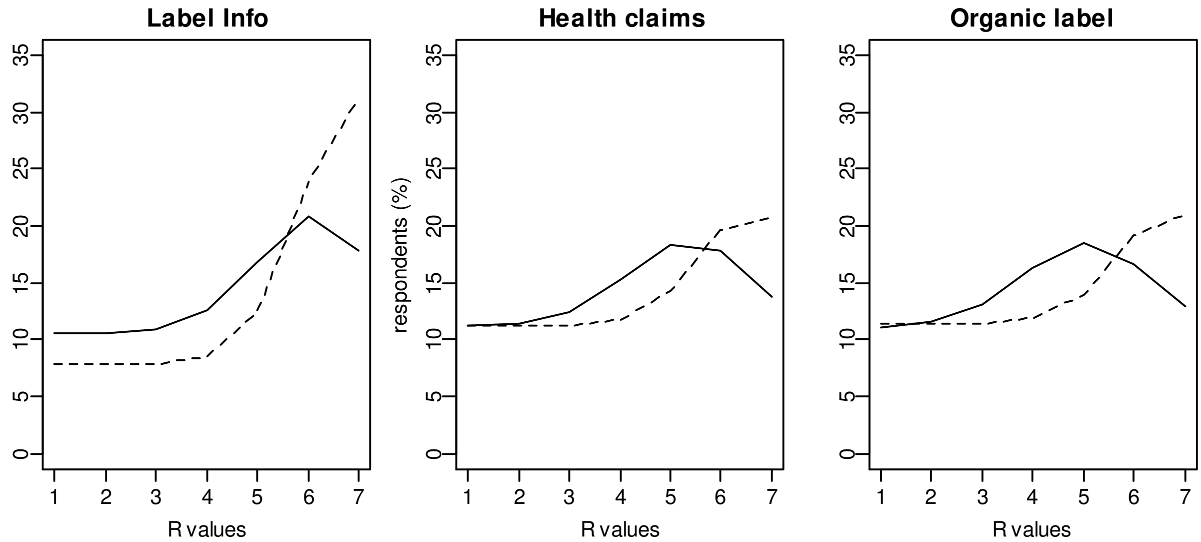


**Figure 23.** Estimated CUB distributions for groups of items related to *Food purchasing decisions* (upper panel) and to *Perception about organic food's quality* (lower panel), with significant effect of covariate *gender* (solid line = males; dashed line = female).

Considering covariate *educational level*, it significantly affect consumers' opinion about the presence of organic label and environmental label. Since estimated $\hat{\gamma}_1$ are negative, high-educated respondents shows increasing *feeling* with respect to low-educated ones. *Feeling* about the presence of environmental label also increases considering respondents with a more suitable financial situation with respect to respondents with a worse financial situation (Table 8). According to Ghvanidze *et al.* (2016), the fact that high-educated consumers with a better financial situation tend to transfer into food purchasing decisions their concerns for environment more than respondents with an opposite profile may depend on economic aspects: it is likely that high-educated consumers are more exposed to face discussions about complex issues, such as the environmental ones, as well as that a better financial situation encourage consumers suited towards environmental causes to support them.

### *3.1.5.Analysis of consumers' perception about quality of organic food*[14]

#### 3.1.5.1.CUB models without covariates

Models in equation (1) are estimated for each item related to consumers' perception about quality of organic food, reported in Table 4. Table 9 shows results from fitting CUB(0,0) models on items healthiness, GMO free, and sustainability.

[14] Results of the analysis of consumers' perception about quality of organic food is part of the section *Results and discussion* of a paper entitled "Analysis of consumers' perception about quality of organic food", written by Emilia Lamonaca, Barbara Cafarelli, Crescenza Calculli, and Caterina Tricase, and currently under review at Journal of Cleaner Production.

**Table 9.** Estimated CUB(0,0) models parameters for items related to consumers' perception about quality of organic food.

| Item | $\hat{\xi}$ | $\hat{\pi}$ | *Diss.* |
|---|---|---|---|
| Healthiness | 0.170* | 0.264* | 0.050 |
| GMO free | 0.085* | 0.154* | 0.024 |
| Sustainability | 0.178* | 0.218* | 0.055 |

Note: * indicates *p-values* <0.05.

Estimated values of $\hat{\xi}$ are quite small for all analyzed items, suggesting high levels of *feeling* in responses: consumers attribute high levels of importance in rating items related to perceived quality of organic food. Conversely, estimated values of $\hat{\pi}$ suggest a moderate level of *uncertainty* in responses. For each fitted model, values of dissimilarity index are always lower than 0.1, indicating a good fit for estimated CUB(0,0) models (Table 9). Figure 24 shows the representation in the parametric space of results in terms of latent component $(1-\xi)$ and $(1-\pi)$, highlighting high levels of *feeling/liking* for items related to consumers' perception about quality of organic food, as discussed.

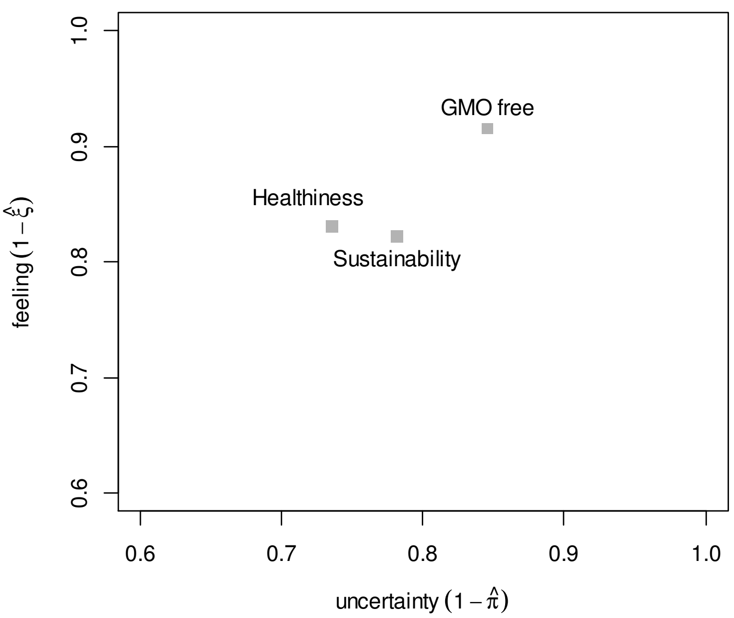


**Figure 24.** Representation in the parametric space of estimated *feeling* and *uncertainty* for items related to consumers' perception about quality of organic food.

As shown in Figure 24, the item related to the awareness to avoid the consumption of GMOs buying organic food products shows the highest *feeling*, although it has also the highest value of *uncertainty* with respect to the other items (i.e. healthiness and sustainability). This finding indicates that for consumers it is obvious perceiving organic food as food free from harmful contents (Lee and Yun, 2016), such as GMOs. The items related to the perception of organic food as healthier and the sustainable are considered less important in terms of *feeling*, but they present lower levels of *uncertainty*. This is not surprisingly since for consumers it is sufficient that a food product is organic to influence their perception about its superior quality, for instance, as regard its healthfulness and/ sustainability with respect to methods of production (e.g., Prada *et al.*, 2016; Lee *et al.*, 2013). In addition, the higher *uncertainty* that, *ceteris paribus*, characterizes the perception of sustainability of organic food with respect to their healthiness, may depend on the fact that health concerns and the consequent decision to consume healthier food products are directly related to health condition of individuals, whereas environmental concerns are impersonal drivers which depend on the degree of awareness of respondents (Ghvanidze *et al.*, 2016).

3.1.5.2. CUB models with socio-demographic variables as covariates

Using four socio-demographic variables as covariates (i.e. *gender*, *educational level*, *financial situation*, and *weekly spending for food*), 12 CUB models concerning consumers' perception about quality of organic food were estimated. Table 10 shows only the significant relationships, pointed out by the estimated CUB(1,0) and CUB(0,1) models. Covariate *gender* is significant with respect to $\xi$ for all the items concerning consumers' perception about quality of organic food: this indicates that males and females behave differently in scoring the degree of *feeling/liking* of considered attributes (Table 10). Since covariates under evaluation are significant only for a few aspects with respect to $\pi$ (i.e. GMO free with covariate *educational level*), final CUB models do not take into account them. Besides, non-significant effects of the *weekly spending for food* has been found in estimated CUB models for both $\xi$ and $\pi$.

**Table 10.** Results from estimated CUB(1,0) and CUB(0,1) models parameters for items related to consumers' perception about quality of organic food, with socio-demographic variables as covariates.

| Item | Gender | | Educational level | | Financial situation | |
|---|---|---|---|---|---|---|
| | $\xi$ | $\pi$ | $\xi$ | $\pi$ | $\xi$ | $\pi$ |
| Healthiness | X | | | | | |
| GMO free | X | | | X | | |
| Sustainability | X | | | | | |

Note: X indicates a significant effect of covariate.

Results from Table 10 highlight that consumers' perception about quality of organic food is related to their socio-demographic characteristics, in particular indicating significant differences with reference to *gender*. This finding is in line with previous researches, indicating how consumer characteristics are determinant in influencing consumers' perception and consequent buying behavior (Hsu and Chen, 2014; Hsu *et al.*, 2012). Table 11 shows results of estimated CUB(0,1) models considering only significant covariates.

**Table 11.** Estimated CUB(0,1) models parameters for items related to consumers' perception about quality of organic food, with significant covariates[†].

| Item | Covariate | $\hat{\pi}$ | $\hat{\gamma}_0$ | $\hat{\gamma}_1$ |
|---|---|---|---|---|
| Healthiness | *Gender* | 0.271* | -1.135* | -1.135* |
| GMO free | *Gender* | 0.188* | -0.858* | -1.837* |
| Sustainability | *Gender* | 0.233* | -0.853* | -0.978* |

[†] For each covariate, two levels of importance are assumed: 0 = *male* and 1 = *female*.
Note: * indicates *p-values* <0.05.

Considering covariate *gender*, negative values of estimated $\hat{\gamma}_1$ suggest increasing *feeling* for females (gender=1) compared with males (gender=0). This evidence is clear in Figure 25, where the estimated distributions for males and females respondents are plotted: females' distributions are mainly right shifted for any considered items showing a propensity to choose ratings from the end of the evaluation scale.

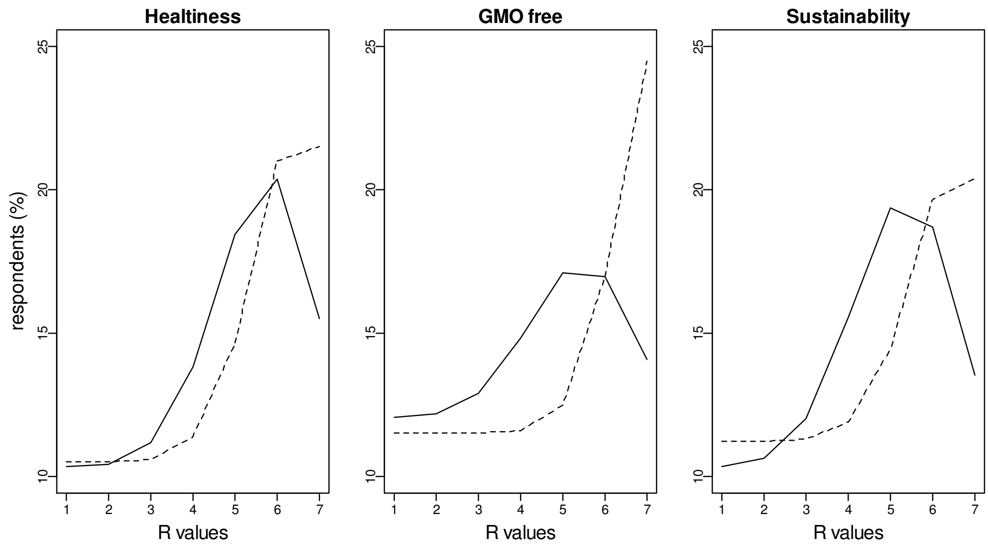


**Figure 25.** Estimated CUB distributions for groups of items related to *Food purchasing decisions* (upper panel) and to *Perception about organic food's quality* (lower panel), with significant effect of covariate *gender* (solid line = males; dashed line = female).

Females generally confer a greater importance than males in scoring attributes related to perception about quality of organic food. In particular females respondents exhibit higher concerns for environment, as also demonstrated in Ghvanidze *et al.* (2016) and Hunter *et al.* (2004); conversely males respondents are less health conscious than females respondents, confirming previous findings from Ghvanidze *et al.* (2016).

3.1.5.3. CUB models with drivers of purchasing decisions as covariates

For each item related to consumers' perception about quality of organic food, CUB(0,1) models were estimated using items that might affect consumers food purchasing decisions, as covariates. Since none of covariates under evaluation is significant with respect to $\pi$, Table 12 reports results from estimated CUB(0,1) models.

**Table 12.** Estimated CUB(0,1) models parameters for items related to consumers' perception about quality of organic food, with items related to food purchasing decisions as covariates[†].

| Item | Covariate | $\hat{\pi}$ | $\hat{\gamma}_0$ | $\hat{\gamma}_1$ |
|---|---|---|---|---|
| Healthiness | Label info | 0.476* | 4.794* | -3.151* |
| | Health claims | 0.429* | 4.511* | -3.084* |
| | Quality label | 0.462* | 4.845* | -3.179* |
| | Organic label | 0.537* | 4.222* | -2.890* |
| | Environmental label | 0.356* | 4.372* | -3.049* |
| GMO free | Label info | 0.384* | 5.530* | -3.694* |
| | Health claims | 0.425* | 4.468* | -3.171* |
| | Quality label | 0.399* | 5.517* | -3.646* |
| | Organic label | 0.444* | 4.913* | -3.367* |
| | Environmental label | 0.332* | 4.867* | -3.437* |
| Sustainability | Label info | 0.416 * | 5.032* | -3.218* |
| | Health claims | 0.417* | 3.996* | -2.785* |
| | Quality label | 0.436* | 4.907* | -3.161* |
| | Organic label | 0.456* | 4.284* | -2.912* |
| | Environmental label | 0.375* | 4.223* | -2.933* |

[†] For each covariate, two levels of importance are assumed: 0 = *low importance* and 1 = *high importance*.

Note: * indicates *p-values* <0.05.

All covariates are significant with respect to $\xi$ for items representing the consumers' perception about quality of organic food. In particular, since all $\hat{\gamma}_1$ are negative, the higher the level of importance, that respondents attribute to the presence of specific labels on food products, the higher the *feeling* related to consumers' perception about quality of organic food, in terms of healthiness, awareness to avoid the consumption of GMOs, and sustainability, compared to those who consider these issues less important.

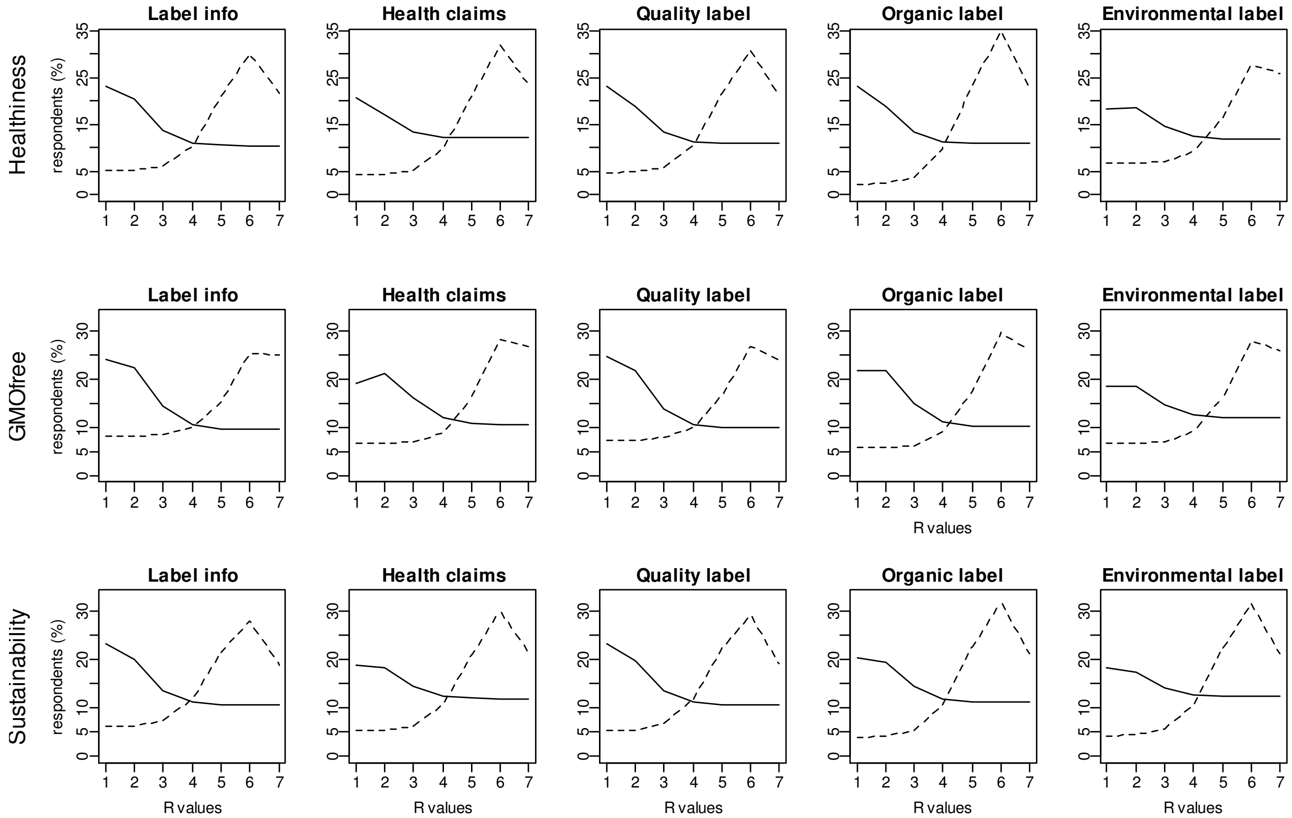


**Figure 26.** Estimated CUB distributions for items related to *Perception about organic food's quality*[†], with items related to *Food purchasing decisions*[††] as covariates, considering two levels of assumed importance for covariates (solid line = low importance, dashed line = high importance).

[†] Items related to *Perception about organic food's quality* are healthiness, GMOs free, and sustainability.

[††] Items related to *Food purchasing decisions* are the presence of detailed information on label, health claims, quality label, organic label, environmental label.

As shown in Figure 26, for each item related to consumers' perception about quality of organic food the estimated distributions are clearly different, for all considered covariates, between respondents that attribute a low level of importance and respondent that attribute a high level of importance to items under judgment: for respondents that attribute high level of importance to considered items, the estimated distributions are always right shifted. These findings clearly highlight that consumers that attribute high importance to the presence of information related to quality on label of food products show the tendency to perceive organic food of higher quality, especially in terms of healthiness and sustainability: this may be due to the fact that modern consumers are more familiar with information on food labels and are used to consult them (Ghvanidze *et al.*, 2016).

## 3.2. LCA of barley supply chain

### *3.2.1. Goal and scope definition*[15]

The study discussed in this paper regards a comparative LCA between organic and conventional farming systems for production of winter barley, to highlight the most favourable option in terms of environmental sustainability and productive efficiency. For greater understanding, it is specified that the study is focussed just upon the cultivation phase, because it represents the essential first stage in the supply chain of any barley-derivate food. In addition, it is expected to cause significant environmental impacts that need to be addressed and reduced to contribute, in turn, to the reduction of the downstream impacts, so enabling both implementation and development of cleaner barley supply chains.

#### 3.2.1.1. Functional Units

According to the International Standards (ISO 2006, a,b), it is important to operate an accurate choice of the Functional Unit (FU). From a theoretical point of view, a FU is defined as a measure of a system's performance (Krozer and Vis, 1998), that can be described through a collection of unit processes performing a well-defined function (ISO, 2006a). In agricultural LCAs, crop production could be considered and so modelled as land-oriented or product-oriented. The former, which is generally used in agricultural LCAs, corresponds to the use of a land area FU (e.g. 1 ha), whereas the latter, which is frequent in product LCAs, corresponds to the use of a product mass FU (e.g. 1 kg). With a land-based FU, inputs are materials and outputs include both products and environmental impacts whereas, with a mass-based FU, inputs include materials and land (invested for cultivation), and outputs are only environmental impacts (Hayashi, 2013).
A land-based FU represents the land management function of agriculture (Hayashi, 2013; Cerutti *et al.*, 2013; Nemecek *et al.*, 2011). Although it does not provide a productive function, land-based FU can provide remarkable results with respect to mass-based FU, because it allows the comparison between low and high input/output systems (Cerutti *et al.*, 2013). A mass-based FU is suitable for the evaluation of activities and phases comprised within an agro-food product's life cycles, and allows the assessment of differences in efficiency in production and sustainability of land use (Fedele *et al.*, 2014; Hayashi, 2013; van der Werf *et al.*, 2007; Brentrup *et al.*, 2004).
The comparative LCA discussed in this paper relies upon the use of the two different FUs to show whether and how they affect the final results, allowing a comprehensive and more in-depth interpretation of them. As a consequence, the environmental impacts will be related to the management of both 1 ha of land invested for barley cultivation and 1 kg dry-matter (DM) barley grain produced at the farm's gate. This is in agreement with other studies carried out in the agricultural field: for instance, Aguilera *et al.* (2015) used 1 ha and 1 kg FUs for LCA of organic versus conventional cereals and legumes; Cerutti *et al.* (2013) and Nemecek *et al.* (2011) used land-based, mass-based FUs for LCA of ancient apple and barley respectively.
The International Standards (ISO, 2006a,b) were followed duly to make the comparison accurate and consistent with the aim and scope of the study: in particular, the comparative assessment of the two barley cultivation systems (conventional and organic) was based upon equivalent methodological assumptions, and was conducted on the same FU basis.

#### 3.2.1.2. System boundaries

System boundary defines unit processes that a specific LCA study has to include for the assessment of the environmental impacts (ISO 2006a,b). In this study, as a standard procedure in agricultural LCAs, system boundary was defined as to include all the agricultural activities specifically required to produce barley in a

[15] The description of goal and scope definition is part of the section *Materials and methods* of a paper entitled "A comparative Life Cycle Assessment between organic and conventional barley cultivation for sustainable agriculture pathways", written by Caterina Tricase, Emilia Lamonaca, Carlo Ingrao, Jacopo Baceneti, and Agata Lo Giudice, and currently under review at Journal of Cleaner Production.

from-cradle-to-farm-gate perspective. The phases of product distribution, processing and consumption were excluded because they were considered as outside of the focus and scope of the study.

Equivalent system boundaries were considered for the comparative assessment: the two involved farms follow almost the same agricultural procedures for cultivation of barley, except for the difference in the establishment phase relying upon the utilisation of organic and synthetic fertilisers. The considered field related processes for both organic and conventional barley cultivation systems were split up into three main steps: seedbed preparation, establishment, external control agents, and finalization (Tricase *et al.*, 2016; Niero *et al.*, 2015a). Seedbed preparation involves processes of ploughing and harrowing for conventional barley cultivation, to which rolling process is added for organic production. Establishment refers to sowing, and to the phases of: compost spreading for organic system and plant protection application and chemical fertilising for conventional farming. Finalisation involves the steps of combine harvesting, bailing, and loading of bales (Dijkman *et al.*, 2016; Niero *et al.*, 2015a; Fedele *et al.*, 2014).

The land invested in barley cultivation was considered as part of the product system, inasmuch it is a resource: each crossing substance is treated as an emission to the environment (Dijkman *et al.*, 2016; Dijkman *et al.*, 2012). Emissions in air of ammonia ($NH_3$) and dinitrogen monoxide ($N_2O$) were considered as impacting on human health (HH), climate changes (CC) and ecosystem quality (EQ). Amongst the inputs, depending upon the production regime, organic or conventional barley seeds as well as natural or chemical fertilisers were accounted for and included in system boundaries. For conventional cultivation system, also pesticides were included in the system boundaries, due to their widespread use in conventional agriculture (Fedele *et al.*, 2014; Hokazono and Hayashi, 2012; Roer *et al.*, 2012). Neither organic nor conventional system boundaries do include irrigation process, because barley cultivation is rain-fed and additional water is not required subsequently (Tricase *et al.*, 2016; Fedele *et al.*, 2014).

Figure 27 represents system boundaries for typical annual barley cultivation both in organic and conventional farming. Main inputs and outputs as well as transport flows were depicted in the Figure.

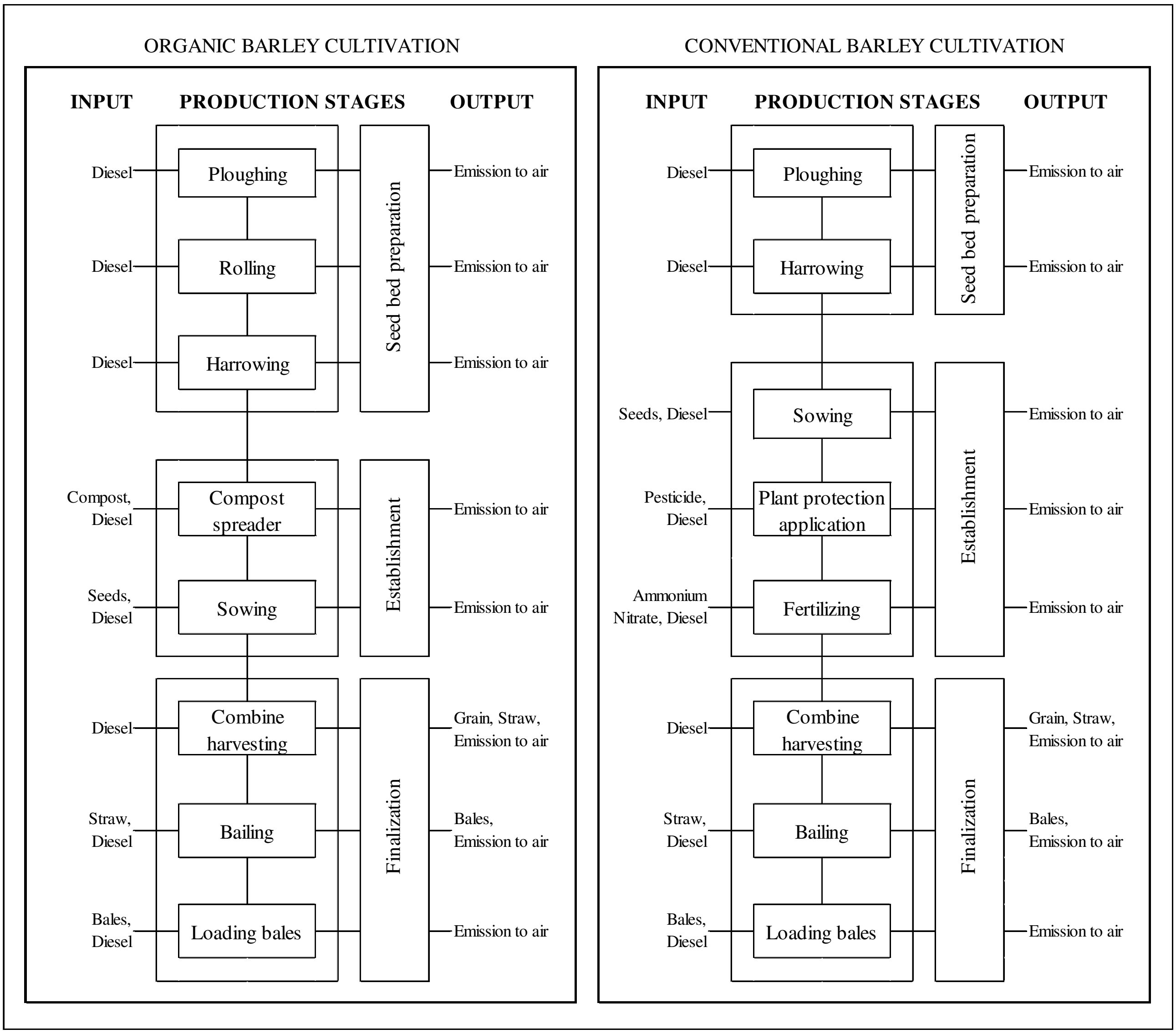


**Figure 27.** System boundary for organic and conventional barley production.

### 3.2.1.3. Allocation procedure

Because from an economic point of view a relevant by-product of barley production is straw, ascribing all impacts only to barley grain would be misleading. Thus, it is reasonable to apply an economic allocation for either of considered cultivation systems, so complying with related studies, such as Dijkman *et al.* (2016) and Ardente and Cellura (2012). Doing so allowed to take into account different straw's usage pathways and to consistently allocate the environmental impacts with respect to the aim and scope of the study.
The allocation considers annual average prices, available in specific national databases[16]. Prices are expressed as €/t of product deriving from barley cultivation (i.e. grains and straw) in both of considered cultivation regimes. Grain price in Italy is typically between 175.10 €/t and 177.10 €/t for conventional barley, and between 276.10 €/t and 281.10 €/t for organic barley. Straw price in Italy is 51.26 €/t for conventional barley, and between 79.60 €/t and 82.60 €/t for organic barley (Associazione Granaria di Milano, 2016). Average price values were computed between minimum and maximum and, then, combined with a mass ratio that was estimated for both harvested grains and straw with respect to the gross barley

[16] The databse of Associazione Granaria di Milano were choosen because it involves prices that may be considered as average prices applied to grains and straw at farm gate, at national level.

cultivation yield. Yield of barley was constituted by grains for 48% and by straw for the remaining 52%[17]. For both cultivation systems, the allocation factors are equal to: 76% for barley grain; and 24% for barley straw. They, were computed as:

$$AF_g = \frac{(Q_g * P_g)}{(Q_g * P_g) + (Q_s * P_s)} \quad (6)$$

and

$$AF_s = \frac{(Q_s * P_s)}{(Q_g * P_g) + (Q_s * P_s)} \quad (7)$$

where $AF_g$ and $AF_s$ are the allocation factors for grain and straw, expressed as percentage; $Q_g$ and $Q_s$ are the produced tonnes of barley grain and straw, respectively; and $P_g$ and $P_s$ represent the prices of barley grain and straw, respectively.

For completeness reasons, Figure 28 shows all the economic allocation process as well as the values obtained.

[17] These percent values were extrapolated from the production data provided by the two farms involved and resulted to be the same for both conventional and organic cultivation systems.

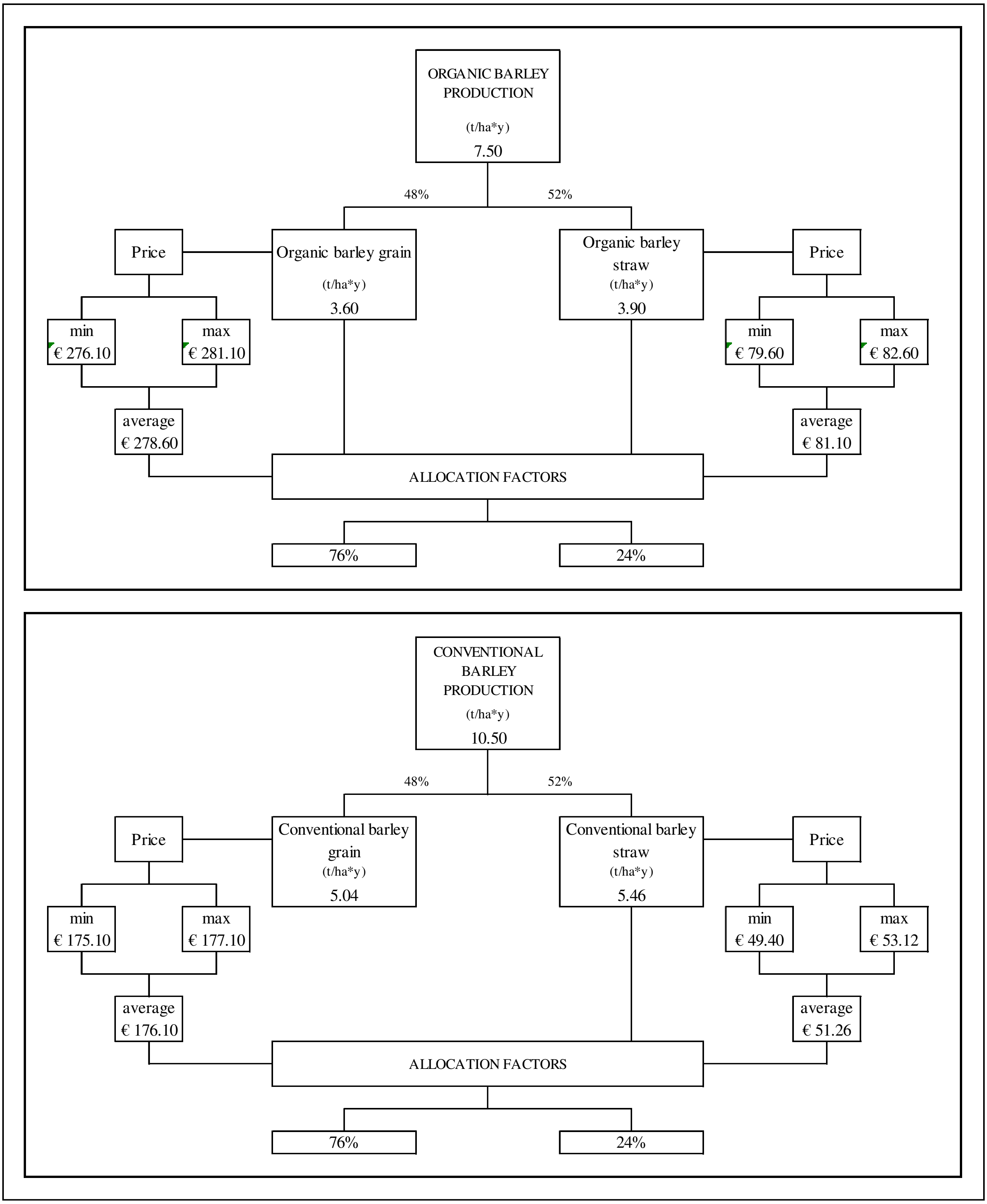


**Figure 28.** Process of economic allocation between barley products.

### *3.2.2.LCI*[18]

A detailed check list for data collection, referred to the annual farms' activity, were drafted and specifically implemented for each of the two farms that were positively involved in providing the data required for the study development. Same was done by other authors such as, for instance, Fedele *et al.* (2014) and Mourad *et al.* (2007). Check list includes questions related to agricultural procedures and auxiliary processes, as well as input materials and fuels (e.g. seeds, compost, fertilisers, pesticides, fuels), required for barley cultivation in organic and conventional farming. A specific section for transports was included in the check list to provide information about geographical positioning of suppliers, distances between suppliers and farms, type and characteristics of vehicle. Data were collected thanks to collaboration of managers of the two farms, farmers, and to technical support of an agronomist. Interviews took place in May 2014, when production of the last year was in progress. The study started in June 2014, after the harvesting activities for barley, and took into account the annual production values (expressed as kg/ha*y), computed as an arithmetic average on a time span of three years (since 2012 until 2014). According to the International Standards (ISO, 2006a,b), the inventory data are representative and consistent in terms of time-related and geographical coverage. Additionally, data referred to input raw materials are comparable in terms of distance between suppliers and farms.

Finally, SimaPro v.7.3.3 (SimaPro, 2006) was used and the Ecoinvent v.2.2 database was accessed for the modelling of the systems investigated (Ecoinvent, 2010).

#### 3.2.2.1. Data collection and modeling

For development of this phase, as a well-standardised practice in LCA development, input and output flows were analysed using both site-specific data supplied by the local farmers (primary data) and background data extrapolated from Ecoinvent v.2.2 (secondary data). Primary data were used to best model the two cultivation systems, considering their strong interconnectedness with the local territories. Data related to input material's typologies and amounts were collected and recorded during in-depth interviews with farm managers and agronomists. Secondary data were considered in this analysis because of the lack of complete information related to the investigated systems. The Ecoinvent database was chosen, due to the scientific importance and reliability of such international data source (Ingrao *et al.*, 2015). Ecoinvent v.2.2 models were used to shape: the extraction of resources and the production of raw materials (i.e. organic and conventional barley seeds, compost, pesticides and fertilisers); the consumption of energies (electricity and fuels) involved in the performed agricultural activities; the usage of transport means, agricultural machinery and other equipment.

As also done in other researches on the issue of barley cultivation LCA (Niero *et al.*, 2015a; Hamelin *et al.*, 2012; Nemecek *et al.*, 2007), data for the agricultural operations, as defined in the system boundaries (e.g. ploughing; rolling; harrowing; compost, fertiliser, and pesticide application; sowing; harvesting; bailing and loading bales) were extrapolated from the Ecoinvent v.2.2 database. In second instance, those data were adjusted on the base of values supplied by the involved farms, in order to carry out a robust assessment in compliance with the case studies (Niero *et al.*, 2015a; Roer *et al.*, 2012).

The main distinction between organic and conventional barley cultivation stands in the different fertilisers utilised and in the administration manners: fertilising activity in conventional farming regards chemical fertilisation, while in organic farming it refers to spreading of compost.

The section below reports a discussion about nitrogen-based emissions resulting from fertiliser administration in either of considered cultivation regimes.

[18] The description of LCI is part of the section *Materials and methods* of a paper entitled "A comparative Life Cycle Assessment between organic and conventional barley cultivation for sustainable agriculture pathways", written by Caterina Tricase, Emilia Lamonaca, Carlo Ingrao, Jacopo Baceneti, and Agata Lo Giudice, and currently under review at Journal of Cleaner Production.

#### 3.2.2.2. Calculation of N-based emissions from fertilization

Organic barley contains approximately the 2.5% of nitrogen (N) (Masoni and Pampana, 2003), which is generally divided between grains (1.9%) and straw (0.6%), as documented by Schmidt Rivera *et al.* (2016). By applying those percentages to organic-barley production data, the total amount of removed N for organic barley (including both grain and straw) is equal to 91.8 kg of N per ha. Considering the little amount of grains that may be lost during the transportation and the straw that may be wasted during the harvesting, the total amount of removed N for both grain and straw was increased by 10% as a precautionary measure, so being in line with Schmidt Rivera *et al.* (2016) and Baldoni and Giardini (2000): by doing so, the N requirement for organic barley plant levelled out at 100.98 kg/ha. Considering that compost (with 50% of moisture), applied for organic barley fertilisation, contains approximately 7 kg of N per t of compost (Centemero, 2002; Brentrup *et al.*, 2000), for organic barley cultivation an amount of compost equal to 14.426 t/ha is required to be administered. Adopting a "substitution approach", the application of this amount of compost allows farm to avoid production and usage of 288.51 kg of ammonium nitrate ($NH_4NO_3$), obtained following the procedures reported in Brentrup *et al.* (2000).

Emissions resulting from administration of chemical fertiliser in conventional faming system was estimated following the calculation procedure contained in Brentrup *et al.* (2000). Process for external control agents includes the application of generic pesticides, as stated by farm that produces in conventional regime. In accordance with Niero *et al.* (2015a) and Sutter (2010), data on pesticide production were taken from Ecoinvent v.2.2 and the applied dosages were adjusted basing on farm values.

Table 13 reports a summary of inventory flows, as well as a brief description of the involved activities. Data for unit process were referred to both to 1 ha of cultivation area and 1 kg of barley grain production; following the allocation criterion used, they were also referred to 1.083 ha of cultivation area and of 1.1 kg of barley straw production basing upon economic allocation procedure.

**Table 13.** Main input inventory-data related to the production of organic and conventional barley, using different F.U.

| Input flow | FU 1 ha of grain and 1.083 ha of straw | | | FU 1 kg of grain and 1.1 kg of straw | | | Comment upon the use of the related module available in Ecoinvent v.2.2 (Ecoinvent, 2011) | Remarks |
|---|---|---|---|---|---|---|---|---|
| | Physic amount | | Measure unit | Physic amount | | Measure unit | | |
| | ORGANIC | CONVENTIONAL | | ORGANIC | CONVENTIONAL | | | |
| *Resources* | | | | | | | | |
| Occupation, arable, non-irrigated | 2.083 | 2.083 | ha*y | 2.780E-4 | 1.900E-4 | ha*y | | |
| Transformation, from arable, non-irrigated | 2.083 | 2.083 | ha | 2.780E-4 | 1.900E-4 | ha | | |
| Transformation, to arable, non-irrigated | 2.083 | 2.083 | ha | 2.780E-4 | 1.900E-4 | ha | | |
| Energy, gross calorific value, in biomass | 113,325 | 157,080 | MJ | 31.47 | 31.420 | MJ | | |
| Carbon dioxide ($CO_2$), in air | 9.750 | 13.520 | t | 2.710 | 2.705 | kg | | |
| *Raw materials and fossil fuels* | | | | | | | | |
| Organic barley seeds | 416.6 | - | kg | 0.056 | - | kg | The seed produced at the farm is transported to the processing centre, treated (pre-cleaning, cleaning, eventually drying, and bag filling), stored and afterwards transported to the regional storage centre. | Chemical dressing is not included |
| Conventional barley seeds | - | 364.53 | kg | - | 0.035 | kg | No data on wastewater production were available. The reference is 1 kg of barley seed (fresh weight), with a maximum water content of 15%. | Chemical dressing is included |
| Compost, at plant | 14.426 | - | t | 1.923 | - | kg | Energy demand for operating a compost plant was included as well as process emissions, infrastructure of the compost plant and transports related to the collection of the biogenic waste. Values refer to compost with a water content of 50% by weight. Compost inventory refers 1 kg fresh weight of compost. | |
| Ammonium nitrate, as N | - | 520.750 | kg | - | 0.050 | kg | The unit process inventory takes into account the production of ammonium nitrate from ammonia and nitric acid. Transports of the intermediate products to the fertiliser plant as well as the transport of the fertiliser product from the factory to the | It refers to 1 kg N, resp. 2.86 kg ammonium nitrate with a N-content of 35.0%. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | regional storehouse are included. Production and waste treatment of catalysts, coating and packaging of the final fertiliser products were not included. Infrastructure was included by means of a proxy module. | |
| Pesticide | - | 2.190 | kg | - | 1.000E-4 | kg | Production of pesticides including materials, energy uses, infrastructure and emissions. | |
| *Main processes and phases* | | | | | | | | |
| Ploughing | 2.083 | 2.083 | ha | 2.780E-4 | 2.000E-4 | ha | | Four-furrow plough. |
| Rolling | 2.083 | - | ha | 2.780E-4 | - | ha | | Rolling, working width 3 m. |
| Harrowing | 2.083 | 2.083 | ha | 2.780E-4 | 2.000E-4 | ha | The inventory takes into account the diesel fuel consumption and the amount of agricultural machinery and of the shed, which has to be attributed to the single activity. Also, taken into consideration is the amount of emissions to the air from combustion and the emission to the soil from tire abrasion during the work process. The following activities where considered part of the work process: preliminary work at the farm, like attaching the adequate machine to the tractor; transfer to field (with an assumed distance of 1 km); field work (for a parcel of land of 1 ha surface); transfer to farm and concluding work, like uncoupling the machine. The overlapping during the field work is considered. Not included are dust other than from combustion and noise. | Rotary harrow, working width 3 m. |
| Sowing | 2.083 | 2.083 | ha | 2.780E-4 | 2.000E-4 | ha | | Seeder, working width 3 m, seed not included. |
| Compost spreading | 14.426 | - | t | 1.923 | - | kg | | |
| Application of plant protection products, by field sprayer | - | 2.083 | ha | - | 4.000E-4 | ha | | |
| Fertilising, by broadcaster | - | 2.083 | ha | - | 2.000E-4 | ha | | |
| Combine harvesting | 2.083 | 2.083 | ha | 2.780E-4 | 2.000E-4 | ha | | Combine harvesting, working width 4.5 m, grain production and straw treatment not included. |
| Baling | 11.580 | 16.460 | p | 0.002 | 0.002 | p | | Round baler for round bales of 1.4 $m^3$, silage with wrapping foil, 700 kg. Time need for baling |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Loading bales | 11.580 | 16.460 | p | 0.002 | 0.002 | p | | and wrapping, without loading and transport. Wrapping foil (PE-film) included, fodder production and cutting not included. Loading of straw bales with bale gripper onto trailer. Without transport to farm and discharging, straw production not included. |
| *Transports* | | | | | | | | |
| Transport, lorry 7.5-16 t, euro 4 | 270.790 | - | t*km | 36.140 | - | kg*km | | Organic barley seeds transport |
| Transport, lorry 3.5-7.5 t, euro 5 | 1426.000 | - | t*km | 192.300 | - | kg*km | Included processes are operation of vehicle; production, maintenance and disposal of vehicles; construction and maintenance and disposal of road. Inventory refers to the entire transport life cycle. | Compost transport |
| Transport, lorry 3.5-7.5 t, euro 5 | - | 255.170 | t*km | - | 24.500 | kg*km | | Conventional barley seed transport |
| Transport, van <3.5 t | - | 26.150 | t*km | - | 2.505 | kg*km | | Pesticide and fertilising transport |
| *Emissions to air* | | | | | | | | |
| Ammonia ($NH_3$) | 0.452 | 3.645 | kg | 0.060 | 0.350 | g | Emissions computed following Bentrup et al. (2000). | |
| Dinitrogen monoxide ($N_2O$) | 1.262 | 2.233 | kg | 0.168 | 0.214 | g | | |

### *3.2.3.LCIA and interpretation*

The resulting flows, quantified within inventory analysis, were aggregated into a limited set of damage and impact categories (ISO, 2006a; De Benedetto and Klemeš, 2009; Suh and Huppes, 2005). The LCIA was elaborated according to the International Standards (ISO, 2006a,b) and so included two mandatory steps, namely classification and characterisation of the output inventories into damage and impact categories, and two optional steps, namely normalisation and weighing of results with respect to a common reference. According to Ingrao *et al.* (2015) and Joillet *et al.* (2003), the categorisation of damages and impacts used for the assessment is the one following the scheme provided by Impact 2002+. Next sections presents results of mandatory steps of LCIA (i.e. classification and characterization) for the comparison between organic and conventional cultivation system of barley, and for each farming system (i.e. organic cultivation of barley and conventional cultivation of barley). The appendix (Section II, sub-Section *i. Comparison between organic and conventional barley cultivation*, *ii. Organic barley cultivation*, and *iii. Conventional barley cultivation*) shows results of optional steps of LCIA (normalization and weighting) for comparison between organic and conventional cultivation system of barley, and for each farming system.
Interpretation combines together findings from LCI and LCIA, to obtain conclusions and recommendations consistent with the goal and scope of this study (De Benedetto and Klemeš, 2009; ISO, 2006a).

#### 3.2.3.1.Comparison between organic and conventional barley cultivation[19]

Figures 29 and 30 show the environmental impacts related to barley cultivation, making a comparison between organic and conventional farming. In Figure 29 the environmental impacts refer to land-based FU (1 ha of land for grain and 1.083 ha of land for straw), they are expressed as weighing points (pt) and classified by damage categories (namely HH, EQ, CC, R). From the figure, it is straightforward that barley production is more impacting under a conventional farming system rather than an organic one. In Figure 30 the environmental impacts refer to mass-based FU (1 kg of grain and 1.1 kg of straw), they are expressed as weighing points (pt) and classified by damage categories (namely HH, EQ, CC, R): referring to a mass-based FU, results become reversed. Basing upon Figure 30, there is evidence that organic production is more impacting than the conventional one.

[19] The description of the comparison between organic and conventional barley cultivation is part of the section *Results and siscussion* of a paper entitled "A comparative Life Cycle Assessment between organic and conventional barley cultivation for sustainable agriculture pathways", written by Caterina Tricase, Emilia Lamonaca, Carlo Ingrao, Jacopo Baceneti, and Agata Lo Giudice, and currently under review at Journal of Cleaner Production.

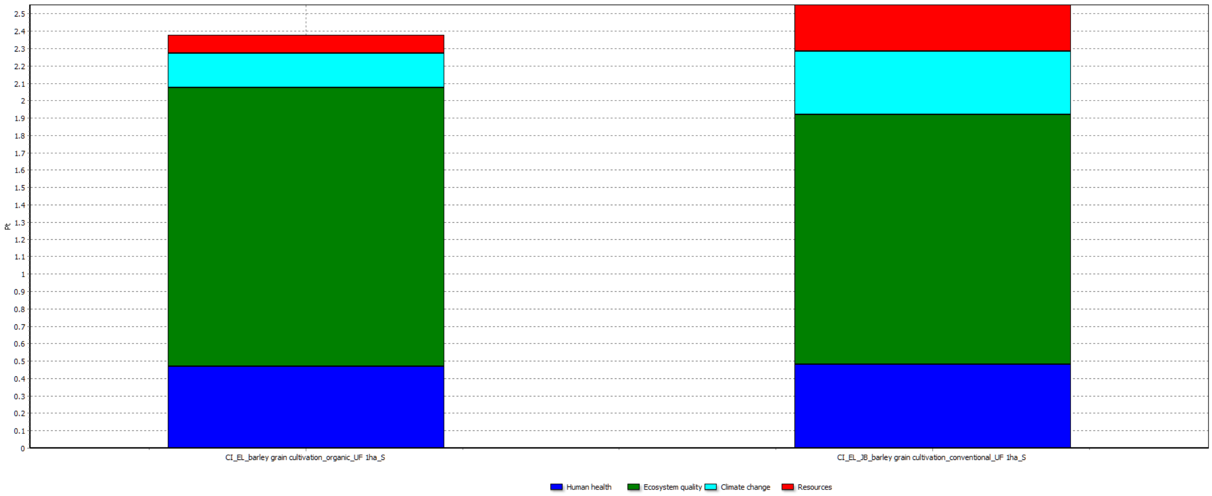


**Figure 29.** Comparison between organic and conventional barley cultivation processes (with reference to 1 ha FU) and related caused-damages (weighing points).

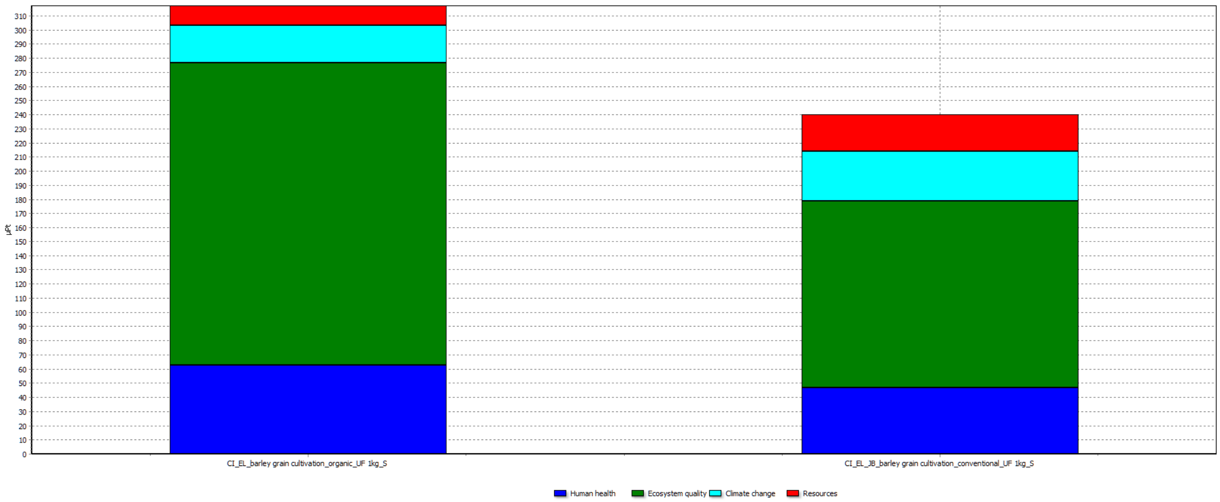


**Figure 30.** Comparison between organic and conventional barley cultivation processes (with reference to 1 kg FU) and related caused-damages (weighing points).

Table 14 compares total damages related to barley cultivation in organic and conventional farming, using both land-based and mass-based FUs. For both 1 ha FU and 1 kg FU, total damages related to the two farming systems are equal to the sum of damages related to each category (namely HH, EQ, CC, R), provided by Impact 2002+. Each damage category is expressed as percentage, weighing point (pt), and damage assessment value, computed by using conversion factors specifically assigned in Impact 2002+. When the analysis relies upon the land-based FU, conventional barley cultivation has a total damage equal to 2.55 pt, compared to 2.33 pt of organic barley cultivation. When the analysis relies upon the mass-based FU, the total damage related to organic barley cultivation is 3.103E-4 pt, with respect to 2.40E-05 pt as calculated for conventional barley cultivation. It should be observed that the difference in magnitude of the total damages is much greater when 1 kg is the FU rather than in the case of 1 ha being the FU: using a mass-based FU causes the amplification of environmental impacts, because of high differences between the two farming systems in yields of production of barley. Although the choice of the FU affects the results enough to overturn them, it emerges a common finding: in accordance with Fedele *et al.* (2014), for two damage categories (CC and R) the conventional cycle results in greater impact than the organic cycle. Referring to CC category, the related damage is 0.36 pt for conventional farming, while it is equal to 0.19 pt for organic farming, using 1 ha FU; referring to 1 kg FU, the related damage is 3.36E-05 pt for conventional barley, compared with 2.48E-05 pt for organic barley. Referring to R category, the related damage is 0.28 pt for conventional farming, while it is equal to 0.09 pt for organic farming, using 1 ha FU; referring to 1 kg FU, the related damage is 2.64E-05 pt for conventional barley, compared with 1.23E-05 pt for organic barley. Damage to EQ is always higher in the organic cycle: it is 1.62 pt with respect to 1.43 pt of conventional regime, when the analysis relies upon the land-based FU; it is 2.16E-04 pt with respect to 1.24E-04 pt of conventional regime, when the analysis relies upon the mass-based FU. With regard to the HH category, based on the obtained results it should be observed that comparable values were obtained when 1 ha is the FU, while a lower value was observed in the conventional system when FU is 1 kg (Table 14). In the latter case, this is attribute to the production yield being greater in the conventional system compared to the organic one.

**Table 14.** Damages assessment and weighing, evaluated by Impact 2002+.

| DAMAGE CATEGORY* | WEIGHING (pt) | | | | DAMAGE ASSESSMENT | | | | Unit |
|---|---|---|---|---|---|---|---|---|---|
| | Organic | | Conventional | | Organic | | Conventional | | |
| | FU 1 ha | FU 1 kg | FU 1 ha | FU 1 kg | FU 1 ha | FU 1 kg | FU 1 ha | FU 1 kg | |
| EQ | 1.58 | 2.11E-04 | 1.43 | 1.34E-04 | 21,565.38 | 2.88 | 19,684.00 | 1.81 | $PDF*m^2*yr$** |
| HH | 0.47 | 6.21E-05 | 0.48 | 4.56E-05 | 0.00294 | 4.35E-07 | 0.003 | 3.32E-07 | DALY*** |
| CC | 0.19 | 2.48E-05 | 0.36 | 3.36E-05 | 1,902.07 | 0.255 | 3,612.51 | 0.35 | kg $CO_2$ eq |
| R | 0.09 | 1.24E-05 | 0.28 | 2.64E-05 | 15,727.22 | 2.097 | 40,889.52 | 3.95 | MJ primary |

* Damage categories are Human health (HH), Ecosystem quality (EQ), Climate change (CC), and Resources (R).
** PDF (Potential Damage Fraction) is the fraction of species that have a high probability of not surviving in the affected area due to unfavorable living conditions.
*** DALY (Disability-Adjusted Life Year) is a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death.

Given the classification of damage categories into impact categories provided by Impact 2002+, the analysis was extended to impacts categories, in order to better explain values obtained at the endpoint level in terms of the damage category. Figure 31 shows the environmental impact related to barley cultivation, making a comparison between organic and conventional farming. The environmental impacts refer to land-based FU (1 ha of land for grain and 1.083 ha of land for straw) and they are expressed as weighing points (pt) and classified by impact categories. Figure 32 shows the environmental impact related to barley cultivation, making a comparison between organic and conventional farming. The environmental impacts refer to mass-based FU (1 kg of grain and 1.1 kg of straw) and they are expressed as weighing points (pt) and classified by impact categories. Using 1 ha as FU, conventional farming is more impacting than organic farming: producing organic barley is a sustainable solution in environmental terms because, being equal the land intended for barley cultivation, it causes lower damages on HH (in terms of RE), CC (in terms of GW), and R (in terms of NRE). Using 1 kg as FU, organic cultivation of barley results more impacting than conventional barley cultivation: conventional farming is an efficient solution from an environmental perspective because, *ceteris paribus*, it allows to obtain the same output with a lesser damage on the EQ, in terms of LO and TE. Also in this case, the common factor that emerges from the comparison is that each impact category has the same influence on the entire process, despite the different FUs.

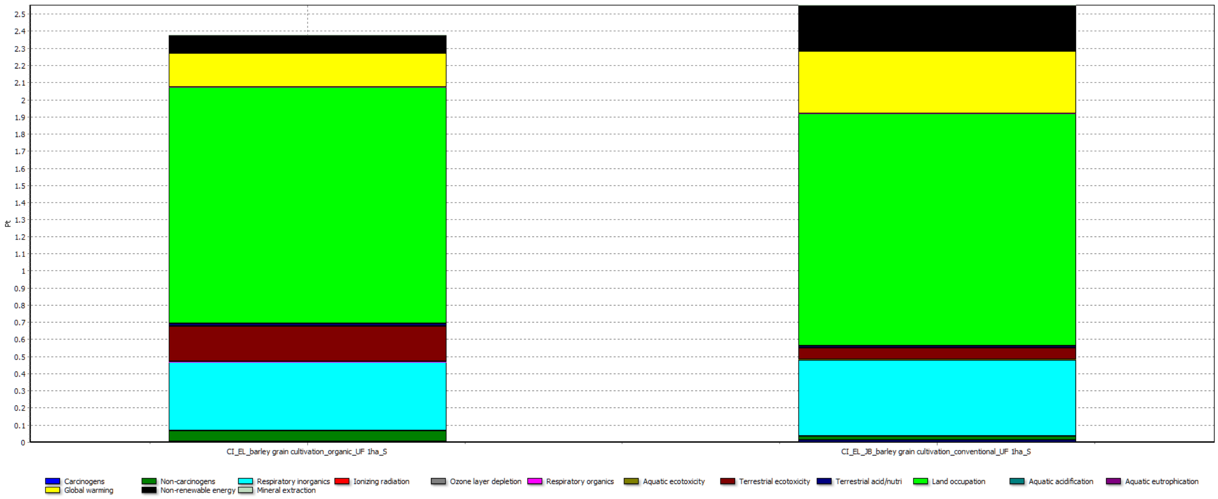


**Figure 31.** Comparison between organic and conventional barley cultivation processes (with reference to 1ha FU) and related caused-impacts (weighing points).

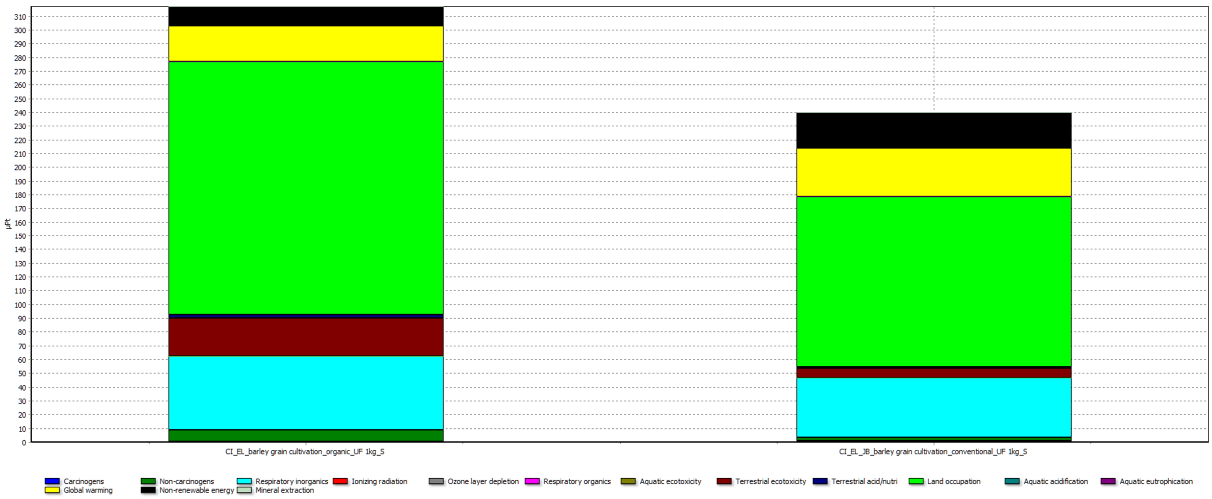


**Figure 32.** Comparison between organic and conventional barley cultivation processes (with reference to 1kg FU) and related caused-impacts (weighing points).

As far as the involved impact categories, Table 15 lists those that, apart from being the most impactful, were considered as representative of the agricultural systems investigated: they were expressed as weighing points (pt) and characterisation values. The table compares the total damage related to barley cultivation in organic and conventional farming, using both land-based and mass-based FUs.

**Table 15.** Characterisation and weighing, evaluated by Impact 2002+.

| IMPACT CATEGORY* | WEIGHING (pt) | | | | CHARACTERISATION | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Organic | | Conventional | | Organic | | Conventional | | Unit |
| | FU 1 ha | FU 1 kg | FU 1 ha | FU 1 kg | FU 1 ha | FU 1 kg | FU 1 ha | FU 1 kg | |
| LO | 1.351 | 1.80E-04 | 1.428 | 1.34E-04 | 18,526.665 | 2.525 | 18,579.43 | 1.697 | $m^2$org.arable |
| RI | 0.396 | 5.28E-05 | 0.459 | 4.32E-05 | 0.00294 | 3.78E-07 | 0.003 | 3.06E-07 | kg PM2.5 eq |
| TE | 0.163 | 2.17E-05 | 0.076 | 7.20E-06 | 2,755.35 | 0.376 | 918.95 | 0.092 | kg TEG soil |
| GW | 0.186 | 2.48E-05 | 0.383 | 3.60E-05 | 1,900.91 | 0.259 | 3.612.51 | 0.349 | kg $CO_2$ eq |
| NRE | 0.116 | 1.55E-05 | 0.281 | 2.64E-05 | 15,692.37 | 2.140 | 40,804.62 | 3,945 | MJ primary |

* Impact categories considered are Respiratory inorganics (RI), Terrestrial ecotoxicity (TE), Land occupation (LO), Global warming (GW), Non-renewable Energy (NRE).

The total damage is almost entirely related to LO category, which accounts for more than the 50% in both cases (Table 15): the impact is a bit greater for organic cultivation rather than for conventional cultivation, because organic farming requires more land to obtain the same yield of conventional farming (Meier *et al.*, 2015; Nemecek *et al.*, 2011).

Table 16 compares the most impacting substances and resources for each damage category, related to barley cultivation in organic and conventional farming, using either land-based and mass-based FUs. Resources and substances are classified among damage categories (HH, EQ, CC, R), and each of them is expressed as percentage and weighing point (pt).

**Table 16.** Most impacting resources and substances referring to organic and conventional barley cultivation, classified by damage categories.

| SUBSTANCES BY DAMAGE CATEGORY | COMPARTMENT | % (with respect to the damage associated with the single damage category) | | | | WEIGHING (pt) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Organic | | Conventional | | Organic | | Conventional | |
| | | FU 1 ha | FU 1 kg | FU 1 ha | FU 1 kg | FU 1 ha | FU 1 kg | FU 1 ha | FU 1 kg |
| *Ecosystem quality* | | | | | | | | | |
| Occupation, arable, non-irrigated | --- | 86 | 86 | 94 | 94 | 1.358 | 1.81E-04 | 1.354 | 1.24E-04 |
| Zinc | Soil | 11 | 11 | 3 | 4 | 0.174 | 2.32E-05 | 0.048 | 4.86E-06 |
| Copper | Soil | 1 | 1 | almost null | | 0.016 | 2.11E-06 | -0.001 | -6.41E-08 |
| *Human health* | | | | | | | | | |
| Nitrogen oxides | Air | 35 | 35 | 40 | 40 | 0.164 | 2.17E-05 | 0.193 | 1.88E-05 |
| Ammonia | Air | 31 | 31 | 14 | 14 | 0.146 | 1.92E-05 | 0.068 | 6.50E-06 |
| Particulates, < 2.5 um | Air | 18 | 18 | 32 | 32 | 0.085 | 1.12E-05 | 0.155 | 1.51E-05 |
| Zinc | Soil | 13 | 13 | 3 | 4 | 0.061 | 8.07E-06 | 0.016 | 1.65E-06 |
| *Climate change* | | | | | | | | | |
| Carbon dioxide, fossil | Air | 52 | 52 | 58 | 58 | 0.099 | 1.25E-05 | 0.211 | 2.04E-05 |
| Methane, biogenic | Air | 44 | 44 | 0 | 0 | 0.084 | 1.09E-05 | 1.12E-05 | 1.07E-09 |
| Dinitrogen monoxide | Air | 2 | 2 | 41 | 40 | 0.004 | 4.96E-07 | 0.149 | 1.43E-05 |
| *Resources* | | | | | | | | | |
| Oil, crude, in ground | --- | 108 | 108 | 48 | 49 | 0.097 | 1.34E-05 | 0.130 | 1.27E-05 |
| Uranium, in ground | | 16 | 16 | 6 | 6 | 0.014 | 1.98E-06 | 0.015 | 1.45E-06 |
| Coal, hard, unspecified, in ground | | 8 | 8 | 4 | 4 | 0.007 | 1.00E-06 | 0.012 | 1.16E-06 |
| Coal, brown, in ground | | 1 | 1 | 2 | 2 | 0.001 | 1.24E-07 | 0.004 | 4.14E-07 |

It should be observed that all the substances and resources listed in Table 16 could be considered as the most significant impact-indicators that should be taken into account for improving environmental sustainability of the agricultural system design, implementation and management.

Findings draw attention to the importance of an appropriate choice of the FU because, as documented by several authors, such as Hayashi (2013), and Cerutti *et al.* (2013), results of an LCA analysis may be strongly influenced by the use of diverse FUs and lead to different findings. This problem is evident in the case study discussed in this paper where, depending upon the used FU, one production system becomes more sustainable than the other and vice versa.

#### 3.2.3.2. Organic barley cultivation

For each impact category at the midpoint level, a specific analysis was performed to understand the impact of each agricultural step on the final result for each category. Figures 33 and 34 present the analysis of characterization factors at midpoint level. The overall long-term effects that each single process, considered in the evaluation of organic barley cultivation, cause on impact categories considering an infinite time horizon are expressed in percentage, with reference both to 1 ha FU (Figure 33) and 1 kg FU (Figure 34). At midpoint level there are no difference in percent results, using different FUs. Transportations are the processes that impact on all impact categories, except for Land occupation (LO) which suffers the impact of the entire process of cultivation of organic barley. Although the production of compost has a great impact on Terrestrial acidification and nutrition (TAN) and Aquatic acidification (AA), it avoids approximately 25-40% of impacts on Mineral extraction (ME), Carcinogens (CA), Non-renewable energy (NRE), Ozone layer depletion (OLD), and Aquatic eutrophication (AE). Other relevant contributions on all impact categories derive from agricultural practices of ploughing, harrowing, and harvesting as also found by Fedele *et al.* (2014). Tables 17 and 18 show midpoint characterization scores expressed in kg-equivalents of a substance compared to a reference substance for each process involved in the cultivation of barley in organic farming: Table 17 refers to 1 ha FU, while Table 18 refers to 1 kg FU. Tables 17 and 18 confirm general finding of Figures 33 and 34, although expressing characterization scores in kg-equivalents of a substance highlights the difference in magnitude of results when FU changes: land-based FU amplifies the effects of process on impact categories. Considering the total effect of that cultivation of barley in organic farming and related processes, Aquatic and Terrestrial ecotoxicity (AE and TE) are the impact categories that suffer the greatest effects. AE accounts for 260,396.74 kg-equivalents of triethylene glycol (TEG) into water when 1 ha is the FU (Table 17), compared to 34.75 kg-equivalents of TEG into water using 1 kg as FU (Table 18). TE accounts for 355,664.05 kg-equivalents of TEG into soil when 1 ha is the FU (Table 17), compared to 47.47 kg-equivalents of TEG into water using 1 kg as FU (Table 18). Relevant are also the overall effects on Ionizing radiation (IR) and LO: the former accounts for 26,556.01 becquerel equivalents of carbon-14 (Bq C-14 eq) using land-based FU (Table 17) and for 3.54 Bq C-14 eq using mass-based FU (Table 18); the latter accounts for 26,556.01 $m^2$-equivalents of organic arable land per year when 1 ha is the FU (Table 17) and for 3.54 $m^2$-equivalents of organic arable land per year when 1 kg is the FU (Table 18). At endpoint level, AE, TE, and LO contribute to create damage to Ecosystem quality (EQ), while IR affects Human health (HH). Other important effects influence Non-renewable energy (NRE), that affects Resources (R) at endpoint leve.

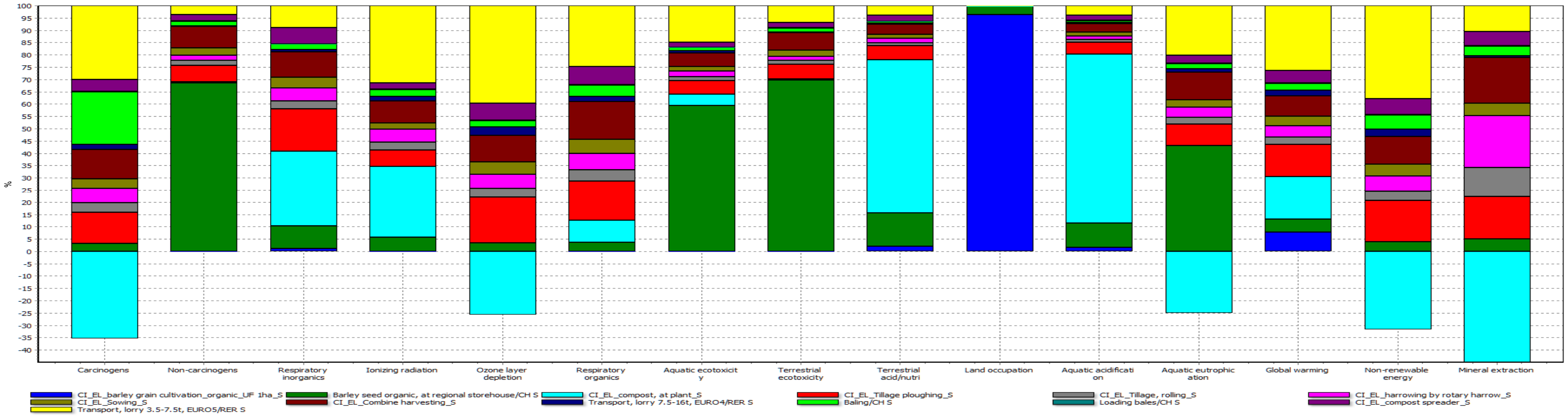


**Figure 33.** Characterization per impact category for organic barley cultivation processes (with reference to 1ha FU).

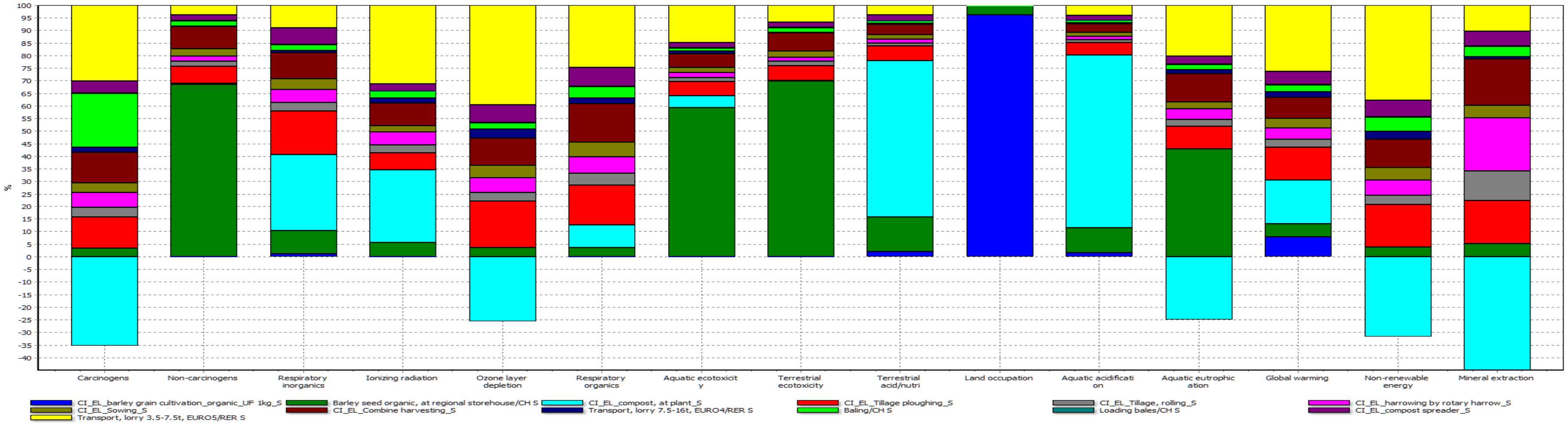


**Figure 34.** Characterization per impact category for organic barley cultivation processes (with reference to 1kg FU).

**Table 17.** Characterization per impact category for organic barley cultivation processes (with reference to 1ha FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Compost | Ploughing | Rolling | Harrowing | Sowing | Compost spreader | Harvesting | Bailing | Loading bales | Transport. lorry 7.5-16t, EURO4 | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | kg $C_2H_3Cl$ eq | 9.07 | 0.00 | 0.46 | -4.95 | 1.76 | 0.53 | 0.85 | 0.55 | 0.66 | 1.68 | 2.98 | 0.03 | 0.29 | 4.23 |
| NC | kg $C_2H_3Cl$ eq | 163.07 | 0.02 | 111.66 | 0.72 | 11.16 | 3.29 | 3.44 | 4.76 | 3.84 | 14.05 | 3.17 | 0.43 | 0.39 | 6.15 |
| RI | kg PM2.5 eq | 4.05 | 0.04 | 0.37 | 1.23 | 0.70 | 0.13 | 0.21 | 0.17 | 0.26 | 0.42 | 0.09 | 7.84E-03 | 0.04 | 0.37 |
| IR | Bq C-14 eq | 26,556.01 | 0.00 | 1,502.59 | 7,664.83 | 1,789.48 | 837.90 | 1,411.84 | 660.21 | 725.13 | 2377.10 | 706.07 | 43.06 | 516.63 | 8321.18 |
| OLD | kg CFC-11 eq | 0.00 | 0.00 | 0.00 | -5.23E-05 | 3.75E-05 | 7.59E-06 | 1.16E-05 | 1.04E-05 | 1.43E-05 | 2.18E-05 | 4.81E-06 | 4.98E-07 | 7.14E-06 | 8.04E-05 |
| RO | kg $C_2H_4$ eq | 1.24 | 0.00 | 0.05 | 0.11 | 0.20 | 0.06 | 0.08 | 0.07 | 0.09 | 0.19 | 0.06 | 3.73E-03 | 0.03 | 0.31 |
| AE | kg TEG water | 260,396.74 | 1.36 | 154,577.24 | 12,230.97 | 14,371.09 | 4,060.60 | 5,682.32 | 4,948.52 | 5,307.71 | 14,279.65 | 3,200.20 | 343.28 | 2,687.62 | 38,706.18 |
| TE | kg TEG soil | 355,664.05 | 3.42 | 248,340.40 | 1,003.26 | 21,151.88 | 5,853.34 | 5,887.15 | 8,835.02 | 7,224.94 | 25,156.25 | 5,717.77 | 788.24 | 1,469.10 | 24,233.29 |
| TAN | kg $SO_2$ eq | 252.67 | 5.22 | 34.34 | 157.37 | 14.60 | 3.01 | 4.27 | 4.40 | 6.31 | 10.07 | 1.96 | 0.18 | 1.29 | 9.63 |
| LO | $m^2$org.arable | 17,354.44 | 16,702.22 | 623.60 | 6.90 | 2.60 | 1.59 | 1.67 | 1.62 | 1.02 | 2.72 | 0.63 | 0.11 | 0.53 | 9.23 |
| AA | kg $SO_2$ eq | 43.86 | 0.66 | 4.39 | 30.16 | 2.14 | 0.46 | 0.66 | 0.64 | 0.91 | 1.51 | 0.33 | 0.03 | 0.21 | 1.75 |
| AEU | kg $PO_4$ P-lim | 0.22 | 0.00 | 0.13 | -0.07 | 0.03 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 5.20E-04 | 4.50E-03 | 0.06 |
| GW | kg $CO_2$ eq | 1,940.89 | 151.76 | 102.75 | 337.20 | 255.78 | 57.57 | 89.25 | 72.51 | 97.78 | 162.92 | 52.79 | 3.55 | 44.35 | 512.68 |
| NRE | MJ primary | 16,022.43 | 0.00 | 885.06 | -7,425.86 | 3,941.04 | 919.26 | 1,439.84 | 1,134.44 | 1,513.15 | 2,622.36 | 1,300.85 | 56.99 | 750.01 | 8,885.29 |
| ME | MJ surplus | 25.75 | 0.00 | 2.39 | -21.06 | 8.06 | 5.57 | 9.86 | 2.33 | 2.69 | 8.67 | 1.88 | 0.14 | 0.33 | 4.89 |

* Impact categories are Carcinogens (CA), Non carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

**Table 18.** Characterization per impact category for organic barley cultivation processes (with reference to 1kg FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Compost | Ploughing | Rolling | Harrowing | Sowing | Compost spreader | Harvesting | Bailing | Loading bales | Transport. lorry 7.5-16t, EURO4 | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | kg $C_2H_3Cl$ eq | 1.21E-03 | 0.00 | 6.09E-05 | -6.61E-04 | 2.34E-04 | 7.14E-05 | 1.14E-04 | 7.29E-05 | 8.82E-05 | 2.24E-04 | 4.02E-04 | 4.23E-06 | 3.86E-05 | 5.64E-04 |
| NC | kg $C_2H_3Cl$ eq | 0.02 | 2.37E-06 | 1.49E-02 | 9.56E-05 | 1.49E-03 | 4.39E-04 | 4.60E-04 | 6.35E-04 | 5.12E-04 | 1.88E-03 | 4.28E-04 | 5.73E-05 | 5.22E-05 | 8.21E-04 |
| RI | kg PM2.5 eq | 5.40E-04 | 5.65E-06 | 4.99E-05 | 1.64E-04 | 9.39E-05 | 1.72E-05 | 2.87E-05 | 2.27E-05 | 3.48E-05 | 5.58E-05 | 1.21E-05 | 1.06E-06 | 5.42E-06 | 4.89E-05 |
| IR | Bq C-14 eq | 3.54 | 0.00 | 0.20 | 1.02 | 0.24 | 0.11 | 0.19 | 0.09 | 0.10 | 0.32 | 9.51E-02 | 5.80E-03 | 0.07 | 1.11 |
| OLD | kg CFC-11 eq | 2.01E-08 | 0.00 | 9.43E-10 | -6.97E-09 | 5.00E-09 | 1.01E-09 | 1.55E-09 | 1.39E-09 | 1.90E-09 | 2.91E-09 | 6.48E-10 | 6.71E-11 | 9.52E-10 | 1.07E-08 |
| RO | kg $C_2H_4$ eq | 1.66E-04 | 0.00 | 6.11E-06 | 1.49E-05 | 2.65E-05 | 7.69E-06 | 1.08E-05 | 9.62E-06 | 1.21E-05 | 2.55E-05 | 7.51E-06 | 5.03E-07 | 3.60E-06 | 4.11E-05 |
| AE | kg TEG water | 34.75 | 1.81E-04 | 20.63 | 1.63 | 1.92 | 0.54 | 0.76 | 0.66 | 0.71 | 1.91 | 0.43 | 0.05 | 0.36 | 5.16 |
| TE | kg TEG soil | 47.47 | 4.56E-04 | 33.14 | 0.13 | 2.82 | 0.78 | 0.79 | 1.18 | 0.96 | 3.36 | 0.77 | 0.11 | 0.20 | 3.23 |
| TAN | kg $SO_2$ eq | 0.03 | 6.96E-04 | 4.58E-03 | 0.02 | 1.95E-03 | 4.02E-04 | 5.70E-04 | 5.87E-04 | 8.42E-04 | 1.34E-03 | 2.64E-04 | 2.46E-05 | 1.73E-04 | 1.28E-03 |
| LO | $m^2$org.arable | 2.32 | 2.23 | 0.08 | 9.21E-04 | 3.47E-04 | 2.12E-04 | 2.23E-04 | 2.16E-04 | 1.35E-04 | 3.63E-04 | 8.48E-05 | 1.46E-05 | 7.10E-05 | 1.23E-03 |
| AA | kg $SO_2$ eq | 5.85E-03 | 8.74E-05 | 5.86E-04 | 4.02E-03 | 2.86E-04 | 6.13E-05 | 8.86E-05 | 8.60E-05 | 1.22E-04 | 2.02E-04 | 4.51E-05 | 3.74E-06 | 2.76E-05 | 2.33E-04 |
| AEU | kg $PO_4$ P-lim | 2.97E-05 | 0.00 | 1.70E-05 | -9.93E-06 | 3.51E-06 | 1.06E-06 | 1.67E-06 | 1.14E-06 | 1.33E-06 | 4.43E-06 | 7.82E-07 | 7.01E-08 | 6.01E-07 | 7.97E-06 |
| GW | kg $CO_2$ eq | 0.26 | 0.02 | 0.01 | 0.04 | 3.41E-02 | 7.68E-03 | 1.19E-02 | 9.68E-03 | 0.01 | 0.02 | 7.11E-03 | 4.79E-04 | 5.92E-03 | 0.07 |
| NRE | MJ primary | 2.14 | 0.00 | 0.12 | -0.99 | 0.53 | 0.12 | 0.19 | 0.15 | 0.20 | 0.35 | 0.18 | 7.68E-03 | 0.10 | 1.19 |
| ME | MJ surplus | 3.44E-03 | 0.00 | 3.19E-04 | -2.81E-03 | 1.08E-03 | 7.43E-04 | 1.32E-03 | 3.11E-04 | 3.58E-04 | 1.16E-03 | 2.53E-04 | 1.93E-05 | 4.44E-05 | 6.53E-04 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

Results obtained at the midpoint level can be used to explain the impact assessment obtained at the endpoint level in terms of the damage category. The endpoint analysis collects the impact categories into four damage categories (namely Human health (HH), Ecosystem quality (EQ), Climate change (CC), Resource (R)), throughout specific conversion factors provided by Impact 2002+. Figures 35 and 36 show the environmental impacts related to barley cultivation in organic farming, classified by damage categories. The environmental impacts are expressed as weighing points (pt) and refer to both land-based FU (1 ha of land for grain and 1.083 ha of land for straw) (Figure 35) and mass-based FU (1 kg of grain and 1.1 kg of straw) (Figure 36). Considering the whole process, from the figures it is straightforward that the cultivation of organic barley produces the greatest impacts on EQ. Also the phase of production of organic seed cause a remarkable effects on EQ. All the other involved processes have a more or less impacting influence on HH. Although transportations damage R, the phase of production of organic compost for the fertilization avoids the use of natural resources. Considering distinct FUs what changes in the allocation of environmental burdens is the magnitude of each impacts, while the general contribution of each process is the same both with land-based and mass-based FUs. Table 19 and 20 shows the total damage related to barley cultivation in organic farming, using either land-based and mass-based FUs. The total damage is classified among damage categories (HH, EQ, CC, R) and is expressed as damage assessment value, computed by using conversion factors specifically assigned in Impact 2002+ (Table 19), and as weighing point (pt) (Table 20). The total damage related to cultivation of barley in organic farming is equal to 2.38 pt, when the analysis relies upon the land-based FU; in comparison, it is 3.17E-04 pt, when the analysis relies upon the mass-based FU (Table 20). Figures and tables highlights how the difference in magnitude of the total damage, from a FU to another, is noteworthy; however, the percentage contribution of each process, involved in cultivation of barley in organic farming, in generating environmental impacts does not show significant differences between the utilization of 1 ha and 1 kg as FU[20]. The overall damage caused on EQ is almost entirely attributable to the whole process of cultivation of organic barley (more than 80%) and to the phase of production of organic seed (about 15%): the former accounts for 18,210.87 PDF*$m^2$*yr using a land-based FU and for 2.43 PDF*$m^2$*yr using a mass-based FU; the latter accounts for 2,687.57 PDF*$m^2$*yr when 1 ha is the FU and for 0.36 PDF*$m^2$*yr when 1 kg is the FU (Table 19). Transportations impacts on each damage category: in particular, they cause a damage of almost 40% on R (557.03 MJ with 1 ha as FU and 7.43E-02 MJ with 1 kg as FU), approximately of 30% on CC (9,640.52 kg $CO_2$ eq with 1 ha as FU and 1.29 kg $CO_2$ eq with 1 kg as FU), of about 10% on HH (3.19E-04 DALY with 1 ha as FU and 4.25E-08 DALY with 1 kg as FU); negligible is the impact of transportations on EQ (Table 19). The production of compost avoids to cause damage on R for 30% (-7,446.93 MJ with 1 ha as FU and -0.99 MJ with 1 kg as FU) (Table 19). Other contributions derive from ploughing and harvesting, which damages on HH, CC, and R range between 10% and 20%.

[20] In this regard, Figure 57 and 58 in the Appendix (Section *ii. Organic barley cultivation*) show the percentage contribution of each process, involved in cultivation of barley in organic farming, in generating environmental impacts. The environmental impacts are classified by damage categories (HH, EQ, CC, R) and they refer both to land-based FU (1 ha of land for grain and 1.083 ha of land for straw) (Figure 57) and to mass-based FU (1 kg of grain and 1.1 kg of straw) (Figure 58).

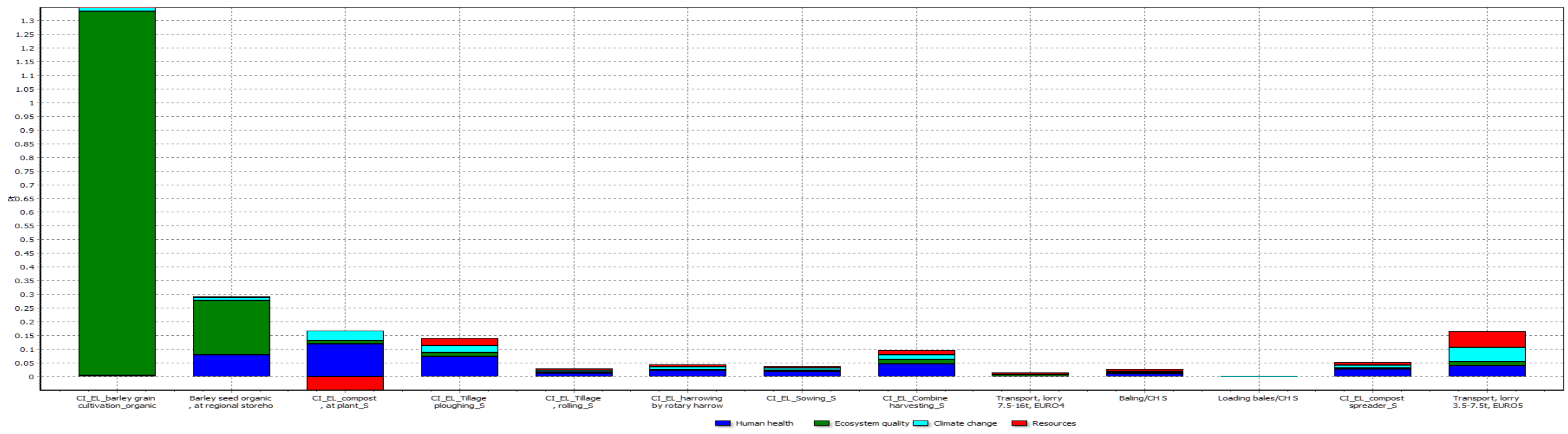


**Figure 35.** Weighing evaluation per damage category for organic barley cultivation processes (with reference to 1ha FU).

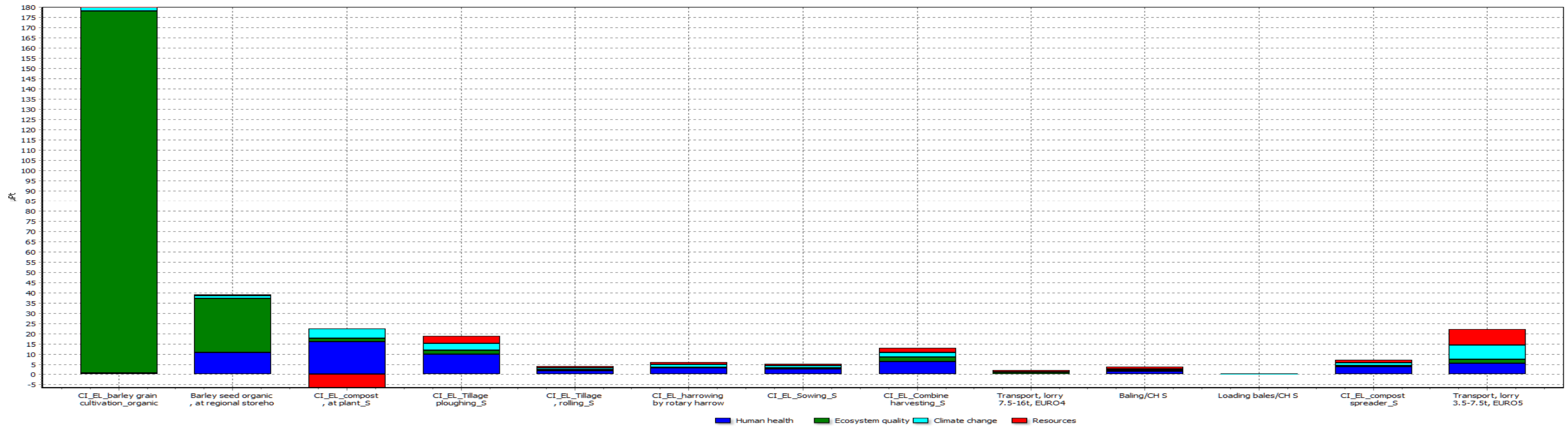


**Figure 36.** Weighing evaluation per damage category for organic barley cultivation processes (with reference to 1kg FU).

**Table 19.** Damages assessment for organic barley cultivation process (with reference to 1ha and 1kg FUs).

| | DAMAGE CATEGORY[*] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | HH (DALY)[**] | | EQ (PDF*m$^2$*yr)[***] | | CC (kg $CO_2$ eq) | | R (MJ primary) | |
| | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| Total | 3.32E-03 | 4.44E-07 | 22,005.49 | 2.94 | 1,940.89 | 0.26 | 16,048.18 | 2.14 |
| Cultivation | 2.97E-05 | 3.96E-09 | 18,210.87 | 2.43 | 151.76 | 2.03E-02 | 0.00 | 0.00 |
| Seed | 5.76E-04 | 7.69E-08 | 2,687.57 | 0.36 | 102.75 | 1.37E-02 | 887.45 | 0.12 |
| Compost | 8.52E-04 | 1.14E-07 | 179.74 | 2.40E-02 | 337.20 | 4.50E-02 | -7,446.93 | -0.99 |
| Ploughing | 5.30E-04 | 7.07E-08 | 186.05 | 2.48E-02 | 255.78 | 3.41E-02 | 3,949.10 | 0.53 |
| Rolling | 1.01E-04 | 1.35E-08 | 51.37 | 6.86E-03 | 57.57 | 7.68E-03 | 924.83 | 0.12 |
| Harrowing | 1.63E-04 | 2.17E-08 | 53.12 | 7.09E-03 | 89.25 | 1.19E-02 | 1,449.71 | 0.19 |
| Sowing | 1.34E-04 | 1.79E-08 | 76.47 | 1.02E-02 | 72.51 | 9.68E-03 | 1,136.77 | 0.15 |
| Compost spreader | 1.96E-04 | 2.61E-08 | 65.09 | 8.68E-03 | 97.78 | 1.30E-02 | 1,515.84 | 0.20 |
| Harvesting | 3.38E-04 | 4.50E-08 | 213.15 | 2.84E-02 | 162.92 | 2.17E-02 | 2,631.03 | 0.35 |
| Bailing | 8.02E-05 | 1.08E-08 | 48.11 | 6.48E-03 | 52.79 | 7.11E-03 | 1,302.72 | 0.18 |
| Loading bales | 6.78E-06 | 9.14E-10 | 6.56 | 8.84E-04 | 3.55 | 4.79E-04 | 57.14 | 7.70E-03 |
| Transport, lorry 7.5-16t, EURO4 | 3.05E-05 | 4.07E-09 | 13.68 | 1.83E-03 | 44.35 | 5.92E-03 | 750.34 | 0.10 |
| Transport, lorry 3.5-7.5t, EURO5 | 2.88E-04 | 3.84E-08 | 213.71 | 2.85E-02 | 512.68 | 6.84E-02 | 8,890.18 | 1.19 |

[*] Damage categories are Human health (HH), Ecosystem quality (EQ), Climate change (CC), and Resources (R).
[**] DALY (Disability-Adjusted Life Year) is a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death.
[***] PDF (Potential Damage Fraction) is the fraction of species that have a high probability of not surviving in the affected area due to unfavorable living conditions.

**Table 20.** Weighing evaluation per damage category for organic barley cultivation process (with reference to 1ha and 1kg FUs).

| | Unit | Total | | DAMAGE CATEGORY[*] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | HH | | EQ | | CC | | R | |
| | | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| Total | Pt | 2.38 | 3.17E-04 | 0.47 | 6.26E-05 | 1.61 | 2.14E-04 | 0.20 | 2.62E-05 | 0.11 | 1.41E-05 |
| Cultivation | Pt | 1.35 | 1.80E-04 | 4.19E-03 | 5.58E-07 | 1.33 | 1.77E-04 | 1.53E-02 | 2.05E-06 | 0.00 | 0.00 |
| Seed | Pt | 0.29 | 3.92E-05 | 8.12E-02 | 1.08E-05 | 0.20 | 2.62E-05 | 1.04E-02 | 1.39E-06 | 5.84E-03 | 7.79E-07 |
| Compost | Pt | 0.12 | 1.58E-05 | 0.12 | 1.60E-05 | 1.31E-02 | 1.75E-06 | 3.41E-02 | 4.54E-06 | -4.90E-02 | -6.54E-06 |
| Ploughing | Pt | 0.14 | 1.87E-05 | 7.47E-02 | 9.96E-06 | 1.36E-02 | 1.81E-06 | 2.58E-02 | 3.45E-06 | 2.60E-02 | 3.47E-06 |
| Rolling | Pt | 2.99E-02 | 3.99E-06 | 1.43E-02 | 1.91E-06 | 3.75E-03 | 5.00E-07 | 5.81E-03 | 7.76E-07 | 6.09E-03 | 8.12E-07 |
| Harrowing | Pt | 4.54E-02 | 6.06E-06 | 2.30E-02 | 3.07E-06 | 3.88E-03 | 5.17E-07 | 9.01E-03 | 1.20E-06 | 9.54E-03 | 1.27E-06 |
| Sowing | Pt | 3.93E-02 | 5.24E-06 | 1.89E-02 | 2.52E-06 | 5.58E-03 | 7.45E-07 | 7.32E-03 | 9.77E-07 | 7.48E-03 | 9.98E-07 |
| Compost spreader | Pt | 5.22E-02 | 6.96E-06 | 2.76E-02 | 3.68E-06 | 4.75E-03 | 6.34E-07 | 9.88E-03 | 1.32E-06 | 9.97E-03 | 1.33E-06 |
| Harvesting | Pt | 9.69E-02 | 1.29E-05 | 4.76E-02 | 6.35E-06 | 1.56E-02 | 2.08E-06 | 1.65E-02 | 2.20E-06 | 1.73E-02 | 2.31E-06 |
| Bailing | Pt | 2.87E-02 | 3.87E-06 | 1.13E-02 | 1.52E-06 | 3.51E-03 | 4.73E-07 | 5.33E-03 | 7.18E-07 | 8.57E-03 | 1.15E-06 |
| Loading bales | Pt | 2.17E-03 | 2.92E-07 | 9.56E-04 | 1.29E-07 | 4.79E-04 | 6.45E-08 | 3.59E-04 | 4.83E-08 | 3.76E-04 | 5.06E-08 |
| Transport, lorry 7.5-16t, EURO4 | Pt | 1.47E-02 | 1.96E-06 | 4.30E-03 | 5.75E-07 | 9.99E-04 | 1.33E-07 | 4.48E-03 | 5.98E-07 | 4.94E-03 | 6.59E-07 |
| Transport, lorry 3.5-7.5t, EURO5 | Pt | 0.17 | 2.22E-05 | 4.06E-02 | 5.42E-06 | 1.56E-02 | 2.08E-06 | 5.18E-02 | 6.91E-06 | 5.85E-02 | 7.80E-06 |

[*] Damage categories are Human health (HH), Ecosystem quality (EQ), Climate change (CC), and Resources (R).

Given the classification of damage categories into impact categories provided by Impact 2002+, the analysis was extended to impacts categories, in order to better explain values obtained at the endpoint level in terms of the damage category. Figures 37 and 38 show the environmental impacts related to barley cultivation in organic farming, classified by impact categories. The environmental impacts are expressed as weighing points (pt) and refer to both land-based FU (1 ha of land for grain and 1.083 ha of land for straw) (Figure 37) and mass-based FU (1 kg of grain and 1.1 kg of straw) (Figure 38). In addition, Table 21 and 22 shows the total damage related to barley cultivation in organic farming, classified among impact categories, provided by Impact 2002+. The total damage is expressed as impact assessment value, computed by using conversion factors specifically assigned in Impact 2002+, using land-based FU (Table 21) and mass-based FU (Table 22), and as weighing point (pt) with 1 ha as FU (Table 23) and with 1 kg as FU (Table 24). Considering the whole process, the cultivation of organic barley damages EQ, impacting on LO for more than 95% and on GW, TAN, and RI for the remaining 5%: in particular, LO accounts for 18,205.42 PDF*$m^2$*yr, standardized in 1.33 pt, when 1 ha is the FU (Tables 21 and 23), and for 2.43 PDF*$m^2$*yr, standardized in 1.77E-04 pt, when 1 kg is the FU (Tables 22 and 24). Also the phase of production of organic seed causes a remarkable effects on EQ, impacting on TE (0.14 pt with 1 ha as FU and 1.91E-05 pt with 1 kg as FU), AE (5.66E-04 pt with 1 ha as FU and 7.56E-08 pt with 1 kg as FU), and NC (4.41E-02 pt with 1 ha as FU and 5.88E-06 pt with 1 kg as FU) which account approximately for 60-70% on EQ (Tables 23 and 24). Transportations influence each impact category, except LO, with percentage values ranging from 5% of TAN to 40% of OLD. The production of compost avoids to cause damage on R and HH: in particular, Mineral extraction (ME) accounts for more than -45%, CA for -35%, NRE about for -30%, and OLD for -25%. Considering distinct FUs what changes in the allocation of environmental burdens is the magnitude of each impacts, while the general contribution of each process is the same both with land-based and mass-based FUs[21].

Figures 39 and 40 show the flow chart of the damages, that materials and processes involved in the system generate to the environment: the former refers to 1 ha of land invested in cultivation of organic barley grain as FU, the latter use as FU 1 kg of DM organic barley grain. The flow charts of the damages confirm that production of organic barley seeds and their transportation from the storehouse to the farm are the most impacting phase. Other relevant contributions to the environmental impacts related to cultivation of barley in organic farming come from production of compost for the fertilization and from the activity of ploughing (Figures 39 and 40). The difference in magnitude of the damage flows between the two FUs, also in this case, is evident: when 1 kg is the FU (Figure 40), the environmental impacts are amplified rather than in the case of 1 ha being the FU (Figure 39).

[21] In this regard, Figure 59 and 60 in the Appendix (Section *ii. Organic barley cultivation*) show the percentage contribution of each process, involved in cultivation of barley in organic farming, in generating environmental impacts. The environmental impacts are classified by impact categories and they refer both to land-based FU (1 ha of land for grain and 1.083 ha of land for straw) (Figure 59) and to mass-based FU (1 kg of grain and 1.1 kg of straw) (Figure 60).

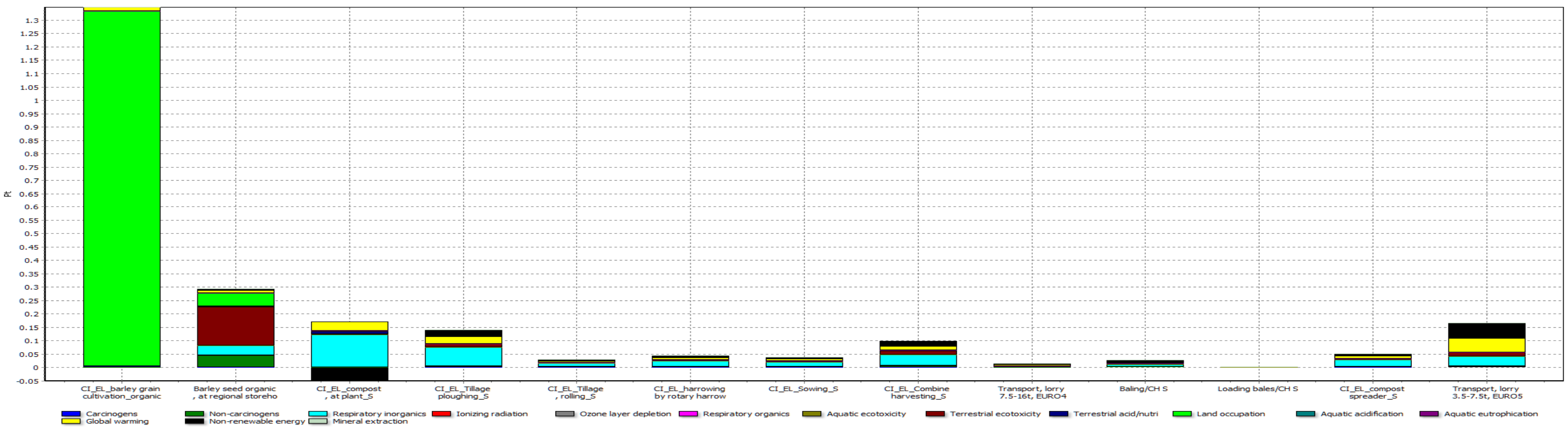


**Figure 37.** Weighing evaluation per impact category for organic barley cultivation processes (with reference to 1ha FU).

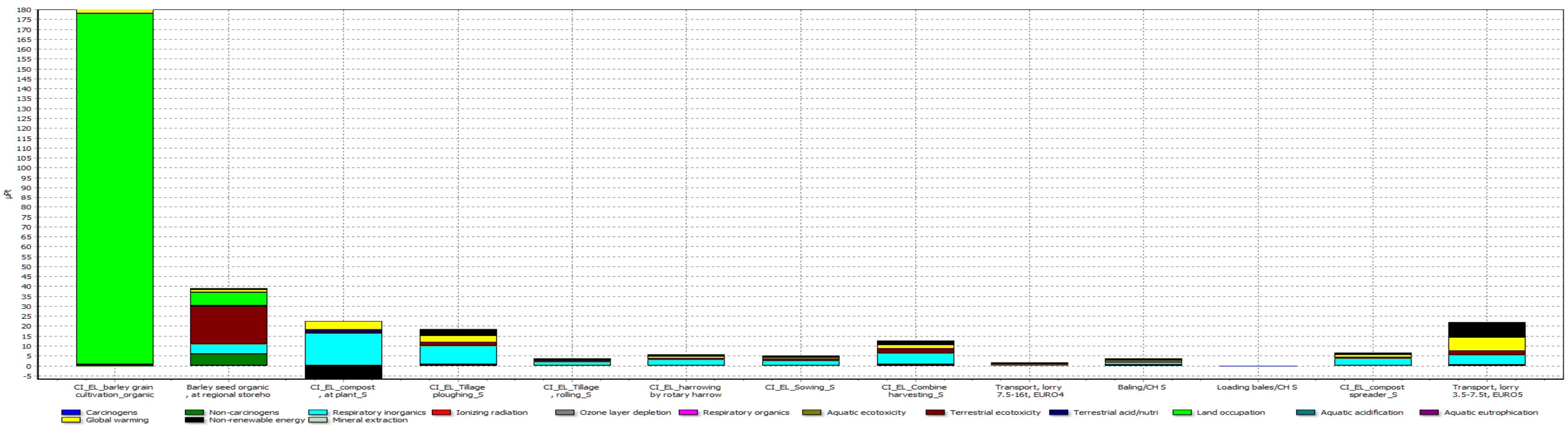


**Figure 38.** Weighing evaluation per impact category for organic barley cultivation processes (with reference to 1kg FU).

**Table 21.** Impacts assessment for organic barley cultivation process (with reference to 1ha FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Compost | Ploughing | Rolling | Harrowing | Sowing | Compost spreader | Harvesting | Bailing | Loading bales | Transport. lorry 7.5-16t, EURO4 | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | DALY** | 2.54E-05 | 0.00 | 1.28E-06 | -1.39E-05 | 4.92E-06 | 1.50E-06 | 2.39E-06 | 1.53E-06 | 1.85E-06 | 4.71E-06 | 8.35E-06 | 8.79E-08 | 8.10E-07 | 1.18E-05 |
| NC | DALY** | 4.57E-04 | 4.99E-08 | 3.13E-04 | 2.01E-06 | 3.12E-05 | 9.20E-06 | 9.64E-06 | 1.33E-05 | 1.07E-05 | 3.94E-05 | 8.89E-06 | 1.19E-06 | 1.09E-06 | 1.72E-05 |
| RI | DALY** | 2.83E-03 | 2.97E-05 | 2.62E-04 | 8.62E-04 | 4.93E-04 | 9.03E-05 | 1.50E-04 | 1.19E-04 | 1.83E-04 | 2.93E-04 | 6.27E-05 | 5.48E-06 | 2.85E-05 | 2.56E-04 |
| IR | DALY** | 5.58E-06 | 0.00 | 3.16E-07 | 1.61E-06 | 3.76E-07 | 1.76E-07 | 2.96E-07 | 1.39E-07 | 1.52E-07 | 4.99E-07 | 1.48E-07 | 9.04E-09 | 1.08E-07 | 1.75E-06 |
| OLD | DALY** | 1.58E-07 | 0.00 | 7.42E-09 | -5.49E-08 | 3.94E-08 | 7.97E-09 | 1.22E-08 | 1.09E-08 | 1.50E-08 | 2.29E-08 | 5.05E-09 | 5.23E-10 | 7.49E-09 | 8.45E-08 |
| RO | DALY** | 2.65E-06 | 0.00 | 9.74E-08 | 2.37E-07 | 4.23E-07 | 1.23E-07 | 1.73E-07 | 1.53E-07 | 1.93E-07 | 4.07E-07 | 1.19E-07 | 7.95E-09 | 5.75E-08 | 6.56E-07 |
| AE | PDF*m$^{2}$*yr*** | 13.07 | 6.83E-05 | 7.76 | 0.61 | 0.72 | 0.20 | 0.29 | 0.25 | 0.27 | 0.72 | 0.16 | 1.72E-02 | 0.13 | 1.94 |
| TE | PDF*m$^{2}$*yr*** | 2813.30 | 2.70E-02 | 1964.37 | 7.94 | 167.31 | 46.30 | 46.57 | 69.88 | 57.15 | 198.99 | 45.23 | 6.23 | 11.62 | 191.69 |
| TAN | PDF*m$^{2}$*yr*** | 262.78 | 5.43 | 35.71 | 163.66 | 15.19 | 3.13 | 4.44 | 4.57 | 6.57 | 10.48 | 2.04 | 0.19 | 1.35 | 10.01 |
| LO | PDF*m$^{2}$*yr*** | 18,916.34 | 18,205.42 | 679.72 | 7.53 | 2.83 | 1.73 | 1.82 | 1.77 | 1.11 | 2.97 | 0.69 | 0.12 | 0.58 | 10.06 |
| AA | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | kg $CO_2$ eq | 1940.89 | 151.76 | 102.75 | 337.20 | 255.78 | 57.57 | 89.25 | 72.51 | 97.78 | 162.92 | 52.79 | 3.55 | 44.35 | 512.68 |
| NRE | MJ primary | 16022.43 | 0.00 | 885.06 | -7425.86 | 3941.04 | 919.26 | 1439.84 | 1134.44 | 1513.15 | 2622.36 | 1300.85 | 56.99 | 750.01 | 8885.29 |
| ME | MJ primary | 25.75 | 0.00 | 2.39 | -21.06 | 8.06 | 5.57 | 9.86 | 2.33 | 2.69 | 8.67 | 1.88 | 0.14 | 0.33 | 4.89 |

* Impact categories are Carcinogens (CA), Non carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

** DALY (Disability-Adjusted Life Year) is a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death.

*** PDF (Potential Damage Fraction) is the fraction of species that have a high probability of not surviving in the affected area due to unfavorable living conditions.

**Table 22.** Impacts assessment for organic barley cultivation process (with reference to 1kg FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Compost | Ploughing | Rolling | Harrowing | Sowing | Compost spreader | Harvesting | Bailing | Loading bales | Transport. lorry 7.5-16t, EURO4 | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | DALY** | 3.40E-09 | 0.00 | 1.71E-10 | -1.85E-09 | 6.57E-10 | 2.00E-10 | 3.19E-10 | 2.04E-10 | 2.47E-10 | 6.28E-10 | 1.12E-09 | 1.18E-11 | 1.08E-10 | 1.58E-09 |
| NC | DALY** | 6.10E-08 | 6.65E-12 | 4.17E-08 | 2.68E-10 | 4.17E-09 | 1.23E-09 | 1.29E-09 | 1.78E-09 | 1.43E-09 | 5.25E-09 | 1.20E-09 | 1.60E-10 | 1.46E-10 | 2.30E-09 |
| RI | DALY** | 3.78E-07 | 3.95E-09 | 3.49E-08 | 1.15E-07 | 6.57E-08 | 1.20E-08 | 2.01E-08 | 1.59E-08 | 2.44E-08 | 3.90E-08 | 8.44E-09 | 7.39E-10 | 3.80E-09 | 3.42E-08 |
| IR | DALY** | 7.44E-10 | 0.00 | 4.21E-11 | 2.15E-10 | 5.02E-11 | 2.35E-11 | 3.96E-11 | 1.85E-11 | 2.03E-11 | 6.66E-11 | 2.00E-11 | 1.22E-12 | 1.45E-11 | 2.33E-10 |
| OLD | DALY** | 2.11E-11 | 0.00 | 9.90E-13 | -7.32E-12 | 5.25E-12 | 1.06E-12 | 1.63E-12 | 1.46E-12 | 2.00E-12 | 3.06E-12 | 6.80E-13 | 7.04E-14 | 1.00E-12 | 1.13E-11 |
| RO | DALY** | 3.53E-10 | 0.00 | 1.30E-11 | 3.17E-11 | 5.65E-11 | 1.64E-11 | 2.31E-11 | 2.05E-11 | 2.57E-11 | 5.43E-11 | 1.60E-11 | 1.07E-12 | 7.68E-12 | 8.75E-11 |
| AE | PDF*m$^{2}$*yr*** | 1.74E-03 | 9.11E-09 | 1.04E-03 | 8.19E-05 | 9.63E-05 | 2.72E-05 | 3.81E-05 | 3.32E-05 | 3.55E-05 | 9.57E-05 | 2.16E-05 | 2.32E-06 | 1.80E-05 | 2.59E-04 |
| TE | PDF*m$^{2}$*yr*** | 0.38 | 3.61E-06 | 2.62E-01 | 1.06E-03 | 2.23E-02 | 6.18E-03 | 6.21E-03 | 9.33E-03 | 7.62E-03 | 2.66E-02 | 6.09E-03 | 8.40E-04 | 1.55E-03 | 2.56E-02 |
| TAN | PDF*m$^{2}$*yr*** | 3.51E-02 | 7.23E-04 | 4.77E-03 | 2.18E-02 | 2.03E-03 | 4.18E-04 | 5.93E-04 | 6.10E-04 | 8.76E-04 | 1.40E-03 | 2.75E-04 | 2.56E-05 | 1.80E-04 | 1.34E-03 |
| LO | PDF*m$^{2}$*yr*** | 2.52 | 2.43 | 9.07E-02 | 1.00E-03 | 3.78E-04 | 2.31E-04 | 2.43E-04 | 2.36E-04 | 1.48E-04 | 3.96E-04 | 9.24E-05 | 1.59E-05 | 7.73E-05 | 1.34E-03 |
| AA | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | kg $CO_2$ eq | 0.26 | 0.02 | 1.37E-02 | 4.50E-02 | 3.41E-02 | 7.68E-03 | 1.19E-02 | 9.68E-03 | 1.30E-02 | 2.17E-02 | 7.11E-03 | 4.79E-04 | 5.92E-03 | 6.84E-02 |
| NRE | MJ primary | 2.14 | 0.00 | 0.12 | -0.99 | 0.53 | 0.12 | 0.19 | 0.15 | 0.20 | 0.35 | 0.18 | 7.68E-03 | 0.10 | 1.19 |
| ME | MJ primary | 0.00 | 0.00 | 3.19E-04 | -2.81E-03 | 1.08E-03 | 7.43E-04 | 1.32E-03 | 3.11E-04 | 3.58E-04 | 1.16E-03 | 2.53E-04 | 1.93E-05 | 4.44E-05 | 6.53E-04 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

** DALY (Disability-Adjusted Life Year) is a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death.

*** PDF (Potential Damage Fraction) is the fraction of species that have a high probability of not surviving in the affected area due to unfavorable living conditions.

**Table 23.** Weighing evaluation per impact category for organic barley cultivation process (with reference to 1ha FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Compost | Ploughing | Rolling | Harrowing | Sowing | Compost spreader | Harvesting | Bailing | Loading bales | Transport. lorry 7.5-16t, EURO4 | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Pt | 2.38 | 1.35 | 0.29 | 0.12 | 0.14 | 2.99E-02 | 4.54E-02 | 3.93E-02 | 5.22E-02 | 9.69E-02 | 2.87E-02 | 2.17E-03 | 1.47E-02 | 0.17 |
| CA | Pt | 3.58E-03 | 0.00 | 1.80E-04 | -1.95E-03 | 6.94E-04 | 2.11E-04 | 3.37E-04 | 2.16E-04 | 2.61E-04 | 6.64E-04 | 1.18E-03 | 1.24E-05 | 1.14E-04 | 1.67E-03 |
| NC | Pt | 6.44E-02 | 7.03E-06 | 4.41E-02 | 2.83E-04 | 4.41E-03 | 1.30E-03 | 1.36E-03 | 1.88E-03 | 1.51E-03 | 5.55E-03 | 1.25E-03 | 1.68E-04 | 1.54E-04 | 2.43E-03 |
| RI | Pt | 0.40 | 4.18E-03 | 3.69E-02 | 1.22E-01 | 6.94E-02 | 1.27E-02 | 2.12E-02 | 1.68E-02 | 2.57E-02 | 4.12E-02 | 8.84E-03 | 7.73E-04 | 4.01E-03 | 3.61E-02 |
| IR | Pt | 7.86E-04 | 0.00 | 4.45E-05 | 2.27E-04 | 5.30E-05 | 2.48E-05 | 4.18E-05 | 1.95E-05 | 2.15E-05 | 7.04E-05 | 2.09E-05 | 1.28E-06 | 1.53E-05 | 2.46E-04 |
| OLD | Pt | 2.23E-05 | 0.00 | 1.05E-06 | -7.74E-06 | 5.55E-06 | 1.12E-06 | 1.72E-06 | 1.54E-06 | 2.11E-06 | 3.23E-06 | 7.12E-07 | 7.37E-08 | 1.06E-06 | 1.19E-05 |
| RO | Pt | 3.73E-04 | 0.00 | 1.37E-05 | 3.35E-05 | 5.96E-05 | 1.73E-05 | 2.44E-05 | 2.16E-05 | 2.72E-05 | 5.74E-05 | 1.67E-05 | 1.12E-06 | 8.11E-06 | 9.25E-05 |
| AE | Pt | 9.54E-04 | 4.99E-09 | 5.66E-04 | 4.48E-05 | 5.27E-05 | 1.49E-05 | 2.08E-05 | 1.81E-05 | 1.95E-05 | 5.23E-05 | 1.17E-05 | 1.26E-06 | 9.85E-06 | 1.42E-04 |
| TE | Pt | 0.21 | 1.97E-06 | 0.14 | 5.79E-04 | 1.22E-02 | 3.38E-03 | 3.40E-03 | 5.10E-03 | 4.17E-03 | 1.45E-02 | 3.30E-03 | 4.55E-04 | 8.48E-04 | 1.40E-02 |
| TAN | Pt | 1.92E-02 | 3.96E-04 | 2.61E-03 | 1.19E-02 | 1.11E-03 | 2.29E-04 | 3.24E-04 | 3.34E-04 | 4.79E-04 | 7.65E-04 | 1.49E-04 | 1.39E-05 | 9.83E-05 | 7.31E-04 |
| LO | Pt | 1.38 | 1.33 | 4.96E-02 | 5.49E-04 | 2.07E-04 | 1.27E-04 | 1.33E-04 | 1.29E-04 | 8.08E-05 | 2.17E-04 | 5.01E-05 | 8.64E-06 | 4.23E-05 | 7.35E-04 |
| AA | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | Pt | 0.20 | 1.53E-02 | 1.04E-02 | 3.41E-02 | 2.58E-02 | 5.81E-03 | 9.01E-03 | 7.32E-03 | 9.88E-03 | 1.65E-02 | 5.33E-03 | 3.59E-04 | 4.48E-03 | 5.18E-02 |
| NRE | Pt | 0.11 | 0.00 | 5.82E-03 | -4.89E-02 | 2.59E-02 | 6.05E-03 | 9.47E-03 | 7.46E-03 | 9.96E-03 | 1.73E-02 | 8.56E-03 | 3.75E-04 | 4.94E-03 | 5.85E-02 |
| ME | Pt | 1.69E-04 | 0.00 | 1.57E-05 | -1.39E-04 | 5.31E-05 | 3.66E-05 | 6.49E-05 | 1.53E-05 | 1.77E-05 | 5.71E-05 | 1.23E-05 | 9.45E-07 | 2.19E-06 | 3.22E-05 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

**Table 24.** Weighing evaluation per impact category for organic barley cultivation process (with reference to 1kg FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Compost | Ploughing | Rolling | Harrowing | Sowing | Compost spreader | Harvesting | Bailing | Loading bales | Transport. lorry 7.5-16t, EURO4 | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Pt | 3.17E-04 | 1.80E-04 | 3.92E-05 | 1.58E-05 | 1.87E-05 | 3.99E-06 | 6.06E-06 | 5.24E-06 | 6.96E-06 | 1.29E-05 | 3.87E-06 | 2.92E-07 | 1.96E-06 | 2.22E-05 |
| CA | Pt | 4.79E-07 | 0.00 | 2.41E-08 | -2.61E-07 | 9.26E-08 | 2.82E-08 | 4.50E-08 | 2.88E-08 | 3.48E-08 | 8.86E-08 | 1.59E-07 | 1.67E-09 | 1.52E-08 | 2.23E-07 |
| NC | Pt | 8.59E-06 | 9.37E-10 | 5.88E-06 | 3.77E-08 | 5.88E-07 | 1.73E-07 | 1.81E-07 | 2.51E-07 | 2.02E-07 | 7.41E-07 | 1.69E-07 | 2.26E-08 | 2.06E-08 | 3.24E-07 |
| RI | Pt | 5.33E-05 | 5.57E-07 | 4.92E-06 | 1.62E-05 | 9.27E-06 | 1.70E-06 | 2.83E-06 | 2.24E-06 | 3.43E-06 | 5.50E-06 | 1.19E-06 | 1.04E-07 | 5.35E-07 | 4.82E-06 |
| IR | Pt | 1.05E-07 | 0.00 | 5.94E-09 | 3.03E-08 | 7.07E-09 | 3.31E-09 | 5.58E-09 | 2.61E-09 | 2.86E-09 | 9.39E-09 | 2.82E-09 | 1.72E-10 | 2.04E-09 | 3.29E-08 |
| OLD | Pt | 2.98E-09 | 0.00 | 1.40E-10 | -1.03E-09 | 7.41E-10 | 1.50E-10 | 2.29E-10 | 2.06E-10 | 2.82E-10 | 4.31E-10 | 9.59E-11 | 9.93E-12 | 1.41E-10 | 1.59E-09 |
| RO | Pt | 4.98E-08 | 0.00 | 1.83E-09 | 4.46E-09 | 7.96E-09 | 2.31E-09 | 3.25E-09 | 2.89E-09 | 3.63E-09 | 7.66E-09 | 2.25E-09 | 1.51E-10 | 1.08E-09 | 1.23E-08 |
| AE | Pt | 1.27E-07 | 6.65E-13 | 7.56E-08 | 5.98E-09 | 7.03E-09 | 1.99E-09 | 2.78E-09 | 2.42E-09 | 2.59E-09 | 6.98E-09 | 1.58E-09 | 1.69E-10 | 1.31E-09 | 1.89E-08 |
| TE | Pt | 2.74E-05 | 2.63E-10 | 1.91E-05 | 7.73E-08 | 1.63E-06 | 4.51E-07 | 4.54E-07 | 6.81E-07 | 5.57E-07 | 1.94E-06 | 4.45E-07 | 6.13E-08 | 1.13E-07 | 1.87E-06 |
| TAN | Pt | 2.56E-06 | 5.28E-08 | 3.48E-07 | 1.59E-06 | 1.48E-07 | 3.05E-08 | 4.33E-08 | 4.45E-08 | 6.39E-08 | 1.02E-07 | 2.01E-08 | 1.87E-09 | 1.31E-08 | 9.75E-08 |
| LO | Pt | 1.84E-04 | 1.77E-04 | 6.62E-06 | 7.33E-08 | 2.76E-08 | 1.69E-08 | 1.77E-08 | 1.72E-08 | 1.08E-08 | 2.89E-08 | 6.74E-09 | 1.16E-09 | 5.65E-09 | 9.80E-08 |
| AA | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | Pt | 2.62E-05 | 2.05E-06 | 1.39E-06 | 4.54E-06 | 3.45E-06 | 7.76E-07 | 1.20E-06 | 9.77E-07 | 1.32E-06 | 2.20E-06 | 7.18E-07 | 4.83E-08 | 5.98E-07 | 6.91E-06 |
| NRE | Pt | 1.41E-05 | 0.00 | 7.77E-07 | -6.52E-06 | 3.46E-06 | 8.07E-07 | 1.26E-06 | 9.96E-07 | 1.33E-06 | 2.30E-06 | 1.15E-06 | 5.05E-08 | 6.59E-07 | 7.80E-06 |
| ME | Pt | 2.26E-08 | 0.00 | 2.10E-09 | -1.85E-08 | 7.08E-09 | 4.89E-09 | 8.66E-09 | 2.04E-09 | 2.36E-09 | 7.62E-09 | 1.66E-09 | 1.27E-10 | 2.92E-10 | 4.30E-09 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

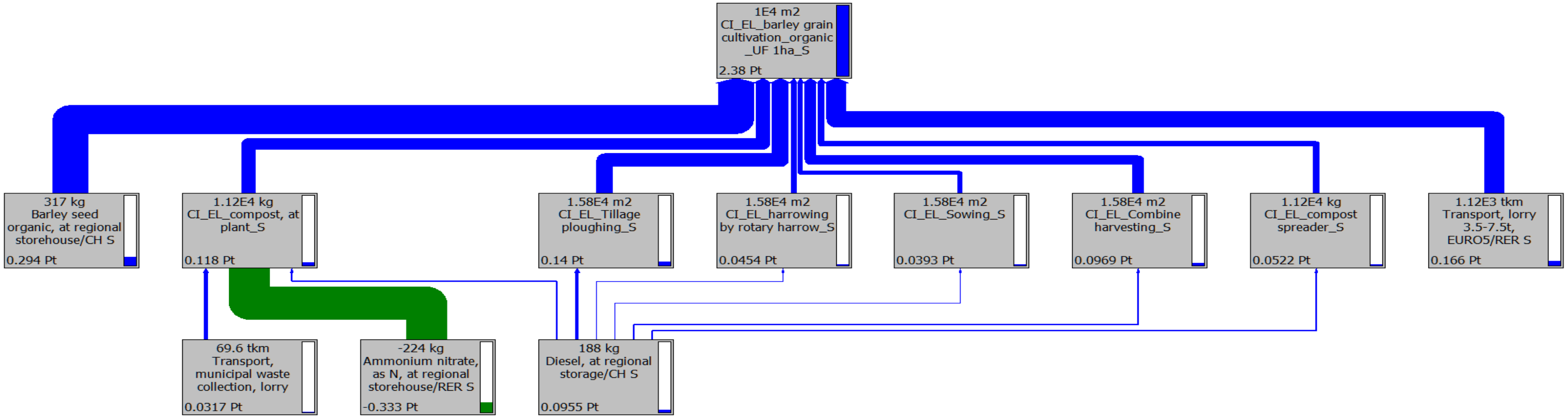


**Figure 39.** Damages flows for organic barley cultivation process (with reference to 1ha FU).

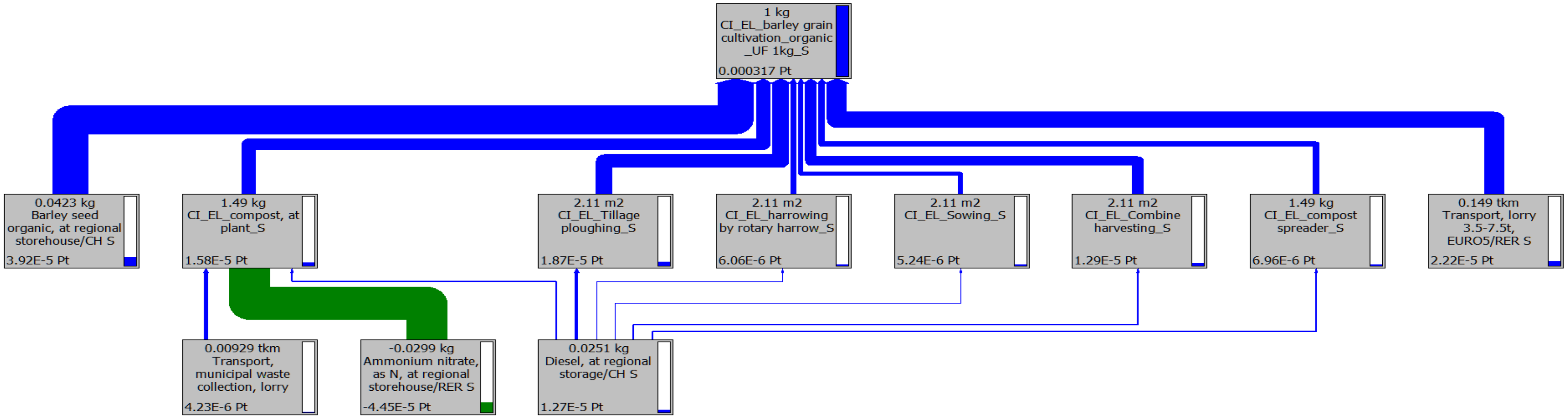


**Figure 40.** Damages flows for organic barley cultivation process (with reference to 1kg FU).

#### 3.2.3.3. Conventional barley cultivation

For each impact category at the midpoint level, a specific analysis was performed to understand the impact of each agricultural step on the final result for each category. Figures 41 and 42 present the analysis of characterization factors at midpoint level. The overall long-term effects that each single process, considered in the evaluation of conventional barley cultivation, cause on impact categories considering an infinite time horizon are expressed in percentage, with reference both to 1 ha FU (Figure 41) and 1 kg FU (Figure 42). At midpoint level, there are no difference in percent results, using different FUs. Production of ammonium nitrate (as N) is the process that has the greatest impacts on all impact categories, except for Land occupation (LO) which suffers the impact of the entire process of cultivation of conventional barley. Other relevant contributions on all impact categories derive from agricultural practices of harvesting and ploughing, as also found by Fedele *et al.* (2014).

Tables 25 and 26 show midpoint characterization scores expressed in kg-equivalents of a substance compared to a reference substance for each process involved in the cultivation of barley in conventional farming: Table 25 refers to 1 ha FU, while Table 26 refers to 1 kg FU. Tables 25 and 26 confirm general finding of Figures 41 and 42, although expressing characterization scores in kg-equivalents of a substance highlights the difference in magnitude of results when FU changes: land-based FU amplifies the effects of process on impact categories. Considering the total effect of that cultivation of barley in conventional farming and related processes, Aquatic and Terrestrial ecotoxicity (AE and TE) are the impact categories that suffer the greatest effects. AE accounts for 125,745.44 kg-equivalents of triethylene glycol (TEG) into water when 1 ha is the FU (Table 25), compared to 12.20 kg-equivalents of TEG into water using 1 kg as FU (Table 26). TE accounts for 116,175.86 kg-equivalents of TEG into soil when 1 ha is the FU (Table 25), compared to 11.60 kg-equivalents of TEG into water using 1 kg as FU (Table 26). Relevant is also the overall effect on LO which accounts for 17,045.35 $m^2$-equivalents of organic arable land per year using land-based FU (Table 25) and for 1.56 $m^2$-equivalents of organic arable land per year using mass-based FU (Table 26). AE, TE, and LO contribute to create damage to Ecosystem quality (EQ) at endpoint level. Other important effects influence Non-renewable energy (NRE), that affects Resources (R) at endpoint level, and Ionizing radiation (IR), that affects Human health (HH) at endpoint level.

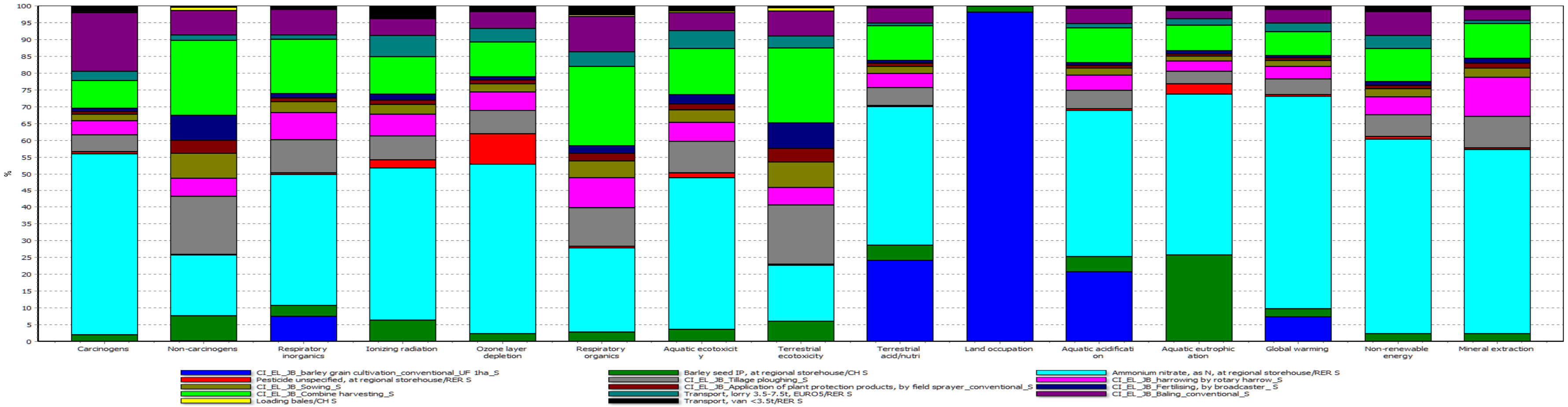


**Figure 41.** Characterization per impact category for conventional barley cultivation processes (with reference to 1ha FU).

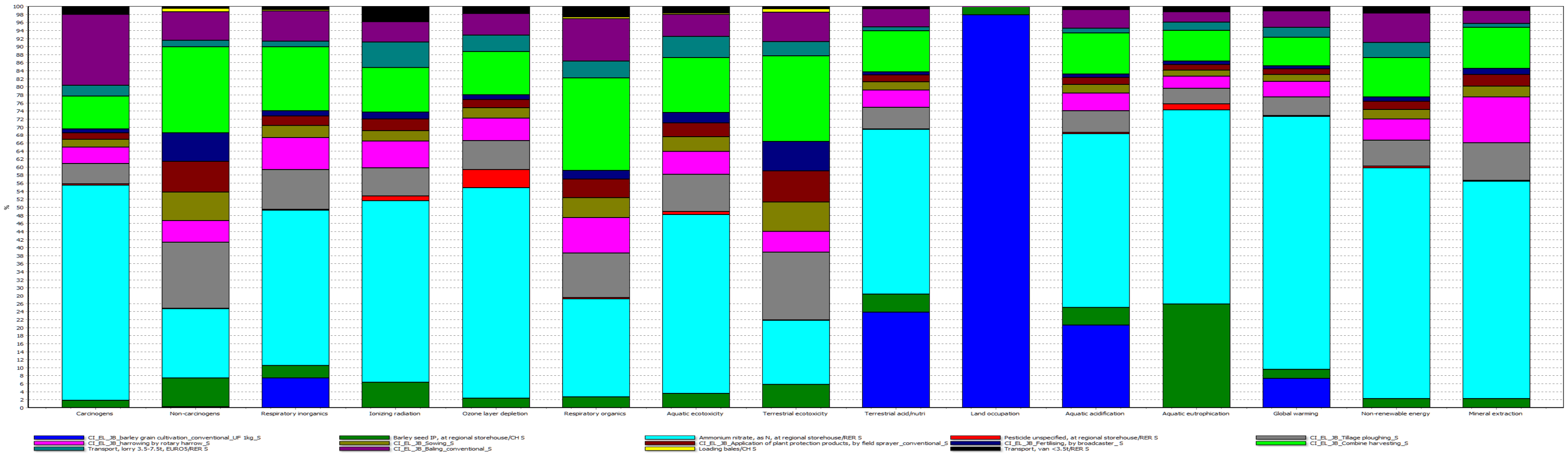


**Figure 42.** Characterization per impact category for conventional barley cultivation processes (with reference to 1kg FU).

**Table 25.** Characterization per impact category for conventional barley cultivation processes (with reference to 1ha FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Ammonium nitrate (N) | Pesticide | Ploughing | Harrowing | Sowing | Application of plant protection products | Fertilizing | Harvesting | Bailing | Loading bales | Transport, van<3.5t | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | kg $C_2H_3Cl$ eq | 26.39 | 0.00 | 0.50 | 14.24 | 0.20 | 1.32 | 1.10 | 0.49 | 0.22 | 0.26 | 2.17 | 4.60 | 4.46E-02 | 0.50 | 0.73 |
| NC | kg $C_2H_3Cl$ eq | 64.01 | 0.14 | 4.77 | 11.50 | 0.18 | 11.01 | 3.53 | 4.74 | 2.53 | 4.73 | 14.23 | 4.64 | 0.60 | 0.34 | 1.07 |
| RI | kg PM2.5 eq | 4.50 | 0.34 | 0.14 | 1.77 | 1.71E-02 | 0.45 | 0.37 | 0.14 | 5.38E-02 | 5.74E-02 | 0.72 | 0.34 | 1.11E-02 | 4.05E-02 | 6.34E-02 |
| IR | Bq C-14 eq | 23,003.48 | 0.00 | 1,463.59 | 10,441.78 | 554.67 | 1,619.74 | 1,509.83 | 639.21 | 326.85 | 392.90 | 2,566.91 | 1,148.08 | 61.21 | 837.24 | 1,441.49 |
| OLD | kg CFC-11 eq | 3.53E-04 | 0.00 | 7.84E-06 | 1.78E-04 | 3.24E-05 | 2.43E-05 | 1.92E-05 | 8.78E-06 | 3.61E-06 | 3.70E-06 | 3.65E-05 | 1.80E-05 | 7.08E-07 | 5.36E-06 | 1.39E-05 |
| RO | kg $C_2H_4$ eq | 1.24 | 0.00 | 3.44E-02 | 0.31 | 7.32E-03 | 0.14 | 0.11 | 6.27E-02 | 2.91E-02 | 2.80E-02 | 0.29 | 0.13 | 5.30E-03 | 3.39E-02 | 5.33E-02 |
| AE | kg TEG water | 125,745.44 | 10.81 | 4,544.54 | 56,743.93 | 1,864.63 | 11,700.35 | 7,223.18 | 4,617.97 | 2,254.60 | 3,373.75 | 17,266.92 | 6,821.29 | 487.94 | 2,130.40 | 6,705.13 |
| TE | kg TEG soil | 116,175.86 | 27.15 | 6,914.78 | 19,382.98 | 241.80 | 20,514.60 | 6,254.62 | 8,756.13 | 4,669.72 | 8,813.14 | 25,869.31 | 8,669.47 | 1,120.41 | 743.77 | 4,197.97 |
| TAN | kg $SO_2$ eq | 172.41 | 41.43 | 7.95 | 71.33 | 0.35 | 9.22 | 7.44 | 3.64 | 1.47 | 1.37 | 17.78 | 7.58 | 0.26 | 0.93 | 1.67 |
| LO | m$^2$org.arable | 17,045.35 | 16,702.22 | 322.43 | 7.29 | 7.09E-02 | 2.50 | 1.73 | 1.61 | 0.60 | 0.53 | 2.83 | 0.98 | 0.15 | 0.82 | 1.60 |
| AA | kg $SO_2$ eq | 25.17 | 5.21 | 1.12 | 10.98 | 0.15 | 1.38 | 1.12 | 0.54 | 0.22 | 0.21 | 2.59 | 1.16 | 3.94E-02 | 0.17 | 0.30 |
| AEU | kg $PO_4$ P-lim | 0.53 | 0.00 | 0.14 | 0.25 | 1.60E-02 | 2.03E-02 | 1.60E-02 | 7.81E-03 | 3.63E-03 | 4.58E-03 | 3.99E-02 | 1.34E-02 | 7.39E-04 | 6.57E-03 | 1.04E-02 |
| GW | kg $CO_2$ eq | 3,612.51 | 264.74 | 83.65 | 2,289.10 | 15.65 | 170.66 | 137.96 | 61.83 | 26.05 | 26.54 | 258.03 | 147.21 | 5.05 | 37.23 | 88.81 |
| NRE | MJ primary | 40,804.62 | 0.00 | 933.37 | 23,627.12 | 331.70 | 2,672.17 | 2,172.39 | 977.47 | 417.74 | 440.54 | 4,041.23 | 2,928.92 | 81.01 | 641.77 | 1,539.21 |
| ME | MJ surplus | 84.90 | 0.00 | 1.97 | 46.59 | 0.35 | 8.00 | 9.90 | 2.32 | 1.25 | 1.25 | 8.74 | 2.72 | 0.20 | 0.74 | 0.85 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

**Table 26.** Characterization per impact category for conventional barley cultivation processes (with reference to 1kg FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Ammonium nitrate (N) | Pesticide | Ploughing | Harrowing | Sowing | Application of plant protection products | Fertilizing | Harvesting | Bailing | Loading bales | Transport, van<3.5t | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | kg $C_2H_3Cl$ eq | 2.55E-03 | 0.00 | 4.77E-05 | 1.37E-03 | 9.00E-06 | 1.27E-04 | 1.06E-04 | 4.73E-05 | 4.31E-05 | 2.53E-05 | 2.08E-04 | 4.48E-04 | 4.34E-06 | 4.78E-05 | 7.03E-05 |
| NC | kg $C_2H_3Cl$ eq | 6.39E-03 | 1.36E-05 | 4.58E-04 | 1.10E-03 | 8.44E-06 | 1.06E-03 | 3.39E-04 | 4.55E-04 | 4.86E-04 | 4.54E-04 | 1.37E-03 | 4.51E-04 | 5.88E-05 | 3.22E-05 | 1.02E-04 |
| RI | kg PM2.5 eq | 4.37E-04 | 3.23E-05 | 1.36E-05 | 1.69E-04 | 7.82E-07 | 4.30E-05 | 3.51E-05 | 1.36E-05 | 1.03E-05 | 5.51E-06 | 6.95E-05 | 3.30E-05 | 1.08E-06 | 3.88E-06 | 6.09E-06 |
| IR | Bq C-14 eq | 2.21 | 0.00 | 0.14 | 1.00 | 2.53E-02 | 0.16 | 0.14 | 6.14E-02 | 6.28E-02 | 3.77E-02 | 0.25 | 0.11 | 5.95E-03 | 8.02E-02 | 0.14 |
| OLD | kg CFC-11 eq | 3.26E-08 | 0.00 | 7.53E-10 | 1.71E-08 | 1.48E-09 | 2.34E-09 | 1.84E-09 | 8.43E-10 | 6.93E-10 | 3.55E-10 | 3.51E-09 | 1.75E-09 | 6.88E-11 | 5.13E-10 | 1.34E-09 |
| RO | kg $C_2H_4$ eq | 1.22E-04 | 0.00 | 3.30E-06 | 2.98E-05 | 3.34E-07 | 1.36E-05 | 1.07E-05 | 6.02E-06 | 5.59E-06 | 2.69E-06 | 2.80E-05 | 1.28E-05 | 5.15E-07 | 3.24E-06 | 5.12E-06 |
| AE | kg TEG water | 12.20 | 1.04E-03 | 0.44 | 5.45 | 8.51E-02 | 1.12 | 0.69 | 0.44 | 0.43 | 0.32 | 1.66 | 0.66 | 4.74E-02 | 0.20 | 0.64 |
| TE | kg TEG soil | 11.60 | 2.61E-03 | 0.66 | 1.86 | 1.10E-02 | 1.97 | 0.60 | 0.84 | 0.90 | 0.85 | 2.48 | 0.84 | 0.11 | 7.12E-02 | 0.40 |
| TAN | kg $SO_2$ eq | 1.67E-02 | 3.98E-03 | 7.63E-04 | 6.85E-03 | 1.60E-05 | 8.85E-04 | 7.15E-04 | 3.49E-04 | 2.82E-04 | 1.31E-04 | 1.71E-03 | 7.37E-04 | 2.52E-05 | 8.94E-05 | 1.60E-04 |
| LO | m$^2$org.arable | 1.56 | 1.52 | 3.10E-02 | 7.00E-04 | 3.24E-06 | 2.40E-04 | 1.66E-04 | 1.54E-04 | 1.15E-04 | 5.09E-05 | 2.72E-04 | 9.50E-05 | 1.50E-05 | 7.88E-05 | 1.54E-04 |
| AA | kg $SO_2$ eq | 2.43E-03 | 5.00E-04 | 1.08E-04 | 1.05E-03 | 6.70E-06 | 1.32E-04 | 1.07E-04 | 5.16E-05 | 4.22E-05 | 2.02E-05 | 2.48E-04 | 1.12E-04 | 3.83E-06 | 1.59E-05 | 2.91E-05 |
| AEU | kg $PO_4$ P-lim | 5.03E-05 | 0.00 | 1.30E-05 | 2.44E-05 | 7.30E-07 | 1.95E-06 | 1.54E-06 | 7.50E-07 | 6.97E-07 | 4.40E-07 | 3.84E-06 | 1.30E-06 | 7.19E-08 | 6.30E-07 | 9.94E-07 |
| GW | kg $CO_2$ eq | 0.35 | 2.54E-02 | 8.03E-03 | 0.22 | 7.14E-04 | 1.64E-02 | 1.32E-02 | 5.94E-03 | 5.00E-03 | 2.55E-03 | 2.48E-02 | 1.43E-02 | 4.91E-04 | 3.57E-03 | 8.53E-03 |
| NRE | MJ primary | 3.94 | 0.00 | 8.96E-02 | 2.27 | 1.51E-02 | 0.26 | 0.21 | 9.39E-02 | 8.02E-02 | 4.23E-02 | 0.39 | 0.28 | 7.87E-03 | 6.15E-02 | 0.15 |
| ME | MJ surplus | 8.26E-03 | 0.00 | 1.90E-04 | 4.47E-03 | 1.62E-05 | 7.68E-04 | 9.51E-04 | 2.23E-04 | 2.41E-04 | 1.20E-04 | 8.40E-04 | 2.64E-04 | 1.98E-05 | 7.05E-05 | 8.14E-05 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

Results obtained at the midpoint level can be used to explain the impact assessment obtained at the endpoint level in terms of the damage category. The endpoint analysis collects the impact categories into four damage categories (namely Human health (HH), Ecosystem quality (EQ), Climate change (CC), Resource (R)), throughout specific conversion factors provided by Impact 2002+. Figures 43 and 44 show the environmental impacts related to barley cultivation in conventional farming, classified by damage categories. The environmental impacts are expressed as weighing points (pt) and refer to both land-based FU (1 ha of land for grain and 1.083 ha of land for straw) (Figure 43) and mass-based FU (1 kg of grain and 1.1 kg of straw) (Figure 44). Considering the whole process, from the figures it is straightforward that the cultivation of conventional barley produces the greatest impacts on EQ. All the other involved processes have a more or less impacting influence on HH. Considering distinct FUs what changes in the allocation of environmental burdens is the magnitude of each impacts, while the general contribution of each process is the same both with land-based and mass-based FUs. Table 27 and 28 shows the total damage related to barley cultivation in conventional farming, using either land-based and mass-based FUs. The total damage is classified among damage categories (HH, EQ, CC, R) and is expressed as damage assessment value, computed by using conversion factors specifically assigned in Impact 2002+ (Table 27), and as weighing point (pt) (Table 28). The total damage related to cultivation of barley in conventional farming is equal to 2.55 pt, when the analysis relies upon the land-based FU; in comparison, it is 2.40E-04 pt, when the analysis relies upon the mass-based FU (Table 28). Figures and tables highlights how the difference in magnitude of the total damage, from a FU to another, is noteworthy; however, the percentage contribution of each process, involved in cultivation of barley in conventional farming, in generating environmental impacts does not show significant differences between the utilization of 1 ha and 1 kg as FU[22]. The overall damage caused on EQ is almost entirely attributable to the whole process of cultivation of conventional barley (more than 90%) and to the phase of production of conventional seed (about 7%): the former accounts for 18,248.73 PDF*$m^2$*yr using a land-based FU and for 1.66 PDF*$m^2$*yr using a mass-based FU; the latter accounts for 414.63 PDF*$m^2$*yr when 1 ha is the FU and for 3.98E-02 PDF*$m^2$*yr when 1 kg is the FU (Table 27). The production of ammonium nitrate as N causes a relevant damage of almost 65% on CC (2,289.10 kg $CO_2$ eq with 1 ha as FU and 0.22 kg $CO_2$ eq with 1 kg as FU), approximately of 60% on R (23,673.71 MJ with 1 ha as FU and 2.27 MJ with 1 kg as FU), of about 45-50% on HH (1.31E-03 DALY with 1 ha as FU and 1.26E-07 DALY with 1 kg as FU); negligible is the impact of transportations on EQ (Table 27). Other contributions derive from harvesting, bailing, ploughing, and harrowing, which damages on HH, CC, and R range between 10% and 20%.

[22] In this regard, Figure 69 and 70 in the Appendix (Section *ii. Conventional barley cultivation*) show the percentage contribution of each process, involved in cultivation of barley in organic farming, in generating environmental impacts. The environmental impacts are classified by damage categories (HH, EQ, CC, R) and they refer both to land-based FU (1 ha of land for grain and 1.083 ha of land for straw) (Figure 69) and to mass-based FU (1 kg of grain and 1.1 kg of straw) (Figure 70).

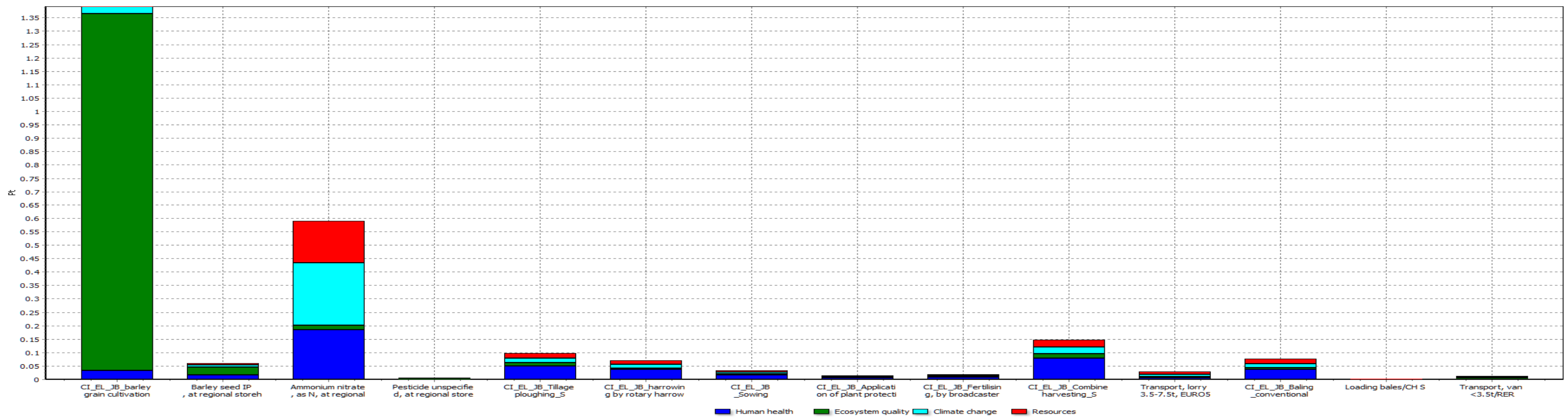


**Figure 43.** Weighing evaluation per damage category for conventional barley cultivation processes (with reference to 1ha FU).

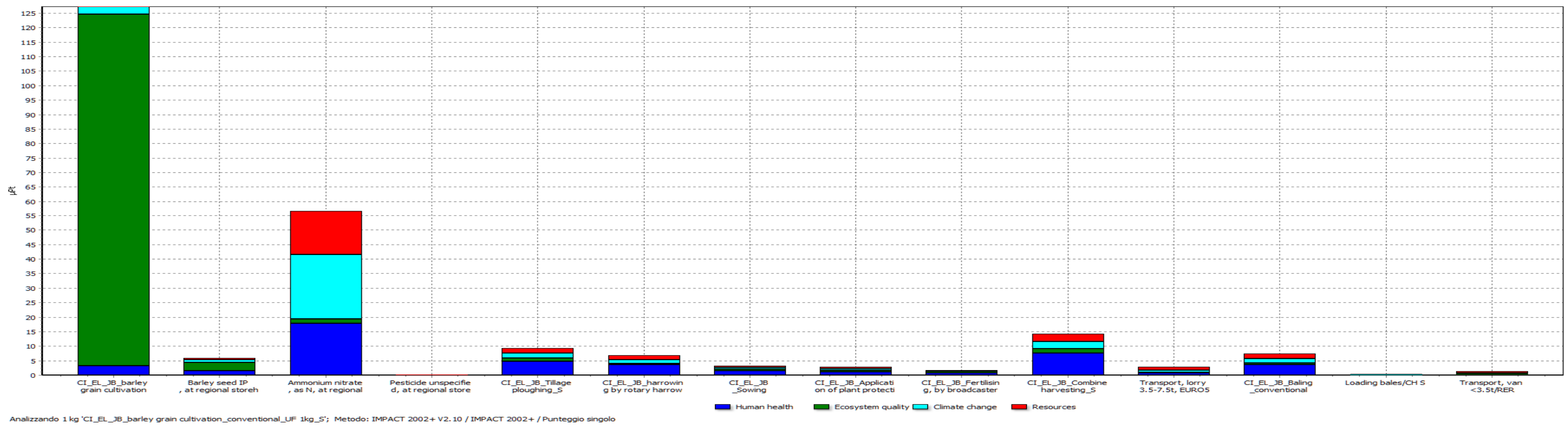


**Figure 44.** Weighing evaluation per damage category for conventional barley cultivation processes (with reference to 1kg FU).

**Table 27.** Damages assessment for conventional barley cultivation process (with reference to 1ha and 1kg FUs).

| | DAMAGE CATEGORY* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | HH (DALY)** | | EQ ($PDF*m^2*yr$)*** | | CC (kg $CO_2$ eq) | | R (MJ primary) | |
| | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| Total | 3.41E-03 | 3.32E-07 | 19,684.00 | 1.81 | 3,612.51 | 0.35 | 40,889.52 | 3.95 |
| Cultivation | 2.36E-04 | 2.26E-08 | 18,248.73 | 1.66 | 264.74 | 0.03 | 0.00 | 0.00 |
| Seed | 1.14E-04 | 1.10E-08 | 414.63 | 3.98E-02 | 83.65 | 8.03E-03 | 935.34 | 0.09 |
| Ammonium nitrate (N) | 1.31E-03 | 1.26E-07 | 238.29 | 2.29E-02 | 2,289.10 | 0.22 | 23,673.71 | 2.27 |
| Pesticide | 1.32E-05 | 6.04E-10 | 2.45 | 1.12E-04 | 15.65 | 7.14E-04 | 332.05 | 0.02 |
| Ploughing | 3.49E-04 | 3.35E-08 | 175.17 | 1.68E-02 | 170.66 | 0.02 | 2,680.17 | 0.26 |
| Harrowing | 2.70E-04 | 2.59E-08 | 59.46 | 5.71E-03 | 137.96 | 0.01 | 2,182.29 | 0.21 |
| Sowing | 1.14E-04 | 1.09E-08 | 75.03 | 7.20E-03 | 61.83 | 5.94E-03 | 979.79 | 0.09 |
| Application of plant protection products | 4.55E-05 | 8.73E-09 | 39.23 | 7.53E-03 | 26.05 | 5.00E-03 | 418.99 | 0.08 |
| Fertilizing | 5.43E-05 | 5.22E-09 | 71.88 | 6.90E-03 | 26.54 | 2.55E-03 | 441.79 | 0.04 |
| Harvesting | 5.54E-04 | 5.32E-08 | 227.07 | 2.18E-02 | 258.03 | 0.02 | 4,049.98 | 0.39 |
| Bailing | 2.64E-04 | 2.56E-08 | 77.87 | 7.57E-03 | 147.21 | 0.01 | 2,931.64 | 0.28 |
| Loading bales | 9.64E-06 | 9.37E-10 | 9.32 | 9.06E-04 | 5.05 | 4.91E-04 | 81.21 | 0.01 |
| Transport, van<3.5t | 3.09E-05 | 2.96E-09 | 7.86 | 7.53E-04 | 37.23 | 3.57E-03 | 642.51 | 0.06 |
| Transport, lorry 3.5-7.5t, EURO5 | 4.99E-05 | 4.79E-09 | 37.02 | 3.55E-03 | 88.81 | 8.53E-03 | 1,540.06 | 0.15 |

* Damage categories are Human health (HH), Ecosystem quality (EQ), Climate change (CC), and Resources (R).

** DALY (Disability-Adjusted Life Year) is a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death.

*** PDF (Potential Damage Fraction) is the fraction of species that have a high probability of not surviving in the affected area due to unfavorable living conditions.

**Table 28.** Weighing evaluation per damage category for conventional barley cultivation process (with reference to 1ha and 1kg FUs).

| | Unit | Total | | DAMAGE CATEGORY* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | HH | | EQ | | CC | | R | |
| | | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| Total | Pt | 2.55 | 2.40E-04 | 0.48 | 4.68E-05 | 1.44 | 1.32E-04 | 0.36 | 3.52E-05 | 0.27 | 2.60E-05 |
| Cultivation | Pt | 1.39 | 1.27E-04 | 3.33E-02 | 3.19E-06 | 1.33 | 1.22E-04 | 2.67E-02 | 2.56E-06 | 0.00 | 0.00 |
| Seed | Pt | 6.10E-02 | 5.86E-06 | 1.61E-02 | 1.55E-06 | 3.03E-02 | 2.91E-06 | 8.45E-03 | 8.11E-07 | 6.15E-03 | 5.91E-07 |
| Ammonium nitrate (N) | Pt | 0.59 | 5.66E-05 | 0.18 | 1.77E-05 | 1.74E-02 | 1.67E-06 | 0.23 | 2.22E-05 | 0.16 | 1.50E-05 |
| Pesticide | Pt | 5.81E-03 | 2.65E-07 | 1.86E-03 | 8.51E-08 | 1.79E-04 | 8.16E-09 | 1.58E-03 | 7.22E-08 | 2.18E-03 | 9.98E-08 |
| Ploughing | Pt | 9.68E-02 | 9.30E-06 | 4.92E-02 | 4.72E-06 | 1.28E-02 | 1.23E-06 | 1.72E-02 | 1.65E-06 | 1.76E-02 | 1.69E-06 |
| Harrowing | Pt | 7.06E-02 | 6.78E-06 | 3.80E-02 | 3.65E-06 | 4.34E-03 | 4.17E-07 | 1.39E-02 | 1.34E-06 | 1.44E-02 | 1.38E-06 |
| Sowing | Pt | 3.42E-02 | 3.28E-06 | 1.60E-02 | 1.54E-06 | 5.48E-03 | 5.26E-07 | 6.24E-03 | 6.00E-07 | 6.45E-03 | 6.19E-07 |
| Application of plant protection products | Pt | 1.47E-02 | 2.82E-06 | 6.41E-03 | 1.23E-06 | 2.86E-03 | 5.50E-07 | 2.63E-03 | 5.05E-07 | 2.76E-03 | 5.29E-07 |
| Fertilizing | Pt | 1.85E-02 | 1.78E-06 | 7.66E-03 | 7.36E-07 | 5.25E-03 | 5.04E-07 | 2.68E-03 | 2.57E-07 | 2.91E-03 | 2.79E-07 |
| Harvesting | Pt | 0.15 | 1.41E-05 | 7.81E-02 | 7.50E-06 | 1.66E-02 | 1.59E-06 | 2.61E-02 | 2.50E-06 | 2.66E-02 | 2.56E-06 |
| Bailing | Pt | 7.70E-02 | 7.49E-06 | 3.72E-02 | 3.62E-06 | 5.68E-03 | 5.53E-07 | 1.49E-02 | 1.45E-06 | 1.93E-02 | 1.88E-06 |
| Loading bales | Pt | 3.08E-03 | 3.00E-07 | 1.36E-03 | 1.32E-07 | 6.81E-04 | 6.62E-08 | 5.10E-04 | 4.96E-08 | 5.34E-04 | 5.19E-08 |
| Transport, van<3.5t | Pt | 1.29E-02 | 1.24E-06 | 4.36E-03 | 4.18E-07 | 5.74E-04 | 5.49E-08 | 3.76E-03 | 3.60E-07 | 4.23E-03 | 4.05E-07 |
| Transport, lorry 3.5-7.5t, EURO5 | Pt | 2.88E-02 | 2.77E-06 | 7.03E-03 | 6.75E-07 | 2.70E-03 | 2.59E-07 | 8.97E-03 | 8.61E-07 | 1.01E-02 | 9.73E-07 |

* Damage categories are Human health (HH), Ecosystem quality (EQ), Climate change (CC), and Resources (R).

Given the classification of damage categories into impact categories provided by Impact 2002+, the analysis was extended to impacts categories, in order to better explain values obtained at the endpoint level in terms of the damage category. Figures 45 and 46 show the environmental impacts related to barley cultivation in conventional farming, classified by impact categories. The environmental impacts are expressed as weighing points (pt) and refer to both land-based FU (1 ha of land for grain and 1.083 ha of land for straw) (Figure 45) and mass-based FU (1 kg of grain and 1.1 kg of straw) (Figure 46). In addition, Table 29 and 30 shows the total damage related to barley cultivation in conventional farming, classified among impact categories, provided by Impact 2002+. The total damage is expressed as impact assessment value, computed by using conversion factors specifically assigned in Impact 2002+, using land-based FU (Table 29) and mass-based FU (Table 30), and as weighing point (pt) with 1 ha as FU (Table 31) and with 1 kg as FU (Table 32). Considering the whole process, the cultivation of organic barley damages EQ, impacting on LO for more than 97% and on GW, TAN, and RI for the remaining 3%: in particular, LO accounts for 18,205.42 PDF*$m^2$*yr, standardized in 1.33 pt, when 1 ha is the FU (Tables 29 and 31), and for 1.66 PDF*$m^2$*yr, standardized in 1.21E-04 pt, when 1 kg is the FU (Tables 30 and 32). The production of ammonium nitrate as N, as well as harvesting, bailing, ploughing, and harrowing, influence each impact category, except LO, with percentage values ranging from 15% to 65%. Considering distinct FUs what changes in the allocation of environmental burdens is the magnitude of each impacts, while the general contribution of each process is the same both with land-based and mass-based FUs[23].

Figures 47 and 48 show the flow chart of the damages, that materials and processes involved in the system generate to the environment: the former refers to 1 ha of land invested in cultivation of conventional barley grain as FU, the latter use as FU 1 kg of DM conventional barley grain. The flow charts of the damages confirm that production of ammonium nitrate (as N) for the fertilization is the most impacting phase. Other relevant contributions to the environmental impacts related to cultivation of barley in organic farming come agricultural practice of ploughing and harvesting (Figures 47 and 48). Noteworthy is the difference in magnitude of the damage flows from mass-based FU (Figure 48) to land-based FU (Figure 47).

[23] In this regard, Figure 71 and 72 in the Appendix (Section *ii. Conventional barley cultivation*) show the percentage contribution of each process, involved in cultivation of barley in conventional farming, in generating environmental impacts. The environmental impacts are classified by impact categories and they refer both to land-based FU (1 ha of land for grain and 1.083 ha of land for straw) (Figure 71) and to mass-based FU (1 kg of grain and 1.1 kg of straw) (Figure 72).

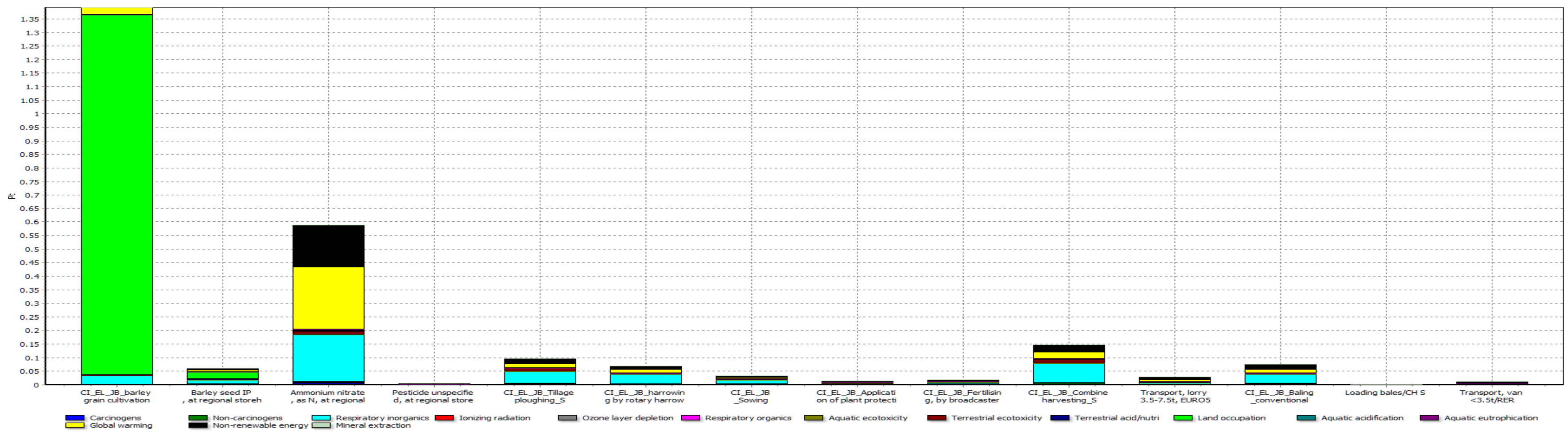


**Figure 45.** Weighing evaluation per impact category for conventional barley cultivation processes (with reference to 1ha FU).

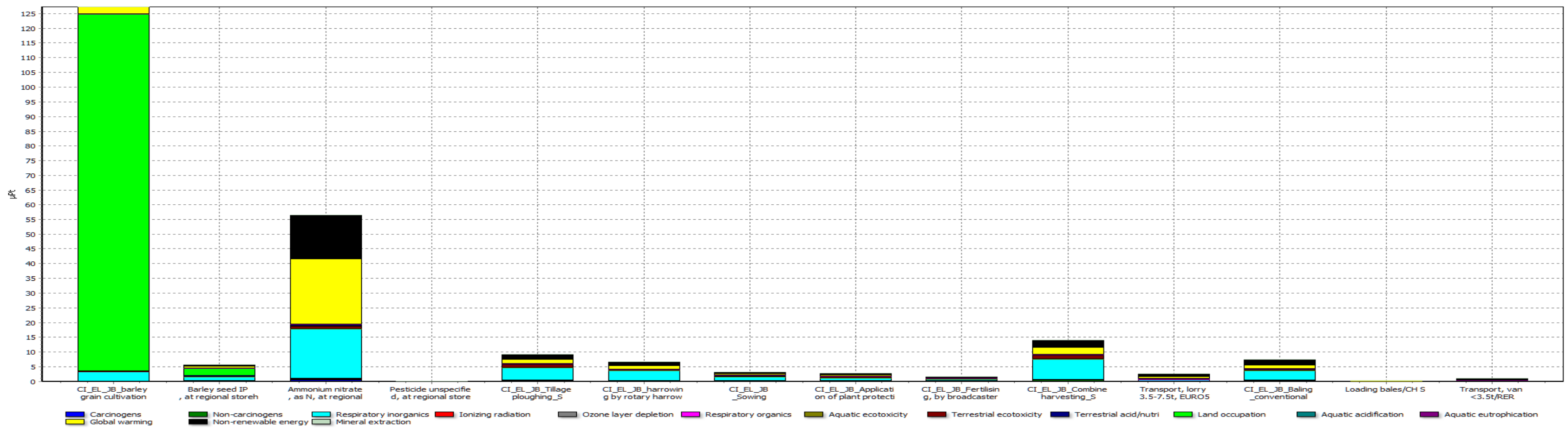


**Figure 46.** Weighing evaluation per impact category for conventional barley cultivation processes (with reference to 1kg FU).

**Table 29.** Impacts assessment for conventional barley cultivation process (with reference to 1ha FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Ammonium nitrate (N) | Pesticide | Ploughing | Harrowing | Sowing | Application of plant protection products | Fertilizing | Harvesting | Bailing | Loading bales | Transport van<3.5t | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | DALY** | 7.39E-05 | 0.00 | 1.39E-06 | 3.99E-05 | 5.52E-07 | 3.71E-06 | 3.09E-06 | 1.38E-06 | 6.29E-07 | 7.38E-07 | 6.06E-06 | 1.29E-05 | 1.25E-07 | 1.40E-06 | 2.05E-06 |
| NC | DALY** | 1.79E-04 | 3.96E-07 | 1.34E-05 | 3.22E-05 | 5.17E-07 | 3.08E-05 | 9.89E-06 | 1.33E-05 | 7.09E-06 | 1.33E-05 | 3.98E-05 | 1.30E-05 | 1.69E-06 | 9.40E-07 | 2.98E-06 |
| RI | DALY** | 3.15E-03 | 2.35E-04 | 9.93E-05 | 1.24E-03 | 1.20E-05 | 3.14E-04 | 2.56E-04 | 9.89E-05 | 3.76E-05 | 4.02E-05 | 5.07E-04 | 2.37E-04 | 7.80E-06 | 2.83E-05 | 4.44E-05 |
| IR | DALY** | 4.83E-06 | 0.00 | 3.07E-07 | 2.19E-06 | 1.16E-07 | 3.40E-07 | 3.17E-07 | 1.34E-07 | 6.86E-08 | 8.25E-08 | 5.39E-07 | 2.41E-07 | 1.29E-08 | 1.76E-07 | 3.03E-07 |
| OLD | DALY** | 3.70E-07 | 0.00 | 8.23E-09 | 1.87E-07 | 3.40E-08 | 2.56E-08 | 2.02E-08 | 9.22E-09 | 3.79E-09 | 3.88E-09 | 3.84E-08 | 1.89E-08 | 7.43E-10 | 5.63E-09 | 1.46E-08 |
| RO | DALY** | 2.64E-06 | 0.00 | 7.33E-08 | 6.60E-07 | 1.56E-08 | 3.02E-07 | 2.37E-07 | 1.33E-07 | 6.20E-08 | 5.97E-08 | 6.22E-07 | 2.81E-07 | 1.13E-08 | 7.21E-08 | 1.14E-07 |
| AE | PDF*m$^2$*yr*** | 6.31 | 5.43E-04 | 0.23 | 2.85 | 9.36E-02 | 0.59 | 0.36 | 0.23 | 0.11 | 0.17 | 0.87 | 0.34 | 2.45E-02 | 0.11 | 0.34 |
| TE | PDF*m$^2$*yr*** | 918.95 | 0.21 | 54.70 | 153.32 | 1.91 | 162.27 | 49.47 | 69.26 | 36.94 | 69.71 | 204.63 | 68.58 | 8.86 | 5.88 | 33.21 |
| TAN | PDF*m$^2$*yr*** | 179.31 | 43.09 | 8.27 | 74.18 | 0.36 | 9.59 | 7.74 | 3.78 | 1.53 | 1.42 | 18.49 | 7.89 | 0.27 | 0.97 | 1.73 |
| LO | PDF*m$^2$*yr*** | 18,579.43 | 18,205.42 | 351.44 | 7.94 | 0.08 | 2.73 | 1.88 | 1.75 | 0.65 | 0.58 | 3.09 | 1.06 | 0.17 | 0.90 | 1.74 |
| AA | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | kg $CO_2$ eq | 3,612.51 | 264.74 | 83.65 | 2,289.10 | 15.65 | 170.66 | 137.96 | 61.83 | 26.05 | 26.54 | 258.03 | 147.21 | 5.05 | 37.23 | 88.81 |
| NRE | MJ primary | 40,804.62 | 0.00 | 933.37 | 23,627.12 | 331.70 | 2,672.17 | 2,172.39 | 977.47 | 417.74 | 440.54 | 4,041.23 | 2,928.92 | 81.01 | 641.77 | 1,539.21 |
| ME | MJ primary | 84.90 | 0.00 | 1.97 | 46.59 | 0.35 | 8.00 | 9.90 | 2.32 | 1.25 | 1.25 | 8.74 | 2.72 | 0.20 | 0.74 | 0.85 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

** DALY (Disability-Adjusted Life Year) is a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death.

*** PDF (Potential Damage Fraction) is the fraction of species that have a high probability of not surviving in the affected area due to unfavorable living conditions.

**Table 30.** Impacts assessment for conventional barley cultivation process (with reference to 1kg FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Ammonium nitrate (N) | Pesticide | Ploughing | Harrowing | Sowing | Application of plant protection products | Fertilizing | Harvesting | Bailing | Loading bales | Transport van<3.5t | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | DALY** | 7.14E-09 | 0.00 | 1.33E-10 | 3.83E-09 | 2.52E-11 | 3.56E-10 | 2.96E-10 | 1.32E-10 | 1.21E-10 | 7.09E-11 | 5.82E-10 | 1.25E-09 | 1.21E-11 | 1.34E-10 | 1.97E-10 |
| NC | DALY** | 1.79E-08 | 3.80E-11 | 1.28E-09 | 3.09E-09 | 2.36E-11 | 2.96E-09 | 9.50E-10 | 1.27E-09 | 1.36E-09 | 1.27E-09 | 3.82E-09 | 1.26E-09 | 1.65E-10 | 9.00E-11 | 2.86E-10 |
| RI | DALY** | 3.06E-07 | 2.26E-08 | 9.54E-09 | 1.19E-07 | 5.47E-10 | 3.01E-08 | 2.46E-08 | 9.49E-09 | 7.23E-09 | 3.86E-09 | 4.86E-08 | 2.31E-08 | 7.58E-10 | 2.72E-09 | 4.26E-09 |
| IR | DALY** | 4.65E-10 | 0.00 | 2.95E-11 | 2.11E-10 | 5.32E-12 | 3.27E-11 | 3.04E-11 | 1.29E-11 | 1.32E-11 | 7.92E-12 | 5.18E-11 | 2.34E-11 | 1.25E-12 | 1.68E-11 | 2.91E-11 |
| OLD | DALY** | 3.42E-11 | 0.00 | 7.91E-13 | 1.80E-11 | 1.55E-12 | 2.45E-12 | 1.94E-12 | 8.85E-13 | 7.28E-13 | 3.73E-13 | 3.68E-12 | 1.84E-12 | 7.22E-14 | 5.39E-13 | 1.40E-12 |
| RO | DALY** | 2.59E-10 | 0.00 | 7.03E-12 | 6.34E-11 | 7.12E-13 | 2.90E-11 | 2.28E-11 | 1.28E-11 | 1.19E-11 | 5.73E-12 | 5.97E-11 | 2.73E-11 | 1.10E-12 | 6.91E-12 | 1.09E-11 |
| AE | PDF*m$^2$*yr*** | 6.13E-04 | 5.21E-08 | 2.19E-05 | 2.74E-04 | 4.27E-06 | 5.64E-05 | 3.48E-05 | 2.23E-05 | 2.17E-05 | 1.63E-05 | 8.32E-05 | 3.33E-05 | 2.38E-06 | 1.02E-05 | 3.23E-05 |
| TE | PDF*m$^2$*yr*** | 9.18E-02 | 2.06E-05 | 5.25E-03 | 1.47E-02 | 8.73E-05 | 1.56E-02 | 4.75E-03 | 6.65E-03 | 7.09E-03 | 6.69E-03 | 1.96E-02 | 6.67E-03 | 8.61E-04 | 5.64E-04 | 3.19E-03 |
| TAN | PDF*m$^2$*yr*** | 1.74E-02 | 4.14E-03 | 7.94E-04 | 7.12E-03 | 1.66E-05 | 9.20E-04 | 7.43E-04 | 3.63E-04 | 2.93E-04 | 1.36E-04 | 1.78E-03 | 7.66E-04 | 2.62E-05 | 9.29E-05 | 1.67E-04 |
| LO | PDF*m$^2$*yr*** | 1.70 | 1.66 | 3.37E-02 | 7.62E-04 | 3.53E-06 | 2.62E-04 | 1.81E-04 | 1.68E-04 | 1.25E-04 | 5.54E-05 | 2.96E-04 | 1.04E-04 | 1.63E-05 | 8.59E-05 | 1.67E-04 |
| AA | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | kg $CO_2$ eq | 0.35 | 2.54E-02 | 8.03E-03 | 0.22 | 7.14E-04 | 1.64E-02 | 1.32E-02 | 5.94E-03 | 5.00E-03 | 2.55E-03 | 2.48E-02 | 1.43E-02 | 4.91E-04 | 3.57E-03 | 8.53E-03 |
| NRE | MJ primary | 3.94 | 0.00 | 8.96E-02 | 2.27 | 1.51E-02 | 0.26 | 0.21 | 9.39E-02 | 8.02E-02 | 4.23E-02 | 0.39 | 0.28 | 7.87E-03 | 6.15E-02 | 0.15 |
| ME | MJ primary | 8.26E-03 | 0.00 | 1.90E-04 | 4.47E-03 | 1.62E-05 | 7.68E-04 | 9.51E-04 | 2.23E-04 | 2.41E-04 | 1.20E-04 | 8.40E-04 | 2.64E-04 | 1.98E-05 | 7.05E-05 | 8.14E-05 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

** DALY (Disability-Adjusted Life Year) is a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death.

*** PDF (Potential Damage Fraction) is the fraction of species that have a high probability of not surviving in the affected area due to unfavorable living conditions.

**Table 31.** Weighing evaluation per impact category for conventional barley cultivation process (with reference to 1ha FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Ammonium nitrate (N) | Pesticide | Ploughing | Harrowing | Sowing | Application of plant protection products | Fertilizing | Harvesting | Bailing | Loading bales | Transport, van<3.5t | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Pt | 2.55 | 1.39 | 6.10E-02 | 5.89E-01 | 5.81E-03 | 9.68E-02 | 7.06E-02 | 3.42E-02 | 1.47E-02 | 1.85E-02 | 1.47E-01 | 7.70E-02 | 3.08E-03 | 1.29E-02 | 2.88E-02 |
| CA | Pt | 1.04E-02 | 0.00 | 1.96E-04 | 5.62E-03 | 7.78E-05 | 5.23E-04 | 4.35E-04 | 1.94E-04 | 8.87E-05 | 1.04E-04 | 8.55E-04 | 1.82E-03 | 1.76E-05 | 1.97E-04 | 2.89E-04 |
| NC | Pt | 2.53E-02 | 5.58E-05 | 1.88E-03 | 4.54E-03 | 7.30E-05 | 4.34E-03 | 1.39E-03 | 1.87E-03 | 1.00E-03 | 1.87E-03 | 5.62E-03 | 1.83E-03 | 2.39E-04 | 1.33E-04 | 4.21E-04 |
| RI | Pt | 4.45E-01 | 3.32E-02 | 1.40E-02 | 1.74E-01 | 1.69E-03 | 4.42E-02 | 3.61E-02 | 1.39E-02 | 5.31E-03 | 5.67E-03 | 7.14E-02 | 3.35E-02 | 1.10E-03 | 4.00E-03 | 6.26E-03 |
| IR | Pt | 6.81E-04 | 0.00 | 4.33E-05 | 3.09E-04 | 1.64E-05 | 4.80E-05 | 4.47E-05 | 1.89E-05 | 9.68E-06 | 1.16E-05 | 7.60E-05 | 3.40E-05 | 1.81E-06 | 2.48E-05 | 4.27E-05 |
| OLD | Pt | 5.22E-05 | 0.00 | 1.16E-06 | 2.64E-05 | 4.79E-06 | 3.60E-06 | 2.84E-06 | 1.30E-06 | 5.34E-07 | 5.47E-07 | 5.41E-06 | 2.67E-06 | 1.05E-07 | 7.94E-07 | 2.06E-06 |
| RO | Pt | 3.73E-04 | 0.00 | 1.03E-05 | 9.31E-05 | 2.20E-06 | 4.25E-05 | 3.34E-05 | 1.88E-05 | 8.75E-06 | 8.41E-06 | 8.77E-05 | 3.96E-05 | 1.59E-06 | 1.02E-05 | 1.60E-05 |
| AE | Pt | 4.61E-04 | 3.96E-08 | 1.67E-05 | 2.08E-04 | 6.83E-06 | 4.29E-05 | 2.65E-05 | 1.69E-05 | 8.26E-06 | 1.24E-05 | 6.33E-05 | 2.50E-05 | 1.79E-06 | 7.81E-06 | 2.46E-05 |
| TE | Pt | 6.71E-02 | 1.57E-05 | 3.99E-03 | 1.12E-02 | 1.40E-04 | 1.18E-02 | 3.61E-03 | 5.06E-03 | 2.70E-03 | 5.09E-03 | 1.49E-02 | 5.01E-03 | 6.47E-04 | 4.29E-04 | 2.42E-03 |
| TAN | Pt | 1.31E-02 | 3.15E-03 | 6.03E-04 | 5.42E-03 | 2.65E-05 | 7.00E-04 | 5.65E-04 | 2.76E-04 | 1.11E-04 | 1.04E-04 | 1.35E-03 | 5.76E-04 | 1.97E-05 | 7.08E-05 | 1.27E-04 |
| LO | Pt | 1.36 | 1.33 | 2.57E-02 | 5.80E-04 | 5.64E-06 | 1.99E-04 | 1.37E-04 | 1.28E-04 | 4.75E-05 | 4.22E-05 | 2.25E-04 | 7.77E-05 | 1.23E-05 | 6.55E-05 | 1.27E-04 |
| AA | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | Pt | 3.65E-01 | 2.67E-02 | 8.45E-03 | 2.31E-01 | 1.58E-03 | 1.72E-02 | 1.39E-02 | 6.24E-03 | 2.63E-03 | 2.68E-03 | 2.61E-02 | 1.49E-02 | 5.10E-04 | 3.76E-03 | 8.97E-03 |
| NRE | Pt | 2.68E-01 | 0.00 | 6.14E-03 | 1.55E-01 | 2.18E-03 | 1.76E-02 | 1.43E-02 | 6.43E-03 | 2.75E-03 | 2.90E-03 | 2.66E-02 | 1.93E-02 | 5.33E-04 | 4.22E-03 | 1.01E-02 |
| ME | Pt | 5.59E-04 | 0.00 | 1.30E-05 | 3.07E-04 | 2.33E-06 | 5.26E-05 | 6.52E-05 | 1.53E-05 | 8.24E-06 | 8.24E-06 | 5.75E-05 | 1.79E-05 | 1.34E-06 | 4.84E-06 | 5.58E-06 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

**Table 32.** Weighing evaluation per impact category for conventional barley cultivation process (with reference to 1kg FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Ammonium nitrate (N) | Pesticide | Ploughing | Harrowing | Sowing | Application of plant protection products | Fertilizing | Harvesting | Bailing | Loading bales | Transport, van<3.5t | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Pt | 2.40E-04 | 1.27E-04 | 5.86E-06 | 5.66E-05 | 2.65E-07 | 9.30E-06 | 6.78E-06 | 3.28E-06 | 2.82E-06 | 1.78E-06 | 1.41E-05 | 7.49E-06 | 3.00E-07 | 1.24E-06 | 2.77E-06 |
| CA | Pt | 1.01E-06 | 0.00 | 1.88E-08 | 5.40E-07 | 3.55E-09 | 5.02E-08 | 4.18E-08 | 1.87E-08 | 1.70E-08 | 9.99E-09 | 8.21E-08 | 1.77E-07 | 1.71E-09 | 1.89E-08 | 2.78E-08 |
| NC | Pt | 2.52E-06 | 5.36E-09 | 1.81E-07 | 4.36E-07 | 3.33E-09 | 4.17E-07 | 1.34E-07 | 1.80E-07 | 1.92E-07 | 1.79E-07 | 5.39E-07 | 1.78E-07 | 2.32E-08 | 1.27E-08 | 4.04E-08 |
| RI | Pt | 4.32E-05 | 3.19E-06 | 1.34E-06 | 1.67E-05 | 7.71E-08 | 4.25E-06 | 3.47E-06 | 1.34E-06 | 1.02E-06 | 5.44E-07 | 6.86E-06 | 3.25E-06 | 1.07E-07 | 3.83E-07 | 6.01E-07 |
| IR | Pt | 6.55E-08 | 0.00 | 4.16E-09 | 2.97E-08 | 7.50E-10 | 4.60E-09 | 4.29E-09 | 1.82E-09 | 1.86E-09 | 1.12E-09 | 7.30E-09 | 3.30E-09 | 1.76E-10 | 2.37E-09 | 4.10E-09 |
| OLD | Pt | 4.82E-09 | 0.00 | 1.11E-10 | 2.53E-09 | 2.19E-10 | 3.46E-10 | 2.73E-10 | 1.25E-10 | 1.03E-10 | 5.26E-11 | 5.19E-10 | 2.59E-10 | 1.02E-11 | 7.60E-11 | 1.98E-10 |
| RO | Pt | 3.66E-08 | 0.00 | 9.92E-10 | 8.94E-09 | 1.00E-10 | 4.08E-09 | 3.21E-09 | 1.81E-09 | 1.68E-09 | 8.08E-10 | 8.42E-09 | 3.85E-09 | 1.55E-10 | 9.74E-10 | 1.54E-09 |
| AE | Pt | 4.47E-08 | 3.80E-12 | 1.60E-09 | 2.00E-08 | 3.12E-10 | 4.12E-09 | 2.54E-09 | 1.62E-09 | 1.59E-09 | 1.19E-09 | 6.08E-09 | 2.43E-09 | 1.74E-10 | 7.48E-10 | 2.36E-09 |
| TE | Pt | 6.70E-06 | 1.51E-09 | 3.83E-07 | 1.07E-06 | 6.38E-09 | 1.14E-06 | 3.47E-07 | 4.85E-07 | 5.18E-07 | 4.89E-07 | 1.43E-06 | 4.87E-07 | 6.29E-08 | 4.11E-08 | 2.33E-07 |
| TAN | Pt | 1.27E-06 | 3.02E-07 | 5.79E-08 | 5.20E-07 | 1.21E-09 | 6.72E-08 | 5.43E-08 | 2.65E-08 | 2.14E-08 | 9.95E-09 | 1.30E-07 | 5.60E-08 | 1.91E-09 | 6.78E-09 | 1.22E-08 |
| LO | Pt | 1.24E-04 | 1.21E-04 | 2.46E-06 | 5.57E-08 | 2.58E-10 | 1.91E-08 | 1.32E-08 | 1.23E-08 | 9.12E-09 | 4.05E-09 | 2.16E-08 | 7.56E-09 | 1.19E-09 | 6.27E-09 | 1.22E-08 |
| AA | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | Pt | 3.52E-05 | 2.56E-06 | 8.11E-07 | 2.22E-05 | 7.22E-08 | 1.65E-06 | 1.34E-06 | 6.00E-07 | 5.05E-07 | 2.57E-07 | 2.50E-06 | 1.45E-06 | 4.96E-08 | 3.60E-07 | 8.61E-07 |
| NRE | Pt | 2.60E-05 | 0.00 | 5.90E-07 | 1.49E-05 | 9.97E-08 | 1.69E-06 | 1.37E-06 | 6.18E-07 | 5.28E-07 | 2.78E-07 | 2.55E-06 | 1.87E-06 | 5.18E-08 | 4.05E-07 | 9.72E-07 |
| ME | Pt | 5.43E-08 | 0.00 | 1.25E-09 | 2.94E-08 | 1.06E-10 | 5.05E-09 | 6.26E-09 | 1.47E-09 | 1.58E-09 | 7.91E-10 | 5.52E-09 | 1.74E-09 | 1.31E-10 | 4.64E-10 | 5.36E-10 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

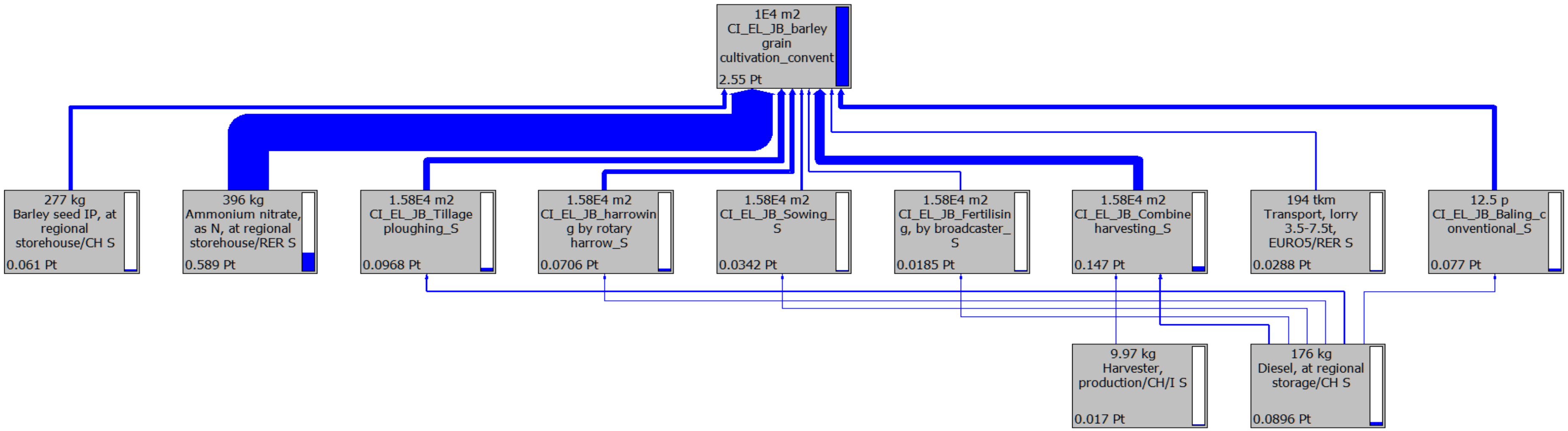


**Figure 47.** Damages flows for conventional barley cultivation process (with reference to 1ha FU).

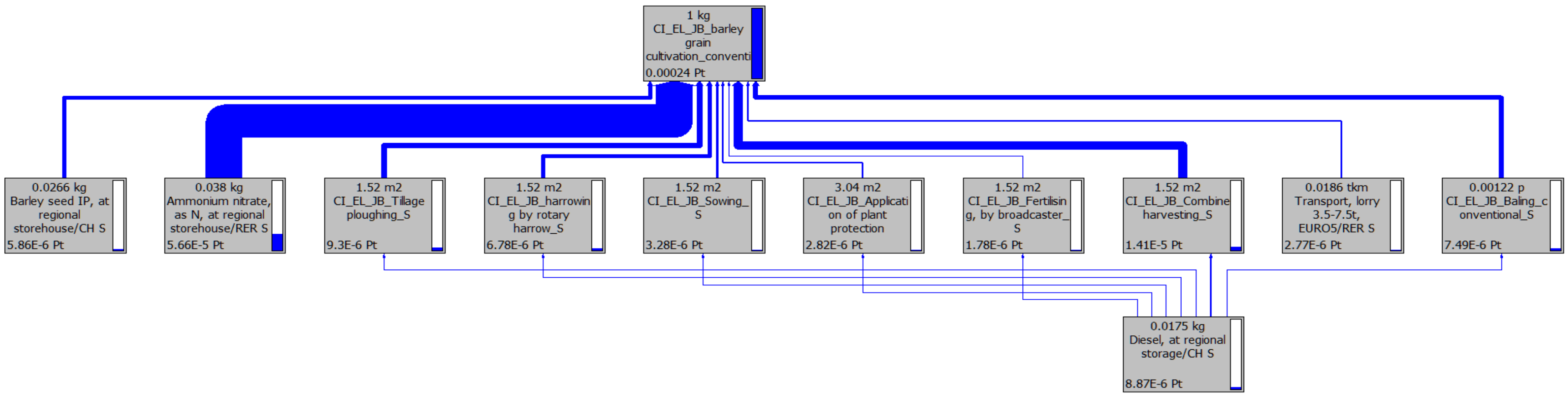


**Figure 48.** Damages flows for conventional barley cultivation process (with reference to 1kg FU).

# CONCLUSIONS

The findings from this research provide valuable insights into barley with reference to its relevant features of healthiness and sustainability. The research has also investigated consumers' food purchasing decisions and their perception about quality of organic food, in terms of healthiness and sustainability, as well as environmental sustainability and productive efficiency of cultivation of barley in both organic and conventional farming.

As regard barley's, given the state of knowledge about the positive traits of barley and barley's current and future attributes, the future for barley use in food products is improving and very promising. In order to take advantage from barley features of sustainability and healthiness, farms and processing firms could invest more effort into improvement of intended land to its cultivation and new healthy product development. Better understanding of the relationships between these two characteristics is essential and will set the future trends in barley utilization.

As regard the analysis of consumers' food purchasing decisions and their perception about quality of organic food, the topic was addressed because, although organic food consumers and their buying behavior are well examined fields of research, findings on consumers' perception about quality of organic food in terms of healthiness and sustainability are still inconsistent, because healthiness and sustainability are often analyzed as distinct features of food, while one of the scopes of organic production is to provide healthful food in a sustainable way (IFOAM, 2012). Still, few attempts have been made to identify motivations behind purchasing decisions of organic food consumers and the magnitude of their influence; but it is also not clear which are the drivers on which consumers base their evaluations about healthiness and sustainability of organic food. Results of the CUB models showed that, with regards to socio-demographic characteristics, in the Italian market females perceive more than males healthy and environmental features related to organic food products, confirming findings from literature (Ghvanidze *et al.*, 2016). Findings also highlight that the presence of label's information related to quality of organic food (e.g. heath claims, environmental label, quality label) contribute to perceive them as food of superior quality, due to modern consumer's awareness about the impacts that their buying behavior may cause on environmental and socio-economic life' aspects (Lee and Yun, 2016), thus tend to choose healthy and environmentally friendly food products (Ghvanidze *et al.*, 2016; Möser, 2016). This research thus provides a general framework for the Italian market, concerning the food purchasing intentions and perception of quality of modern consumers. Although no generalization should be made for consumers of other countries (Aschemann-Witzel *et al.*, 2013), the evidence provided on the influence that socio-demographic factors exert on decisions about organic food consumption may guide further research in other cultural contexts and areas where consumers are characterized by the same features (for instance, to other Mediterranean countries). Since this study demonstrates that consumers perceived the feature of healthiness more important than the feature of sustainability in choosing food products, an interesting further research may be direct towards the understanding in more detail of how consumers perceive healthiness for organic versus functional food. This study may be thus a basis for future researches, intended to explore the relationship between organic food and functional food from a consumer perspective. The information obtained from this study may be used to give suggestion and marketing recommendations to help food supply chain actors in implementing successful production and consumption strategies. In addition, to effectively face the growing demand of organic food market, policy and decision makers should propose marketing strategies, which are tailor-made for consumers' food consumption decisions, and adopt valuable actions oriented towards quality, to achieve a long-term pattern of sustainability for the environment and of healthiness for consumers.

As regard the analysis of environmental sustainability and productive efficiency of cultivation of barley in both organic and conventional farming, the topic of comparative assessment between organic and conventional cultivation for barley was addressed because, to the best of knowledge, among agricultural

LCAs few are those related to barley cultivation. Although some of these researches, such as the ones by Dijkman *et al.* (2016), Niero *et al.* (2015a), Fedele *et al.* (2014), proposed a comparison between conventional and organic cultivation systems for barley, none of them refer to different FUs to define system boundaries under study. This paper would like to contribute to the academic debate on the issue, providing further empirical evidences and allowing the interpretation of final results in terms of environmental sustainability and efficiency in production. From these perspectives, both organic and conventional farming may be considered borderline between environmental sustainability and productive efficiency. It appears that the choice of FU may lead to different environmental performances (Hayashi, 2013). In reality, what needs to be different is the understanding of results, because diverse FUs address different research questions. The comparison based on 1 ha FU seeks the most environmentally sustainable solution, while the comparison based on 1 kg FU looks for the best solution in terms of productive efficiency. In the specific case of barley cultivation, considering 1 ha of land involved in barley cultivation as FU, organic production system should be preferred with respect to conventional one, because lower requirements of diesel and chemical inputs cause less environmental impacts. Considering 1 kg DM of barley grain as FU, conventional farming performs better in environmental terms, compared to the organic ones. Organic farming may be considered the most suitable solution in terms of environmental sustainability, but it is not efficient in productive terms, due to the lower yields of production that amplify environmental impacts related to barley cultivation. Conventional farming may be considered efficient in production, but it is not sustainable.

The analysis of the potential impacts related to barley cultivation puts on evidence that:

- a land-based FU is methodologically proper if the study focuses only on the agricultural stage;
- a mass-based FU is a better solution if the cultivation system is part of a wider system such as the production of a barley-based product.

Results obtained on productive efficiency and environmental sustainability may be balanced also with other methodological assumptions and qualitative elements, to avoid bias in final results. The former may be the allocation of environmental burdens on the base of the economic values of the two main products, deriving from barley cultivation (grain and straw) (Dijkman *et al.*, 2016), also distinguishing between organic and conventional prices. The latter may be the improvement of inventory data with additional information, such as crop quality and adaptiveness to specific pedo-climatic conditions (Fedele *et al.*, 2014). This research has attempted to involve all these elements to describe a scenario strictly close to the realty, though further LCAs would be desirable to deepen the knowledge and practice in this field and to support the creation of guidelines for a proper choice of FU. It would be also desirable to extend system boundaries to the entire supply chain of barley, to evaluate the contribution of processing industry on the environmental impacts. This research wishes to improve knowledge of targeted stakeholders (e.g. LCA practitioners, agronomists, farmers) about input/output flows involved in the analysed system, related environmental impacts and evaluable improvement potentials. This research could be also an occasion for the involved farms to re-examining the environmental strategy related to their production. It may also provide a useful quantitative toolkit, helping the adoption of a more sustainable barley cultivation in the future.

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# APPENDIX

## I. *CUB models*

### *i. Questionnaire*

**SURVEY ON CONSUMPTION OF CEREAL-BASED FOOD PRODUCTS**

**Section I: SOCIO-DEMOGRAPHIC CHARACTERISTICS**

**1**) Gender:

☐ Female

☐ Male

**2**) Age:

☐ 18-25

☐ 26-35

☐ 36-45

☐ 46-55

☐ More than 55

**3**) Residence area:

☐ Norther Italy

☐ Center Italy

☐ Southern Italy

**4)** Educational level:

☐ Primary school

☐ Middle school

☐ Upper secondary school

☐ Bachelor/Master’s degree or equivalent

**5)** Financial situation:

☐ Difficult

☐ Modest

☐ Discreet

☐ Good

☐ Very good

**6)** People of your family (n°): ______________________________

**7)** Weekly spending for food:

☐ Lesser than € 50

☐ €50-€100

☐ €100-€150

☐ €150-€200

☐ More than €200

**Section II: PURCHASING DECISIONS**

**8)** Factors influencing food choice:

☐ Label info
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Health claims
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Quality label
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Organic label
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Environmental label
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

**Section III: EATING HABITS**

**9)** Consumption of organic food:

☐ Never

☐ Rarely

☐ At least once a month

☐ At least once a week

☐ Every day

**10)** About organic food:

☐ Organic food is healthier
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Organic food is GMO free
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Organic food is environmentally sustainable
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

**11)** Recent change of diet towards a more healthier model

☐ Yes

☐ No

**12)** Knowledge of "functional food" concept

☐ Yes

☐ No

**Section IV: FUNCTIONAL FOOD**

**13)** Factors influencing functional food choice:

☐ Advertisement
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Label info
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Packaging
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Solution of health problems
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Prevention of health problems
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

**14)** Factors influencing functional food choice:

☐ Nutrition and diet are important for health
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Better eating habits reduce risks of diseases development
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ It is important to consume food that reduce risks of diseases development
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Any food increases risks of diseases development, while others decrease these risks
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Functional food improve health and reduce risks of diseases
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

☐ Functional food should be part of a varied diet
Not a priority [1], Low priority [2], Somewhat priority [3], Neutral [4], Moderate Priority [5], High priority [6], Essential priority [7]

**15)** Consumption of functional food

☐ Never

☐ Rarely

☐ At least once a month

☐ At least once a week

☐ Every day

**16)** Future intention to purchase functional food

☐ Yes

☐ No

**Section V: BARLEY-BASED FOOD PRODUCTS**

**17)** Knowledge of whole grain's benefits

☐ Yes

☐ No

**18)** Knowledge of barley β-glucan's healthy features

☐ Yes

☐ No

**19)** Choice of food products rich of barley β-glucan

☐ Yes

☐ No

**20)** Consumption of:

☐ Pearl barley
Never [1], Rarely [2], At least once a month [3], At least once a week [4], Every day [5]

☐ Barley flour
Never [1], Rarely [2], At least once a month [3], At least once a week [4], Every day [5]

☐ Barley flakes
Never [1], Rarely [2], At least once a month [3], At least once a week [4], Every day [5]

☐ Barley-based bakery products
Never [1], Rarely [2], At least once a month [3], At least once a week [4], Every day [5]

☐ Whole barley
Never [1], Rarely [2], At least once a month [3], At least once a week [4], Every day [5]

☐ Barley milk
Never [1], Rarely [2], At least once a month [3], At least once a week [4], Every day [5]

☐ Barley coffee
Never [1], Rarely [2], At least once a month [3], At least once a week [4], Every day [5]

## II. Life Cycle Assessment

### *i. Comparison between organic and conventional barley cultivation*

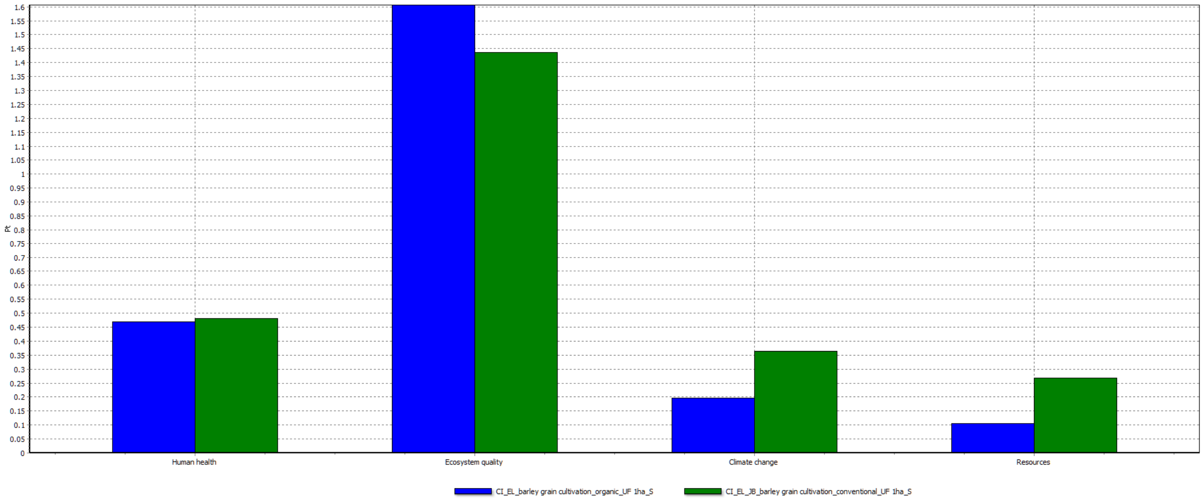


**Figure 49.** Comparison between organic and conventional barley cultivation processes (with reference to 1ha FU) and related caused-damages (weight points).

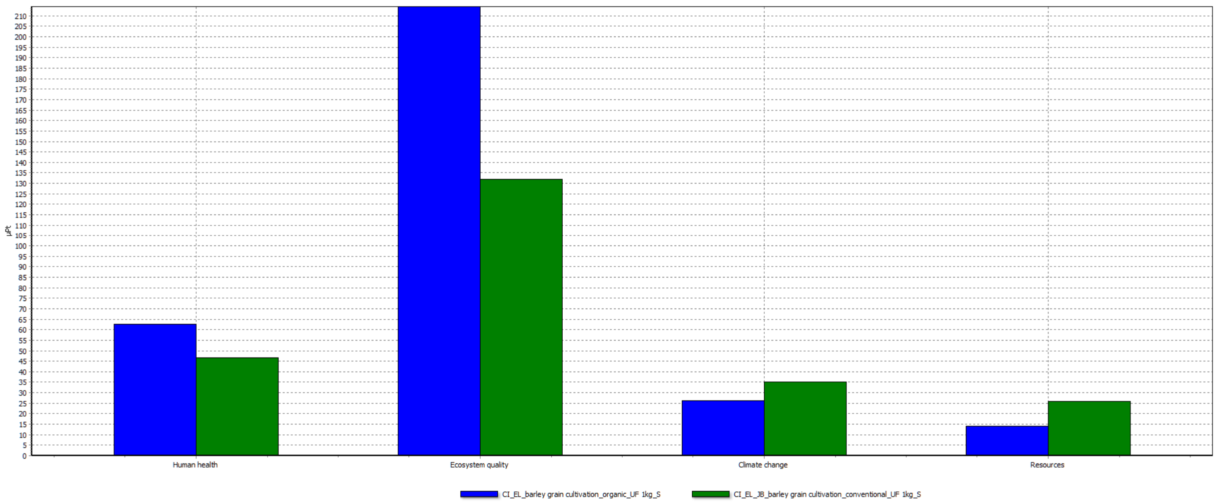


**Figure 50.** Comparison between organic and conventional barley cultivation processes (with reference to 1kg FU) and related caused-damages (weight points).

**Table 33.** Weight evaluation per damage category for organic and conventional barley cultivation processes (with reference to 1ha and 1kg FUs).

| DAMAGE CATEGORY* | Unit | ORGANIC | | CONVENTIONAL | |
|---|---|---|---|---|---|
| | | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| Total | Pt | 2.38 | 3.17E-04 | 2.55 | 2.40E-04 |
| HH | Pt | 0.47 | 6.26E-05 | 0.48 | 4.68E-05 |
| EQ | Pt | 1.61 | 2.14E-04 | 1.44 | 1.32E-04 |
| CC | Pt | 0.20 | 2.62E-05 | 0.36 | 3.52E-05 |
| R | Pt | 0.11 | 1.41E-05 | 0.27 | 2.60E-05 |

* Damage categories are Human health (HH), Ecosystem quality (EQ), Climate change (CC), Resources (R).

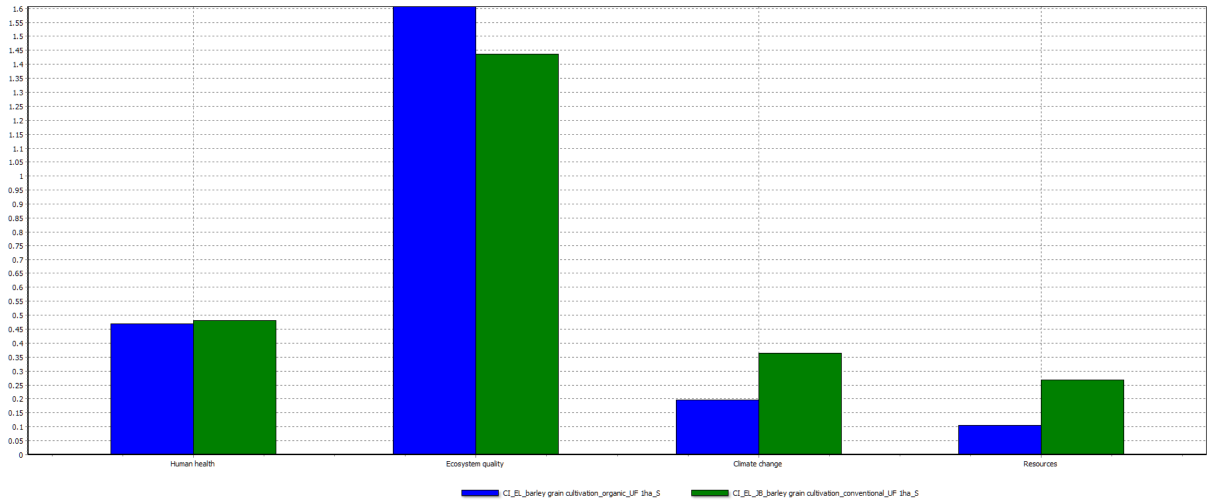


**Figure 51.** Comparison between organic and conventional barley cultivation processes (with reference to 1ha FU) and normalization of related caused-damages.

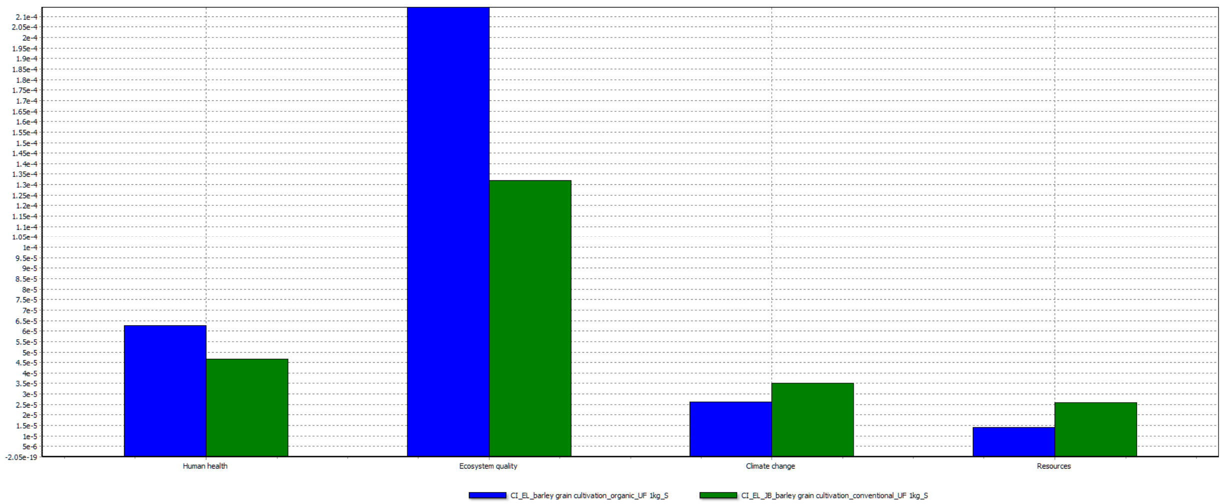


**Figure 52.** Comparison between organic and conventional barley cultivation processes (with reference to 1kg FU) and normalization of related caused-damages.

**Table 34.** Normalization of damage categories for organic and conventional barley cultivation processes (with reference to 1ha and 1kg FUs).

| DAMAGE CATEGORY* | ORGANIC | | CONVENTIONAL | |
|---|---|---|---|---|
| | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| HH | 0.47 | 6.26E-05 | 0.48 | 4.68E-05 |
| EQ | 1.61 | 2.14E-04 | 1.44 | 1.32E-04 |
| CC | 0.20 | 2.62E-05 | 0.36 | 3.52E-05 |
| R | 0.11 | 1.41E-05 | 0.27 | 2.60E-05 |

* Damage categories are Human health (HH), Ecosystem quality (EQ), Climate change (CC), Resources (R).

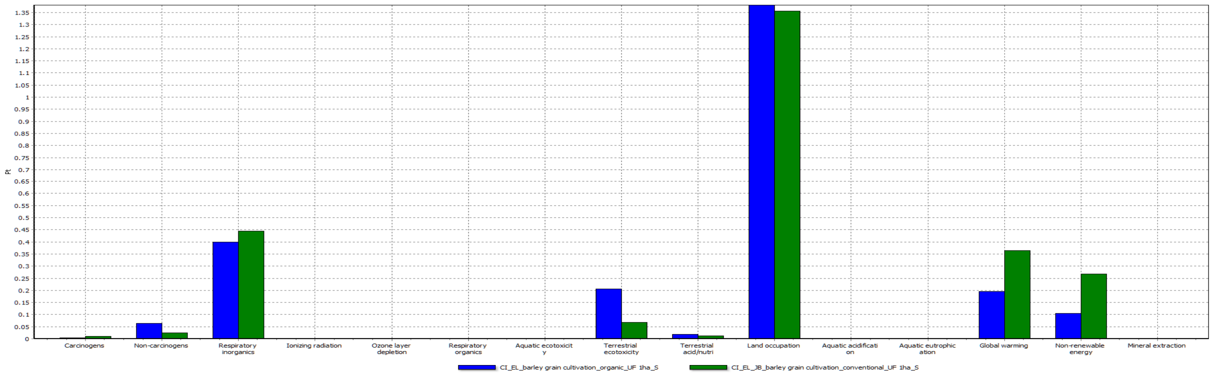


**Figure 53.** Comparison between organic and conventional barley cultivation processes (with reference to 1ha FU) and related caused-impacts (weight points).

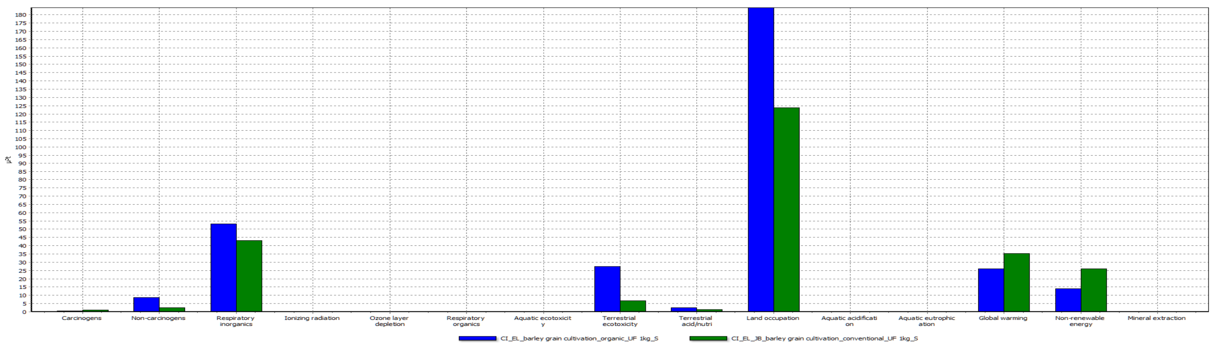


**Figure 54.** Comparison between organic and conventional barley cultivation processes (with reference to 1kg FU) and related caused-impacts (weight points).

**Table 35.** Weight evaluation per impact category for organic and conventional barley cultivation processes (with reference to 1ha and 1kg FUs).

| IMPACT CATEGORY* | Unit | ORGANIC | | CONVENTIONAL | |
|---|---|---|---|---|---|
| | | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| Total | Pt | 2.38 | 3.17E-04 | 2.55 | 2.40E-04 |
| CA | Pt | 3.58E-03 | 4.79E-07 | 1.04E-02 | 1.01E-06 |
| NC | Pt | 6.44E-02 | 8.59E-06 | 2.53E-02 | 2.52E-06 |
| RI | Pt | 0.40 | 5.33E-05 | 0.44 | 4.32E-05 |
| IR | Pt | 7.86E-04 | 1.05E-07 | 6.81E-04 | 6.55E-08 |
| OLD | Pt | 2.23E-05 | 2.98E-09 | 5.22E-05 | 4.82E-09 |
| RO | Pt | 3.73E-04 | 4.98E-08 | 3.73E-04 | 3.66E-08 |
| AE | Pt | 9.54E-04 | 1.27E-07 | 4.61E-04 | 4.47E-08 |
| TE | Pt | 0.21 | 2.74E-05 | 6.71E-02 | 6.70E-06 |
| TAN | Pt | 1.92E-02 | 2.56E-06 | 1.31E-02 | 1.27E-06 |
| LO | Pt | 1.38 | 1.84E-04 | 1.36 | 1.24E-04 |
| AA | Pt | - | - | - | - |
| AEU | Pt | - | - | - | - |
| GW | Pt | 0.20 | 2.62E-05 | 0.36 | 3.52E-05 |
| NRE | Pt | 0.11 | 1.41E-05 | 0.27 | 2.60E-05 |
| ME | Pt | 1.69E-04 | 2.26E-08 | 5.59E-04 | 5.43E-08 |

* Impact categories are Carcinogens (CA), Non carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

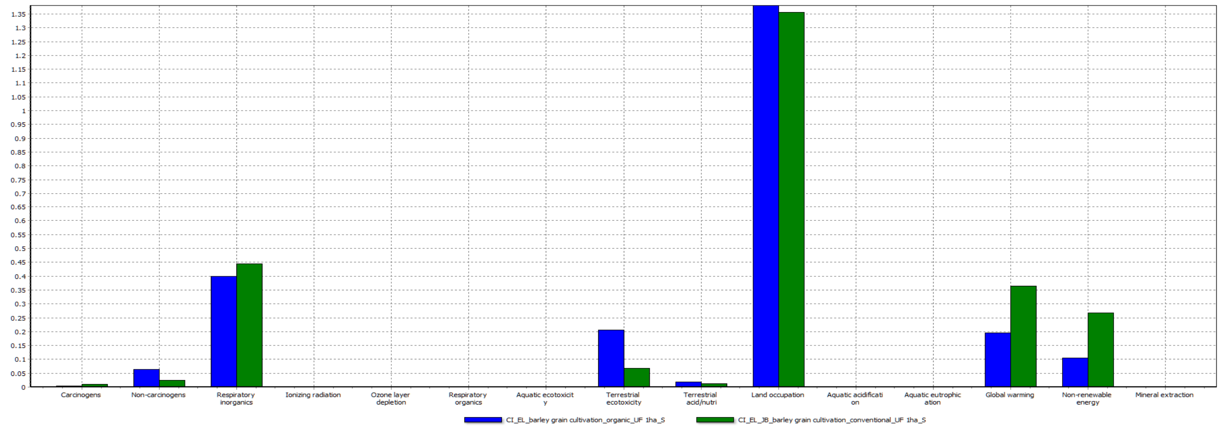

**Figure 55.** Comparison between organic and conventional barley cultivation processes (with reference to 1ha FU) and normalization of related caused-impacts.

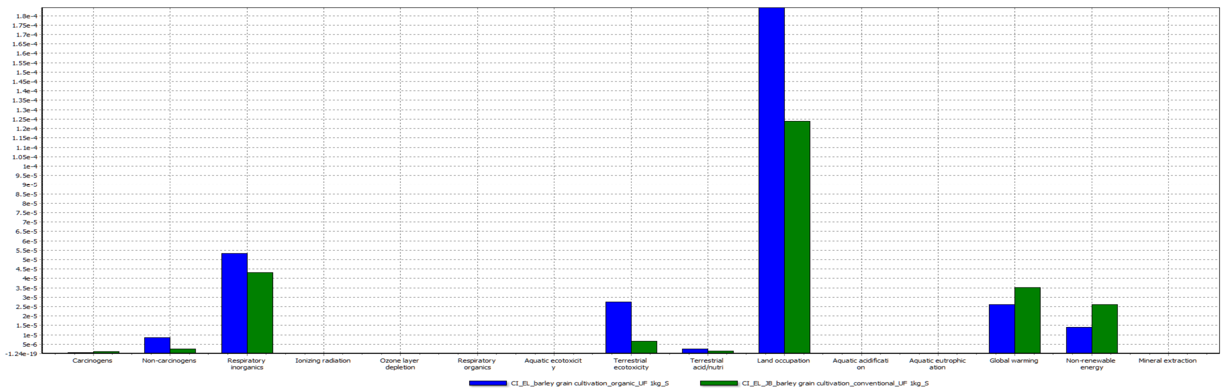

**Figure 56.** Comparison between organic and conventional barley cultivation processes (with reference to 1kg FU) and normalization of related caused-impacts.

**Table 36.** Normalization of impact categories for organic and conventional barley cultivation processes (with reference to 1ha and 1kg FUs).

| IMPACT CATEGORY* | ORGANIC | | CONVENTIONAL | |
|---|---|---|---|---|
| | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| CA | 3.58E-03 | 4.79E-07 | 1.04E-02 | 1.01E-06 |
| NC | 6.44E-02 | 8.59E-06 | 2.53E-02 | 2.52E-06 |
| RI | 4.00E-01 | 5.33E-05 | 4.45E-01 | 4.32E-05 |
| IR | 7.86E-04 | 1.05E-07 | 6.81E-04 | 6.55E-08 |
| OLD | 2.23E-05 | 2.98E-09 | 5.22E-05 | 4.82E-09 |
| RI | 3.73E-04 | 4.98E-08 | 3.73E-04 | 3.66E-08 |
| AE | 9.54E-04 | 1.27E-07 | 4.61E-04 | 4.47E-08 |
| TE | 2.05E-01 | 2.74E-05 | 6.71E-02 | 6.70E-06 |
| TAN | 1.92E-02 | 2.56E-06 | 1.31E-02 | 1.27E-06 |
| LO | 1.38 | 1.84E-04 | 1,36 | 1.24E-04 |
| AA | - | - | - | - |
| AEU | - | - | - | - |
| GW | 1.96E-01 | 2.62E-05 | 3.65E-01 | 3.52E-05 |
| NRE | 1.05E-01 | 1.41E-05 | 2.68E-01 | 2.60E-05 |
| Mineral extraction | 1.69E-04 | 2.26E-08 | 5.59E-04 | 5.43E-08 |

* Impact categories are Carcinogens (CA), Non carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

### *ii. Organic barley cultivation*

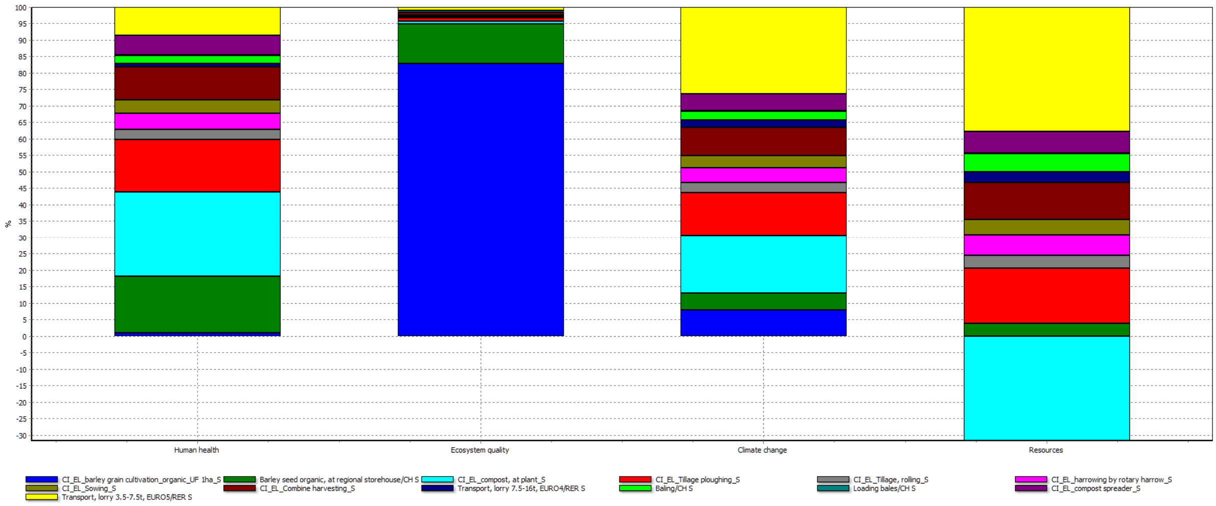


**Figure 57.** Percentage contribution of organic barley cultivation processes on each damage category (with reference to 1ha FU).

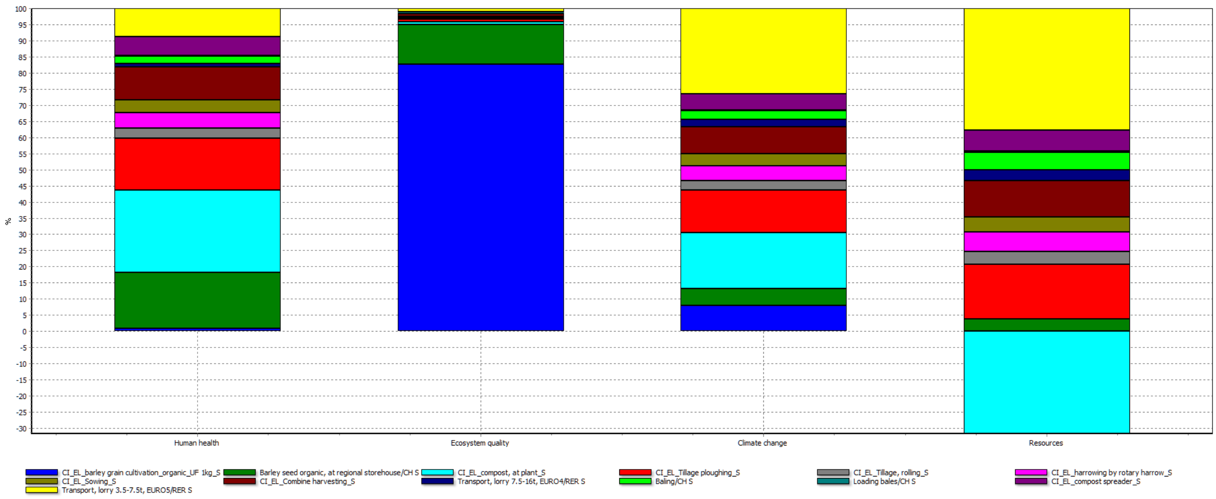


**Figure 58.** Percentage contribution of organic barley cultivation processes on each damage category (with reference to 1kg FU).

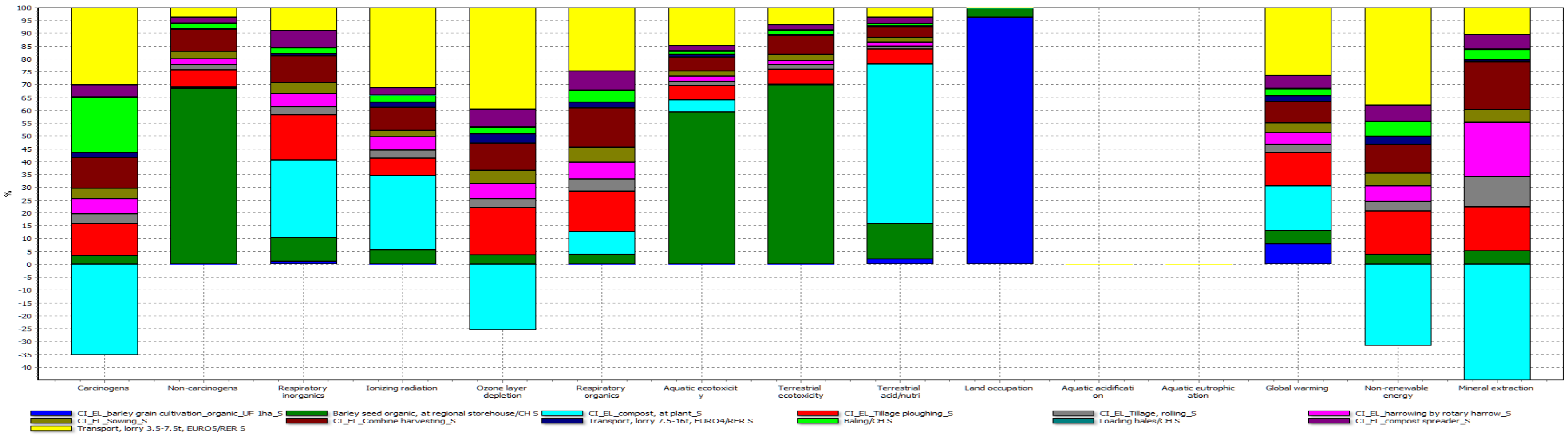


**Figure 59.** Percentage contribution of organic barley cultivation processes on each impact category (with reference to 1ha FU).

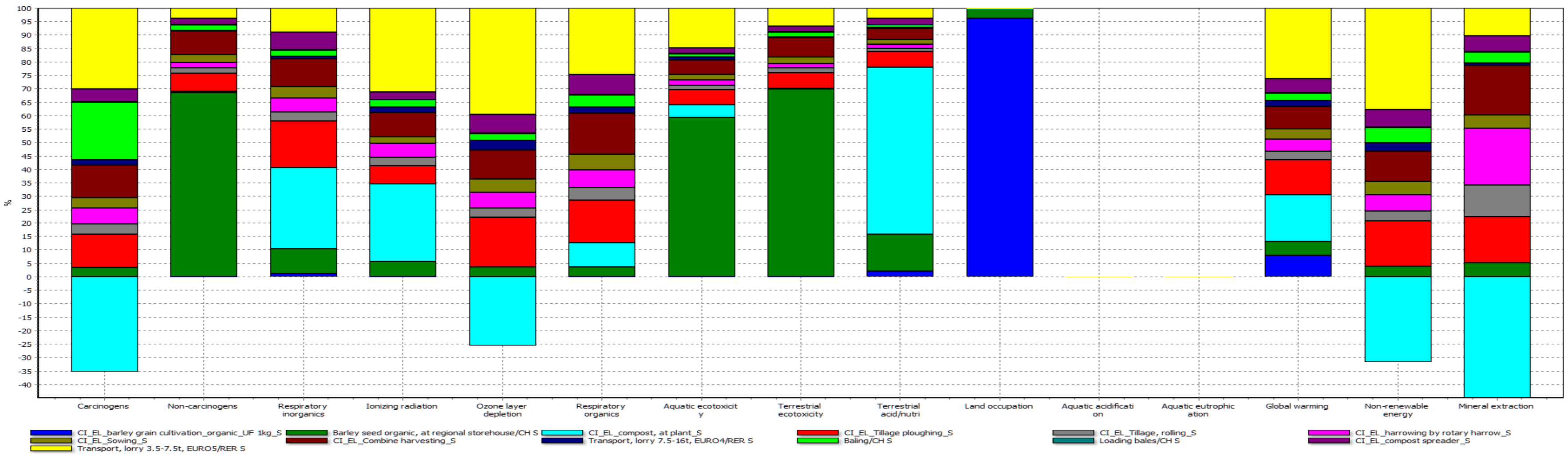


**Figure 60.** Percentage contribution of organic barley cultivation processes on each impact category (with reference to 1kg FU).

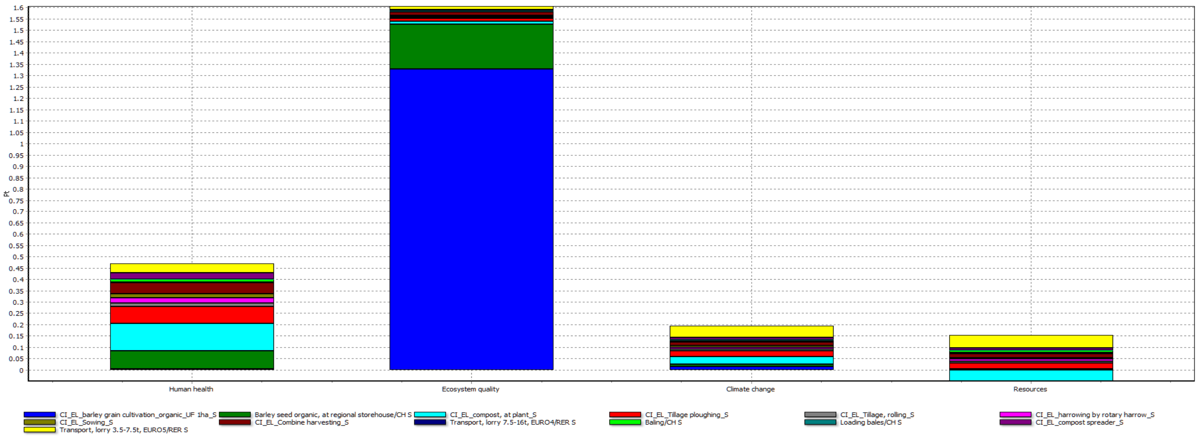


**Figure 61.** Weight evaluation per damage category for organic barley cultivation process (with reference to 1ha FU).

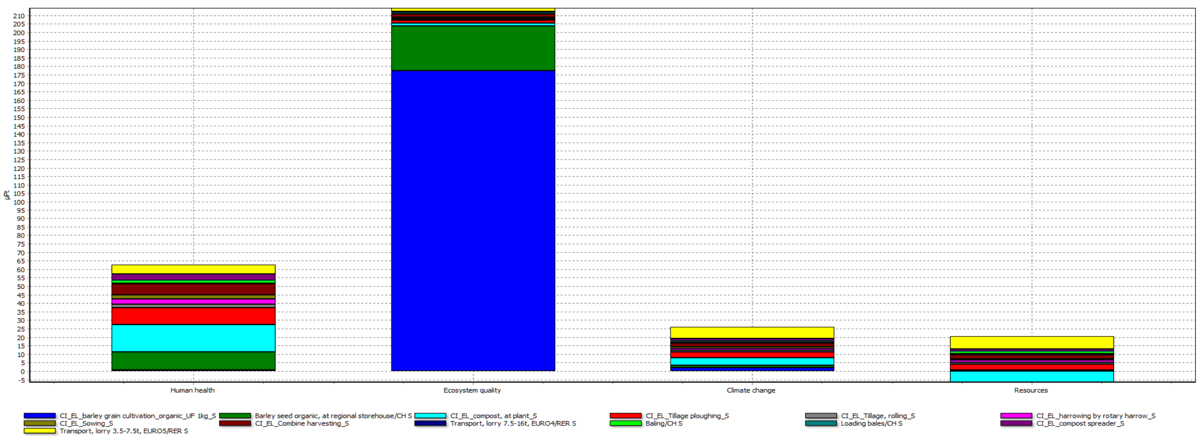


**Figure 62.** Weight evaluation per damage category for organic barley cultivation process (with reference to 1kg FU).

**Table 37.** Weight evaluation per damage category for organic barley cultivation process (with reference to 1ha and 1kg FUs).

| | Unit | Total | | DAMAGE CATEGORY* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | HH | | EQ | | CC | | R | |
| | | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| Total | Pt | 2.38 | 3.17E-04 | 0.47 | 6.26E-05 | 1.61 | 2.14E-04 | 0.20 | 2.62E-05 | 0.11 | 1.41E-05 |
| Cultivation | Pt | 1.35 | 1.80E-04 | 4.19E-03 | 5.58E-07 | 1.33 | 1.77E-04 | 1.53E-02 | 2.05E-06 | 0.00 | 0.00 |
| Seed | Pt | 0.29 | 3.92E-05 | 8.12E-02 | 1.08E-05 | 0.20 | 2.62E-05 | 1.04E-02 | 1.39E-06 | 5.84E-03 | 7.79E-07 |
| Compost | Pt | 0.12 | 1.58E-05 | 0,12 | 1.60E-05 | 1.31E-02 | 1.75E-06 | 3.41E-02 | 4.54E-06 | -4.90E-02 | -6.54E-06 |
| Ploughing | Pt | 0.14 | 1.87E-05 | 7.47E-02 | 9.96E-06 | 1.36E-02 | 1.81E-06 | 2.58E-02 | 3.45E-06 | 2.60E-02 | 3.47E-06 |
| Rolling | Pt | 2.99E-02 | 3.99E-06 | 1.43E-02 | 1.91E-06 | 3.75E-03 | 5.00E-07 | 5.81E-03 | 7.76E-07 | 6.09E-03 | 8.12E-07 |
| Harrowing | Pt | 4.54E-02 | 6.06E-06 | 2.30E-02 | 3.07E-06 | 3.88E-03 | 5.17E-07 | 9.01E-03 | 1.20E-06 | 9.54E-03 | 1.27E-06 |
| Sowing | Pt | 3.93E-02 | 5.24E-06 | 1.89E-02 | 2.52E-06 | 5.58E-03 | 7.45E-07 | 7.32E-03 | 9.77E-07 | 7.48E-03 | 9.98E-07 |
| Compost spreader | Pt | 5,22E-02 | 6.96E-06 | 2.76E-02 | 3.68E-06 | 4.75E-03 | 6.34E-07 | 9.88E-03 | 1.32E-06 | 9.97E-03 | 1.33E-06 |
| Harvesting | Pt | 0.10 | 1.29E-05 | 4.76E-02 | 6.35E-06 | 1.56E-02 | 2.08E-06 | 1.65E-02 | 2.20E-06 | 1.73E-02 | 2.31E-06 |
| Bailing | Pt | 2.87E-02 | 3.87E-06 | 1.13E-02 | 1.52E-06 | 3.51E-03 | 4.73E-07 | 5.33E-03 | 7.18E-07 | 8.57E-03 | 1.15E-06 |
| Loading bales | Pt | 2.17E-03 | 2.92E-07 | 9.56E-04 | 1.29E-07 | 4.79E-04 | 6.45E-08 | 3.59E-04 | 4.83E-08 | 3.76E-04 | 5.06E-08 |
| Transport, lorry 7.5-16t, EURO4 | Pt | 1.47E-02 | 1.96E-06 | 4.30E-03 | 5.75E-07 | 9.99E-04 | 1.33E-07 | 4.48E-03 | 5.98E-07 | 4.94E-03 | 6.59E-07 |
| Transport, lorry 3.5-7.5t, EURO5 | Pt | 0.17 | 2.22E-05 | 4.06E-02 | 5.42E-06 | 1.56E-02 | 2.08E-06 | 5.18E-02 | 6.91E-06 | 5.85E-02 | 7.80E-06 |

* Damage categories are Human health (HH), Ecosystem quality (EQ), Climate change (CC), Resources (R).

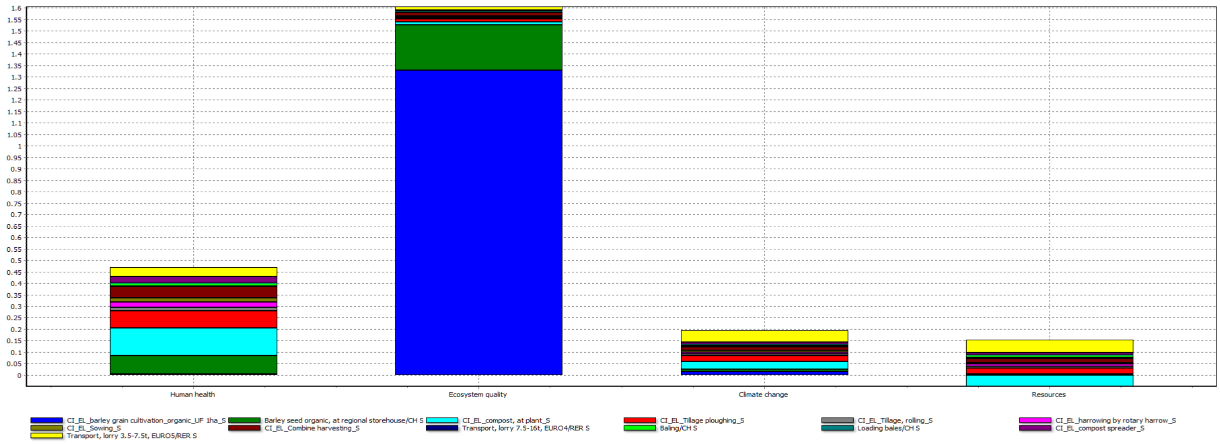


**Figure 63.** Normalization of damage categories for organic barley cultivation process (with reference to 1ha FU).

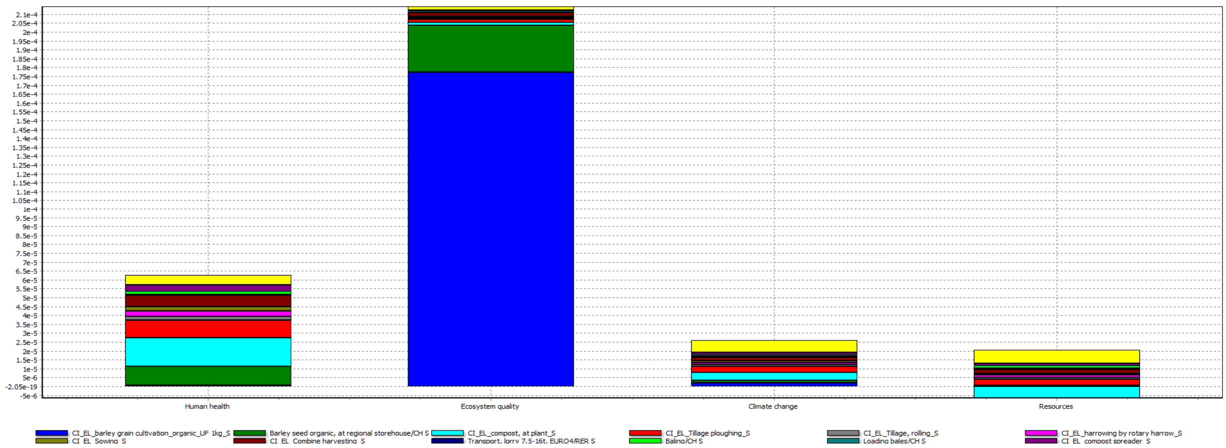


**Figure 64.** Normalization of damage categories for organic barley cultivation process (with reference to 1kg FU).

**Table 38.** Normalization of damage categories for organic barley cultivation process (with reference to 1ha and 1kg FUs).

| | DAMAGE CATEGORY* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | HH | | EQ | | CC | | R | |
| | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| Total | 4.69E-01 | 6.26E-05 | 1.61 | 2.14E-04 | 1.96E-01 | 2.62E-05 | 1.06E-01 | 1.41E-05 |
| Cultivation | 4.19E-03 | 5.58E-07 | 1.33 | 1.77E-04 | 1.53E-02 | 2.05E-06 | 0.00 | 0.00 |
| Seed | 8.12E-02 | 1.08E-05 | 1.96E-01 | 2.62E-05 | 1.04E-02 | 1.39E-06 | 5.84E-03 | 7.79E-07 |
| Compost | 1.20E-01 | 1.60E-05 | 1.31E-02 | 1.75E-06 | 3.41E-02 | 4.54E-06 | -4.90E-02 | -6.54E-06 |
| Ploughing | 7.47E-02 | 9.96E-06 | 1.36E-02 | 1.81E-06 | 2.58E-02 | 3.45E-06 | 2.60E-02 | 3.47E-06 |
| Rolling | 1.43E-02 | 1.91E-06 | 3.75E-03 | 5.00E-07 | 5.81E-03 | 7.76E-07 | 6.09E-03 | 8.12E-07 |
| Harrowing | 2.30E-02 | 3.07E-06 | 3.88E-03 | 5.17E-07 | 9.01E-03 | 1.20E-06 | 9.54E-03 | 1.27E-06 |
| Sowing | 1.89E-02 | 2.52E-06 | 5.58E-03 | 7.45E-07 | 7.32E-03 | 9.77E-07 | 7.48E-03 | 9.98E-07 |
| Compost spreader | 2.76E-02 | 3.68E-06 | 4.75E-03 | 6.34E-07 | 9.88E-03 | 1.32E-06 | 9.97E-03 | 1.33E-06 |
| Harvesting | 4.76E-02 | 6.35E-06 | 1.56E-02 | 2.08E-06 | 1.65E-02 | 2.20E-06 | 1.73E-02 | 2.31E-06 |
| Bailing | 1.13E-02 | 1.52E-06 | 3.51E-03 | 4.73E-07 | 5.33E-03 | 7.18E-07 | 8.57E-03 | 1.15E-06 |
| Loading bales | 9.56E-04 | 1.29E-07 | 4.79E-04 | 6.45E-08 | 3.59E-04 | 4.83E-08 | 3.76E-04 | 5.06E-08 |
| Transport, lorry 7.5-16t, EURO4 | 4.30E-03 | 5.75E-07 | 9.99E-04 | 1.33E-07 | 4.48E-03 | 5.98E-07 | 4.94E-03 | 6.59E-07 |
| Transport, lorry 3.5-7.5t, EURO5 | 4.06E-02 | 5.42E-06 | 1.56E-02 | 2.08E-06 | 5.18E-02 | 6.91E-06 | 5.85E-02 | 7.80E-06 |

* Damage categories are Human health (HH), Ecosystem quality (EQ), Climate change (CC), Resources (R).

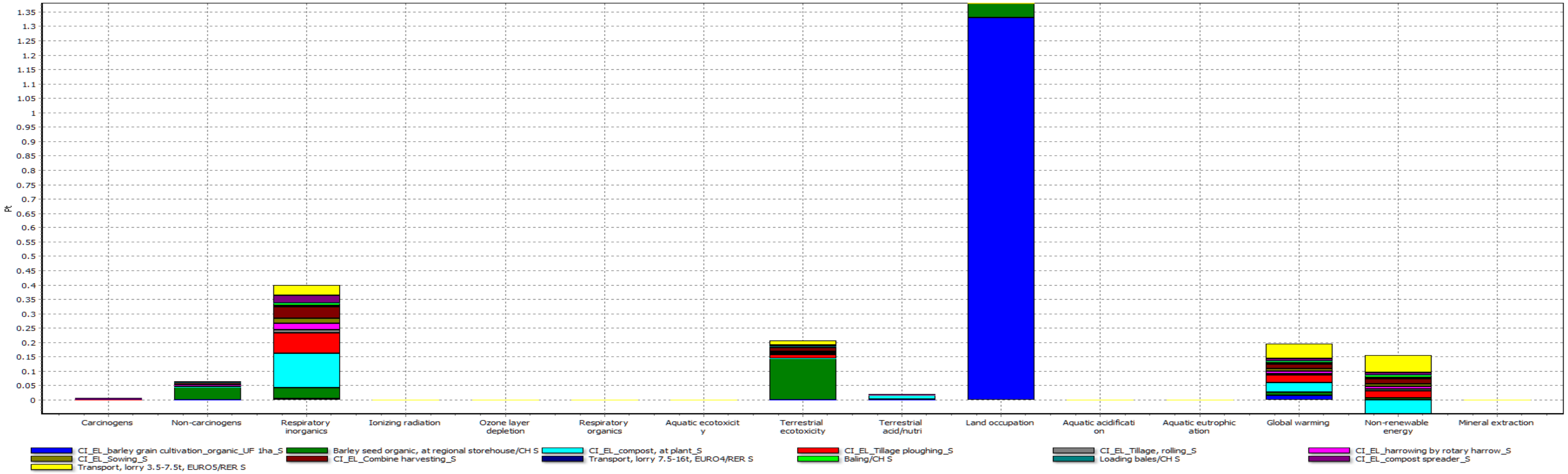


**Figure 65.** Weight evaluation per impact category for organic barley cultivation process (with reference to 1ha FU).

**Table 39.** Weight evaluation per impact category for organic barley cultivation process (with reference to 1ha FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Compost | Ploughing | Rolling | Harrowing | Sowing | Compost spreader | Harvesting | Bailing | Loading bales | Transport. lorry 7.5-16t, EURO4 | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Pt | 2.38 | 1.35 | 2.94E-01 | 1.18E-01 | 1.40E-01 | 2.99E-02 | 4.54E-02 | 3.93E-02 | 5.22E-02 | 9.69E-02 | 2.87E-02 | 2.17E-03 | 1.47E-02 | 1.66E-01 |
| CA | Pt | 3.58E-03 | 0.00 | 1.80E-04 | -1.95E-03 | 6.94E-04 | 2.11E-04 | 3.37E-04 | 2.16E-04 | 2.61E-04 | 6.64E-04 | 1.18E-03 | 1.24E-05 | 1.14E-04 | 1.67E-03 |
| NC | Pt | 6.44E-02 | 7.03E-06 | 4.41E-02 | 2.83E-04 | 4.41E-03 | 1.30E-03 | 1.36E-03 | 1.88E-03 | 1.51E-03 | 5.55E-03 | 1.25E-03 | 1.68E-04 | 1.54E-04 | 2.43E-03 |
| RI | Pt | 4.00E-01 | 4.18E-03 | 3.69E-02 | 1.22E-01 | 6.94E-02 | 1.27E-02 | 2.12E-02 | 1.68E-02 | 2.57E-02 | 4.12E-02 | 8.84E-03 | 7.73E-04 | 4.01E-03 | 3.61E-02 |
| IR | Pt | 7.86E-04 | 0.00 | 4.45E-05 | 2.27E-04 | 5.30E-05 | 2.48E-05 | 4.18E-05 | 1.95E-05 | 2.15E-05 | 7.04E-05 | 2.09E-05 | 1.28E-06 | 1.53E-05 | 2.46E-04 |
| OLD | Pt | 2.23E-05 | 0.00 | 1.05E-06 | -7.74E-06 | 5.55E-06 | 1.12E-06 | 1.72E-06 | 1.54E-06 | 2.11E-06 | 3.23E-06 | 7.12E-07 | 7.37E-08 | 1.06E-06 | 1.19E-05 |
| RO | Pt | 3.73E-04 | 0.00 | 1.37E-05 | 3.35E-05 | 5.96E-05 | 1.73E-05 | 2.44E-05 | 2.16E-05 | 2.72E-05 | 5.74E-05 | 1.67E-05 | 1.12E-06 | 8.11E-06 | 9.25E-05 |
| AE | Pt | 9.54E-04 | 4.99E-09 | 5.66E-04 | 4.48E-05 | 5.27E-05 | 1.49E-05 | 2.08E-05 | 1.81E-05 | 1.95E-05 | 5.23E-05 | 1.17E-05 | 1.26E-06 | 9.85E-06 | 1.42E-04 |
| TE | Pt | 2.05E-01 | 1.97E-06 | 1.43E-01 | 5.79E-04 | 1.22E-02 | 3.38E-03 | 3.40E-03 | 5.10E-03 | 4.17E-03 | 1.45E-02 | 3.30E-03 | 4.55E-04 | 8.48E-04 | 1.40E-02 |
| TAN | Pt | 1.92E-02 | 3.96E-04 | 2.61E-03 | 1.19E-02 | 1.11E-03 | 2.29E-04 | 3.24E-04 | 3.34E-04 | 4.79E-04 | 7.65E-04 | 1.49E-04 | 1.39E-05 | 9.83E-05 | 7.31E-04 |
| LO | Pt | 1.38 | 1,33 | 4.96E-02 | 5.49E-04 | 2.07E-04 | 1.27E-04 | 1.33E-04 | 1.29E-04 | 8.08E-05 | 2.17E-04 | 5.01E-05 | 8.64E-06 | 4.23E-05 | 7.35E-04 |
| AA | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | Pt | 1.96E-01 | 1.53E-02 | 1.04E-02 | 3.41E-02 | 2.58E-02 | 5.81E-03 | 9.01E-03 | 7.32E-03 | 9.88E-03 | 1.65E-02 | 5.33E-03 | 3.59E-04 | 4.48E-03 | 5.18E-02 |
| NRE | Pt | 1.05E-01 | 0.00 | 5.82E-03 | -4.89E-02 | 2.59E-02 | 6.05E-03 | 9.47E-03 | 7.46E-03 | 9.96E-03 | 1.73E-02 | 8.56E-03 | 3.75E-04 | 4.94E-03 | 5.85E-02 |
| ME | Pt | 1.69E-04 | 0.00 | 1.57E-05 | -1.39E-04 | 5.31E-05 | 3.66E-05 | 6.49E-05 | 1.53E-05 | 1.77E-05 | 5,71E-05 | 1.23E-05 | 9.45E-07 | 2.19E-06 | 3.22E-05 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

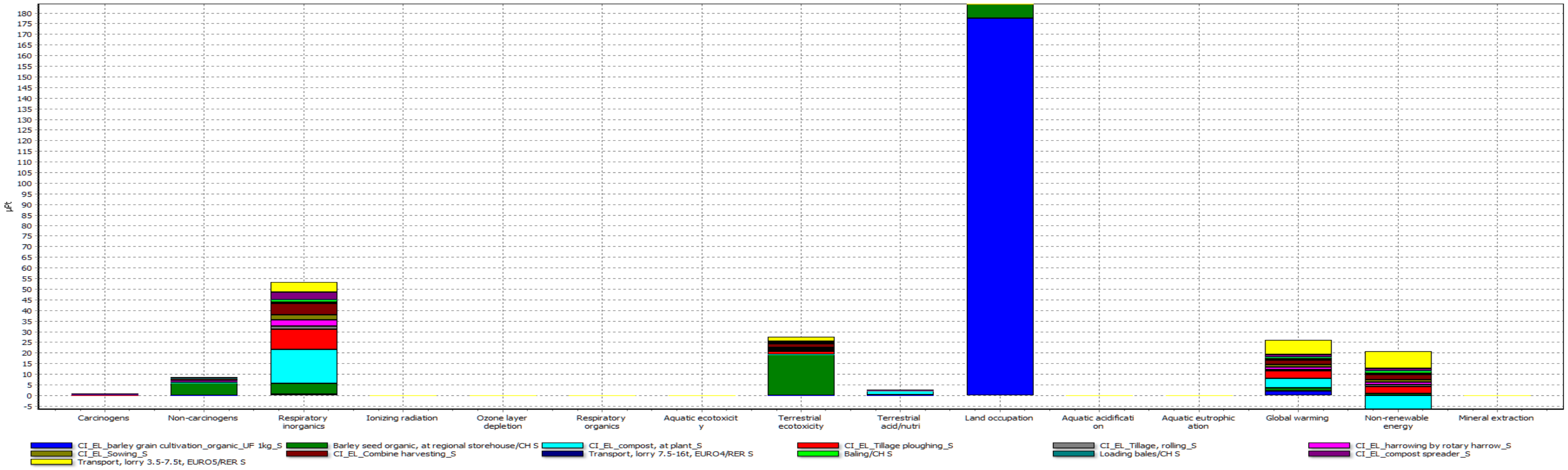


**Figure 66.** Weight evaluation per impact category for organic barley cultivation process (with reference to 1kg FU).

**Table 40.** Weight evaluation per impact category for organic barley cultivation process (with reference to 1kg FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Compost | Ploughing | Rolling | Harrowing | Sowing | Compost spreader | Harvesting | Bailing | Loading bales | Transport, lorry 7.5-16t, EURO4 | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Pt | 3.17E-04 | 1.80E-04 | 3.92E-05 | 1.58E-05 | 1.87E-05 | 3.99E-06 | 6.06E-06 | 5.24E-06 | 6.96E-06 | 1.29E-05 | 3.87E-06 | 2.92E-07 | 1.96E-06 | 2.22E-05 |
| CA | Pt | 4.79E-07 | 0.00 | 2.41E-08 | -2.61E-07 | 9.26E-08 | 2.82E-08 | 4.50E-08 | 2.88E-08 | 3.48E-08 | 8.86E-08 | 1.59E-07 | 1.67E-09 | 1.52E-08 | 2.23E-07 |
| NC | Pt | 8.59E-06 | 9.37E-10 | 5.88E-06 | 3.77E-08 | 5.88E-07 | 1.73E-07 | 1.81E-07 | 2.51E-07 | 2.02E-07 | 7.41E-07 | 1.69E-07 | 2.26E-08 | 2.06E-08 | 3.24E-07 |
| RI | Pt | 5.33E-05 | 5.57E-07 | 4.92E-06 | 1,62E-05 | 9.27E-06 | 1.70E-06 | 2.83E-06 | 2.24E-06 | 3.43E-06 | 5.50E-06 | 1.19E-06 | 1.04E-07 | 5.35E-07 | 4.82E-06 |
| IR | Pt | 1.05E-07 | 0.00 | 5.94E-09 | 3.03E-08 | 7.07E-09 | 3.31E-09 | 5.58E-09 | 2.61E-09 | 2.86E-09 | 9.39E-09 | 2.82E-09 | 1.72E-10 | 2.04E-09 | 3.29E-08 |
| OLD | Pt | 2.98E-09 | 0.00 | 1.40E-10 | -1.03E-09 | 7.41E-10 | 1.50E-10 | 2.29E-10 | 2.06E-10 | 2.82E-10 | 4.31E-10 | 9.59E-11 | 9.93E-12 | 1.41E-10 | 1.59E-09 |
| RO | Pt | 4.98E-08 | 0.00 | 1.83E-09 | 4.46E-09 | 7.96E-09 | 2.31E-09 | 3.25E-09 | 2.89E-09 | 3.63E-09 | 7.66E-09 | 2.25E-09 | 1.51E-10 | 1.08E-09 | 1.23E-08 |
| AE | Pt | 1.27E-07 | 6.65E-13 | 7.56E-08 | 5.98E-09 | 7.03E-09 | 1.99E-09 | 2.78E-09 | 2.42E-09 | 2.59E-09 | 6.98E-09 | 1.58E-09 | 1.69E-10 | 1.31E-09 | 1.89E-08 |
| TE | Pt | 2.74E-05 | 2.63E-10 | 1.91E-05 | 7.73E-08 | 1.63E-06 | 4.51E-07 | 4.54E-07 | 6.81E-07 | 5.57E-07 | 1.94E-06 | 4.45E-07 | 6.13E-08 | 1.13E-07 | 1.87E-06 |
| TAN | Pt | 2.56E-06 | 5.28E-08 | 3.48E-07 | 1.59E-06 | 1.48E-07 | 3.05E-08 | 4.33E-08 | 4.45E-08 | 6.39E-08 | 1.02E-07 | 2.01E-08 | 1.87E-09 | 1.31E-08 | 9.75E-08 |
| LO | Pt | 1.84E-04 | 1.77E-04 | 6.62E-06 | 7.33E-08 | 2.76E-08 | 1.69E-08 | 1.77E-08 | 1.72E-08 | 1.08E-08 | 2.89E-08 | 6.74E-09 | 1.16E-09 | 5.65E-09 | 9.80E-08 |
| AA | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | Pt | 2.62E-05 | 2.05E-06 | 1.39E-06 | 4.54E-06 | 3.45E-06 | 7.76E-07 | 1.20E-06 | 9.77E-07 | 1.32E-06 | 2.20E-06 | 7.18E-07 | 4.83E-08 | 5.98E-07 | 6.91E-06 |
| NRE | Pt | 1.41E-05 | 0.00 | 7.77E-07 | -6.52E-06 | 3.46E-06 | 8.07E-07 | 1.26E-06 | 9.96E-07 | 1.33E-06 | 2.30E-06 | 1.15E-06 | 5.05E-08 | 6.59E-07 | 7.80E-06 |
| ME | Pt | 2.26E-08 | 0.00 | 2.10E-09 | -1.85E-08 | 7.08E-09 | 4.89E-09 | 8,66E-09 | 2.04E-09 | 2.36E-09 | 7.62E-09 | 1.66E-09 | 1.27E-10 | 2.92E-10 | 4.30E-09 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

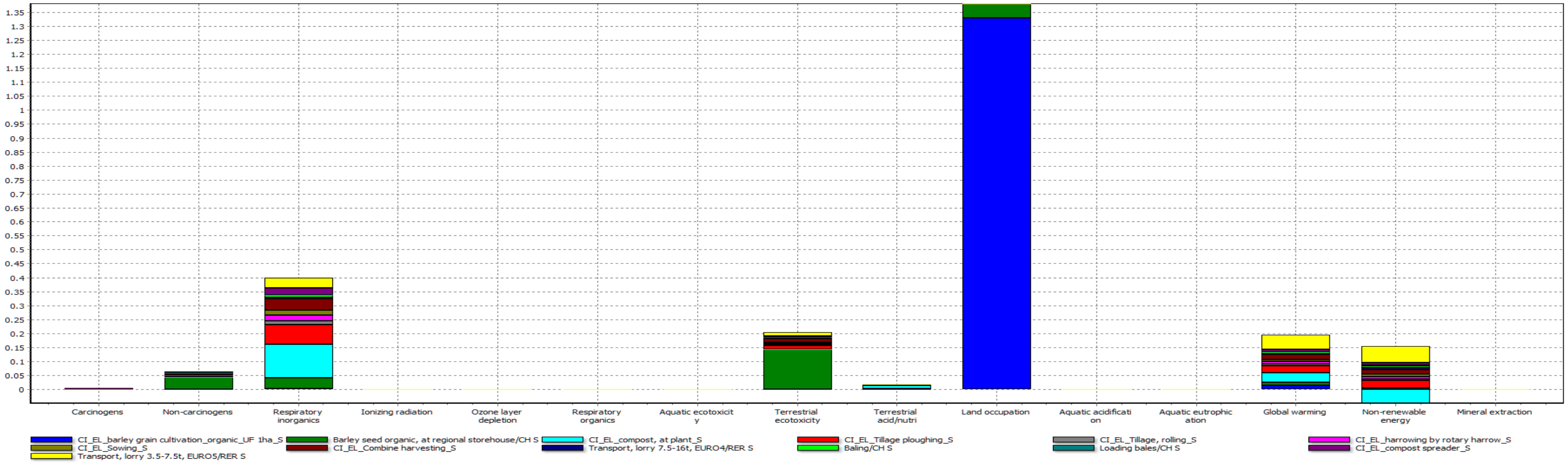


**Figure 67.** Normalization of impact categories for organic barley cultivation process (with reference to 1ha FU).

**Table 41.** Normalization of impact categories for organic barley cultivation process (with reference to 1ha FU).

| IMPACT CATEGORY* | Total | Cultivation | Seed | Compost | Ploughing | Rolling | Harrowing | Sowing | Compost spreader | Harvesting | Bailing | Loading bales | Transport, lorry 7.5-16t, EURO4 | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | 3.58E-03 | 0.00 | 1.80E-04 | -1.95E-03 | 6.94E-04 | 2.11E-04 | 3.37E-04 | 2.16E-04 | 2.61E-04 | 6.64E-04 | 1.18E-03 | 1.24E-05 | 1.14E-04 | 1.67E-03 |
| NC | 6.44E-02 | 7.03E-06 | 4.41E-02 | 2.83E-04 | 4.41E-03 | 1.30E-03 | 1.36E-03 | 1.88E-03 | 1.51E-03 | 5.55E-03 | 1.25E-03 | 1.68E-04 | 1.54E-04 | 2.43E-03 |
| RI | 4.00E-01 | 4.18E-03 | 3.69E-02 | 1.22E-01 | 6.94E-02 | 1.27E-02 | 2.12E-02 | 1.68E-02 | 2.57E-02 | 4.12E-02 | 8.84E-03 | 7.73E-04 | 4.01E-03 | 3.61E-02 |
| IR | 7.86E-04 | 0.00 | 4.45E-05 | 2.27E-04 | 5.30E-05 | 2.48E-05 | 4.18E-05 | 1.95E-05 | 2.15E-05 | 7.04E-05 | 2.09E-05 | 1.28E-06 | 1.53E-05 | 2.46E-04 |
| OLD | 2.23E-05 | 0.00 | 1.05E-06 | -7.74E-06 | 5.55E-06 | 1.12E-06 | 1.72E-06 | 1.54E-06 | 2.11E-06 | 3.23E-06 | 7.12E-07 | 7.37E-08 | 1.06E-06 | 1.19E-05 |
| RO | 3.73E-04 | 0.00 | 1.37E-05 | 3.35E-05 | 5.96E-05 | 1.73E-05 | 2.44E-05 | 2.16E-05 | 2.72E-05 | 5.74E-05 | 1.67E-05 | 1.12E-06 | 8.11E-06 | 9.25E-05 |
| AE | 9.54E-04 | 4.99E-09 | 5.66E-04 | 4.48E-05 | 5.27E-05 | 1.49E-05 | 2.08E-05 | 1.81E-05 | 1.95E-05 | 5.23E-05 | 1.17E-05 | 1.26E-06 | 9.85E-06 | 1.42E-04 |
| TE | 2.05E-01 | 1.97E-06 | 1.43E-01 | 5.79E-04 | 1.22E-02 | 3.38E-03 | 3.40E-03 | 5.10E-03 | 4.17E-03 | 1.45E-02 | 3.30E-03 | 4.55E-04 | 8.48E-04 | 1.40E-02 |
| TAN | 1.92E-02 | 3.96E-04 | 2.61E-03 | 1.19E-02 | 1.11E-03 | 2.29E-04 | 3.24E-04 | 3.34E-04 | 4.79E-04 | 7.65E-04 | 1.49E-04 | 1.39E-05 | 9.83E-05 | 7.31E-04 |
| LO | 1.38 | 1.33 | 4.96E-02 | 5.49E-04 | 2.07E-04 | 1.27E-04 | 1.33E-04 | 1.29E-04 | 8.08E-05 | 2.17E-04 | 5.01E-05 | 8.64E-06 | 4.23E-05 | 7.35E-04 |
| AA | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | 1.96E-01 | 1.53E-02 | 1.04E-02 | 3.41E-02 | 2.58E-02 | 5.81E-03 | 9.01E-03 | 7.32E-03 | 9.88E-03 | 1.65E-02 | 5.33E-03 | 3.59E-04 | 4.48E-03 | 5.18E-02 |
| NRE | 1.05E-01 | 0.00 | 5.82E-03 | -4.89E-02 | 2.59E-02 | 6.05E-03 | 9.47E-03 | 7.46E-03 | 9.96E-03 | 1.73E-02 | 8.56E-03 | 3.75E-04 | 4.94E-03 | 5.85E-02 |
| ME | 1.69E-04 | 0.00 | 1.57E-05 | -1.39E-04 | 5.31E-05 | 3.66E-05 | 6.49E-05 | 1.53E-05 | 1.77E-05 | 5.71E-05 | 1.23E-05 | 9.45E-07 | 2.19E-06 | 3.22E-05 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

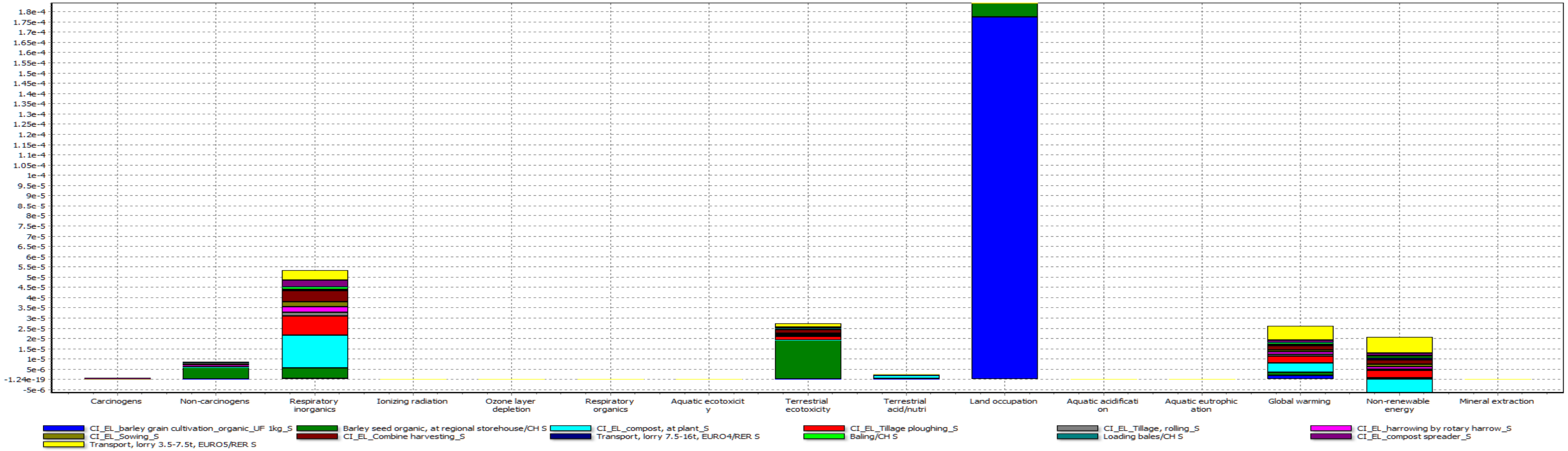


**Figure 68.** Normalization of impact categories for organic barley cultivation process (with reference to 1kg FU).

**Table 42.** Normalization of impact categories for organic barley cultivation process (with reference to 1kg FU).

| IMPACT CATEGORY* | Total | Cultivation | Seed | Compost | Ploughing | Rolling | Harrowing | Sowing | Compost spreader | Harvesting | Bailing | Loading bales | Transport, lorry 7.5-16t, EURO4 | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | 4.79E-07 | 0.00 | 2.41E-08 | -2.61E-07 | 9.26E-08 | 2.82E-08 | 4.50E-08 | 2.88E-08 | 3.48E-08 | 8.86E-08 | 1.59E-07 | 1.67E-09 | 1.52E-08 | 2.23E-07 |
| NC | 8.59E-06 | 9.37E-10 | 5.88E-06 | 3.77E-08 | 5.88E-07 | 1.73E-07 | 1.81E-07 | 2.51E-07 | 2.02E-07 | 7.41E-07 | 1.69E-07 | 2.26E-08 | 2.06E-08 | 3.24E-07 |
| RI | 5.33E-05 | 5.57E-07 | 4.92E-06 | 1.62E-05 | 9.27E-06 | 1.70E-06 | 2.83E-06 | 2.24E-06 | 3.43E-06 | 5.50E-06 | 1.19E-06 | 1.04E-07 | 5.35E-07 | 4.82E-06 |
| IR | 1.05E-07 | 0.00 | 5.94E-09 | 3.03E-08 | 7.07E-09 | 3.31E-09 | 5.58E-09 | 2.61E-09 | 2.86E-09 | 9.39E-09 | 2.82E-09 | 1.72E-10 | 2.04E-09 | 3.29E-08 |
| OLD | 2.98E-09 | 0.00 | 1.40E-10 | -1.03E-09 | 7.41E-10 | 1.50E-10 | 2.29E-10 | 2.06E-10 | 2.82E-10 | 4.31E-10 | 9.59E-11 | 9.93E-12 | 1.41E-10 | 1.59E-09 |
| RO | 4.98E-08 | 0.00 | 1.83E-09 | 4.46E-09 | 7.96E-09 | 2.31E-09 | 3.25E-09 | 2.89E-09 | 3.63E-09 | 7.66E-09 | 2.25E-09 | 1.51E-10 | 1.08E-09 | 1.23E-08 |
| AE | 1.27E-07 | 6.65E-13 | 7.56E-08 | 5.98E-09 | 7.03E-09 | 1.99E-09 | 2.78E-09 | 2.42E-09 | 2.59E-09 | 6.98E-09 | 1.58E-09 | 1.69E-10 | 1.31E-09 | 1.89E-08 |
| TE | 2.74E-05 | 2.63E-10 | 1.91E-05 | 7.73E-08 | 1.63E-06 | 4.51E-07 | 4.54E-07 | 6.81E-07 | 5.57E-07 | 1.94E-06 | 4.45E-07 | 6.13E-08 | 1.13E-07 | 1.87E-06 |
| TAN | 2.56E-06 | 5.28E-08 | 3.48E-07 | 1.59E-06 | 1.48E-07 | 3.05E-08 | 4.33E-08 | 4.45E-08 | 6.39E-08 | 1.02E-07 | 2.01E-08 | 1.87E-09 | 1.31E-08 | 9.75E-08 |
| LO | 1.84E-04 | 1.77E-04 | 6.62E-06 | 7.33E-08 | 2.76E-08 | 1.69E-08 | 1.77E-08 | 1.72E-08 | 1.08E-08 | 2.89E-08 | 6.74E-09 | 1.16E-09 | 5.65E-09 | 9.80E-08 |
| AA | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | 2.62E-05 | 2.05E-06 | 1.39E-06 | 4.54E-06 | 3.45E-06 | 7.76E-07 | 1.20E-06 | 9.77E-07 | 1.32E-06 | 2.20E-06 | 7.18E-07 | 4.83E-08 | 5.98E-07 | 6.91E-06 |
| NRE | 1.41E-05 | 0.00 | 7.77E-07 | -6.52E-06 | 3.46E-06 | 8.07E-07 | 1.26E-06 | 9.96E-07 | 1.33E-06 | 2.30E-06 | 1.15E-06 | 5.05E-08 | 6.59E-07 | 7.80E-06 |
| ME | 2.26E-08 | 0.00 | 2.10E-09 | -1.85E-08 | 7.08E-09 | 4.89E-09 | 8.66E-09 | 2.04E-09 | 2.36E-09 | 7.62E-09 | 1.66E-09 | 1.27E-10 | 2.92E-10 | 4.30E-09 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

*iii. Conventional barley cultivation*

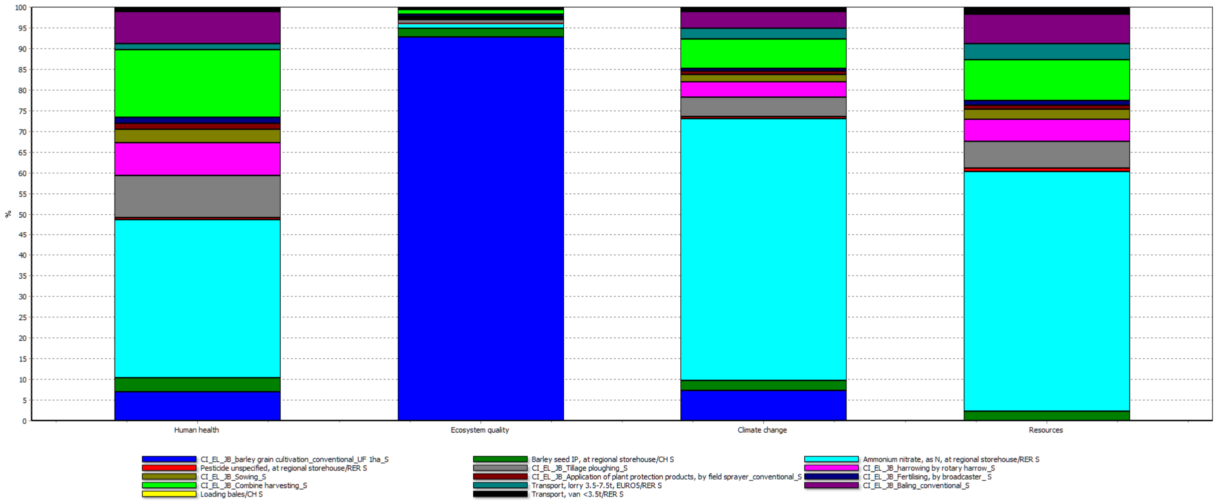


**Figure 69.** Percentage contribution of conventional barley cultivation processes on each damage category (with reference to 1ha FU).

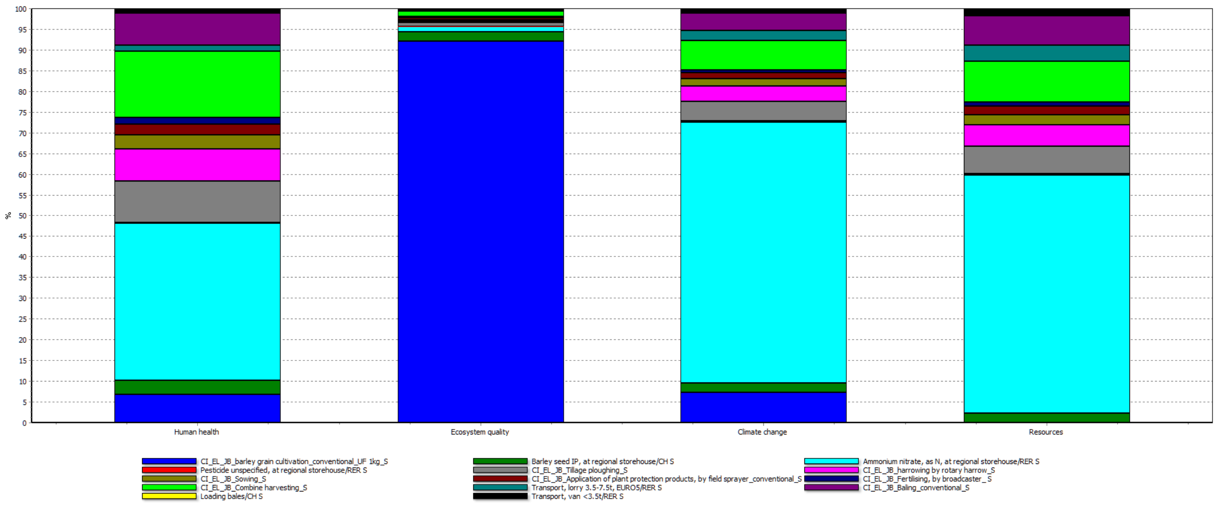


**Figure 70.** Percentage contribution of conventional barley cultivation processes on each damage category (with reference to 1kg FU).

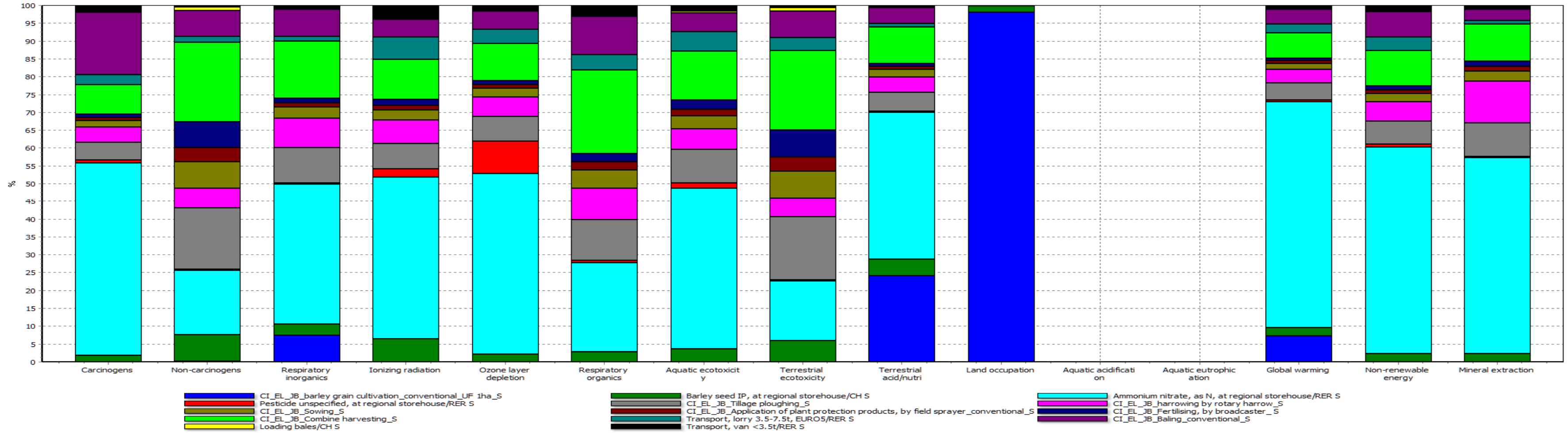


**Figure 71.** Percentage contribution of conventional barley cultivation processes on each impact category (with reference to 1ha FU).

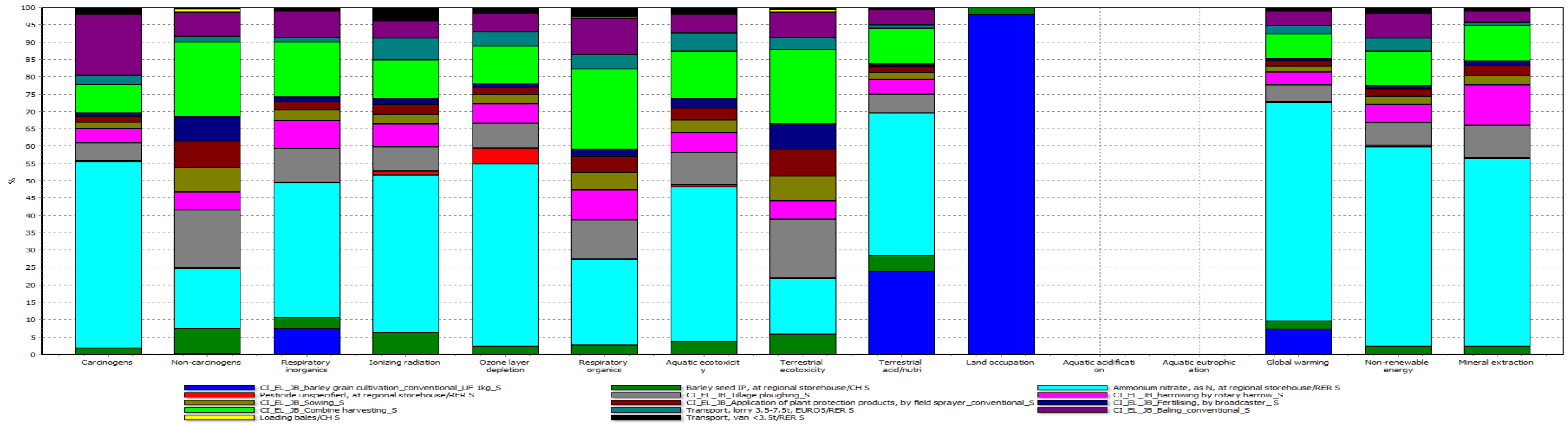


**Figure 72.** Percentage contribution of conventional barley cultivation processes on each impact category (with reference to 1kg FU).

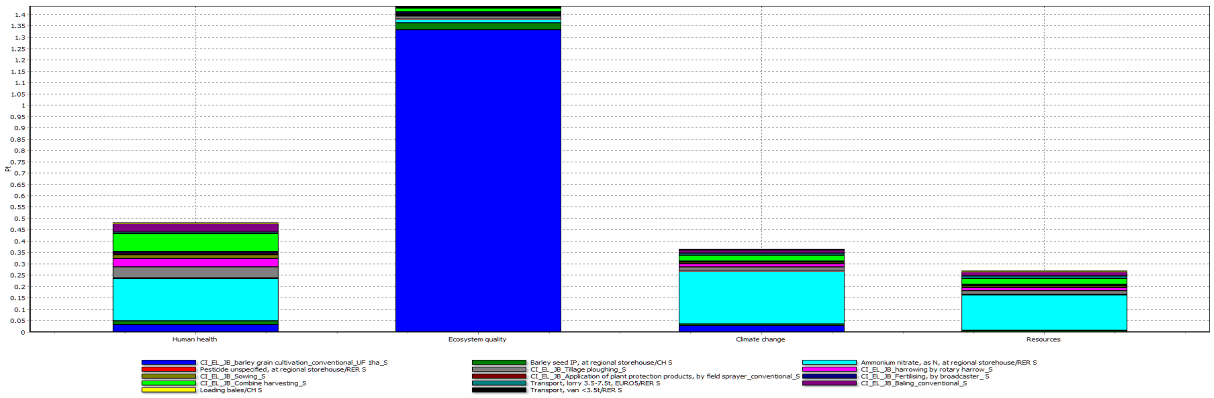


**Figure 73.** Weight evaluation per damage category for conventional barley cultivation process (with reference to 1ha FU).

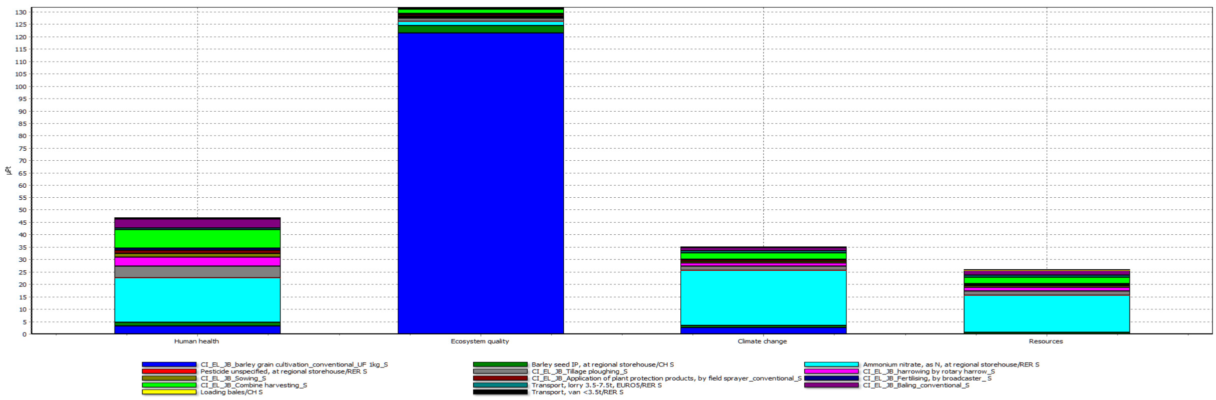


**Figure 74.** Weight evaluation per damage category for conventional barley cultivation process (with reference to 1kg FU).

**Table 43.** Weight evaluation per damage category for conventional barley cultivation process (with reference to 1ha and 1kg FUs).

| | Unit | Total | | DAMAGE CATEGORY* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | HH | | EQ | | CC | | R | |
| | | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| Total | Pt | 2.55 | 2.40E-04 | 4.81E-01 | 4.68E-05 | 1.44 | 1.32E-04 | 3.65E-01 | 3.52E-05 | 2.69E-01 | 2.60E-05 |
| Cultivation | Pt | 1.39 | 1.27E-04 | 3.33E-02 | 3.19E-06 | 1.33 | 1.22E-04 | 2.67E-02 | 2.56E-06 | 0.00 | 0.00 |
| Seed | Pt | 6.10E-02 | 5.86E-06 | 1.61E-02 | 1.55E-06 | 3.03E-02 | 2.91E-06 | 8.45E-03 | 8.11E-07 | 6.15E-03 | 5.91E-07 |
| Ammonium nitrate (N) | Pt | 5.89E-01 | 5.66E-05 | 1.85E-01 | 1.77E-05 | 1.74E-02 | 1.67E-06 | 2.31E-01 | 2.22E-05 | 1.56E-01 | 1.50E-05 |
| Pesticide | Pt | 5.81E-03 | 2.65E-07 | 1.86E-03 | 8.51E-08 | 1.79E-04 | 8.16E-09 | 1.58E-03 | 7.22E-08 | 2.18E-03 | 9.98E-08 |
| Ploughing | Pt | 9.68E-02 | 9.30E-06 | 4.92E-02 | 4.72E-06 | 1.28E-02 | 1.23E-06 | 1.72E-02 | 1.65E-06 | 1.76E-02 | 1.69E-06 |
| Harrowing | Pt | 7.06E-02 | 6.78E-06 | 3.80E-02 | 3.65E-06 | 4.34E-03 | 4.17E-07 | 1.39E-02 | 1.34E-06 | 1.44E-02 | 1.38E-06 |
| Sowing | Pt | 3.42E-02 | 3.28E-06 | 1.60E-02 | 1.54E-06 | 5.48E-03 | 5.26E-07 | 6.24E-03 | 6.00E-07 | 6.45E-03 | 6.19E-07 |
| Application of plant protection products | Pt | 1.47E-02 | 2.82E-06 | 6.41E-03 | 1.23E-06 | 2.86E-03 | 5.50E-07 | 2.63E-03 | 5.05E-07 | 2.76E-03 | 5.29E-07 |
| Fertilizing | Pt | 1.85E-02 | 1.78E-06 | 7.66E-03 | 7.36E-07 | 5.25E-03 | 5.04E-07 | 2.68E-03 | 2.57E-07 | 2.91E-03 | 2.79E-07 |
| Harvesting | Pt | 1.47E-01 | 1.41E-05 | 7.81E-02 | 7.50E-06 | 1.66E-02 | 1.59E-06 | 2.61E-02 | 2.50E-06 | 2.66E-02 | 2.56E-06 |
| Bailing | Pt | 7.70E-02 | 7.49E-06 | 3.72E-02 | 3.62E-06 | 5.68E-03 | 5.53E-07 | 1.49E-02 | 1.45E-06 | 1.93E-02 | 1.88E-06 |
| Loading bales | Pt | 3.08E-03 | 3.00E-07 | 1.36E-03 | 1.32E-07 | 6.81E-04 | 6.62E-08 | 5.10E-04 | 4.96E-08 | 5.34E-04 | 5.19E-08 |
| Transport, van<3.5t | Pt | 1.29E-02 | 1.24E-06 | 4.36E-03 | 4.18E-07 | 5.74E-04 | 5.49E-08 | 3.76E-03 | 3.60E-07 | 4.23E-03 | 4.05E-07 |
| Transport, lorry 3.5-7.5t, EURO5 | Pt | 2.88E-02 | 2.77E-06 | 7.03E-03 | 6.75E-07 | 2.70E-03 | 2.59E-07 | 8.97E-03 | 8.61E-07 | 1.01E-02 | 9.73E-07 |

* Damage categories are Human health (HH), Ecosystem quality (EQ), Climate change (CC), Resources (R).

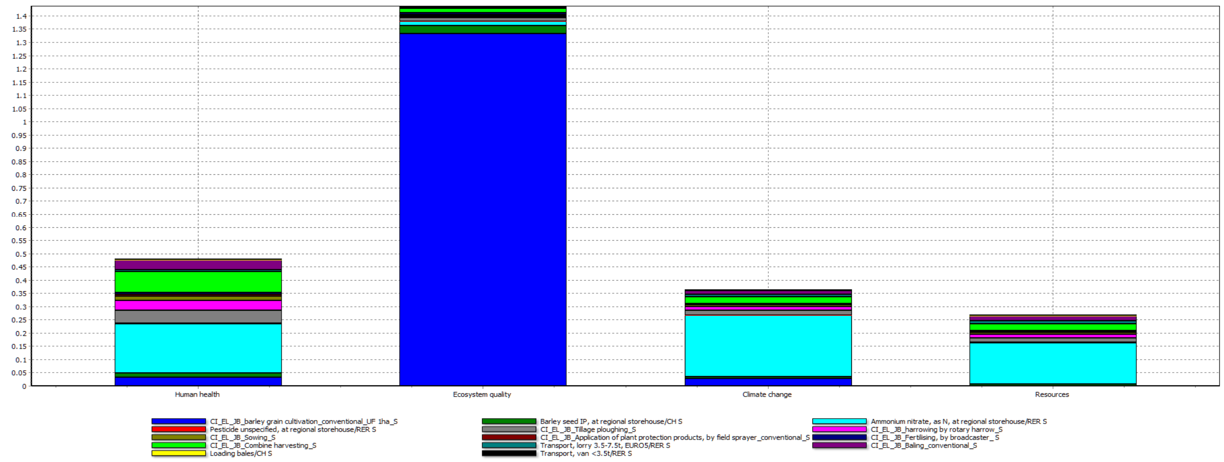


**Figure 75.** Normalization of damage categories for conventional barley cultivation process (with reference to 1ha FU).

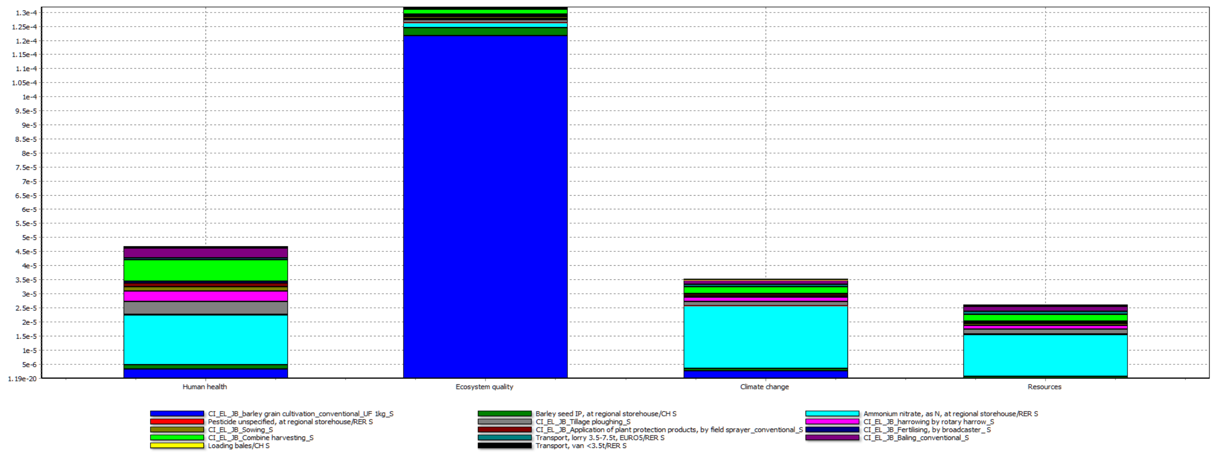


**Figure 76.** Normalization of damage categories for conventional barley cultivation process (with reference to 1kg FU).

**Table 44.** Normalization of damage categories for conventional barley cultivation process (with reference to 1ha and 1kg FUs).

| | DAMAGE CATEGORY* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | HH | | EQ | | CC | | R | |
| | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg | FU 1ha | FU 1kg |
| Total | 4.81E-01 | 4.68E-05 | 1.44 | 1.32E-04 | 3.65E-01 | 3.52E-05 | 2.69E-01 | 2.60E-05 |
| Cultivation | 3.33E-02 | 3.19E-06 | 1.33 | 1.22E-04 | 2.67E-02 | 2.56E-06 | 0.00 | 0.00 |
| Seed | 1.61E-02 | 1.55E-06 | 3.03E-02 | 2.91E-06 | 8.45E-03 | 8.11E-07 | 6.15E-03 | 5.91E-07 |
| Ammonium nitrate (N) | 1.85E-01 | 1.77E-05 | 1.74E-02 | 1.67E-06 | 2.31E-01 | 2.22E-05 | 1.56E-01 | 1.50E-05 |
| Pesticide | 1.86E-03 | 8.51E-08 | 1.79E-04 | 8.16E-09 | 1.58E-03 | 7.22E-08 | 2.18E-03 | 9.98E-08 |
| Ploughing | 4.92E-02 | 4.72E-06 | 1.28E-02 | 1.23E-06 | 1.72E-02 | 1.65E-06 | 1.76E-02 | 1.69E-06 |
| Harrowing | 3.80E-02 | 3.65E-06 | 4.34E-03 | 4.17E-07 | 1.39E-02 | 1.34E-06 | 1.44E-02 | 1.38E-06 |
| Sowing | 1.60E-02 | 1.54E-06 | 5.48E-03 | 5.26E-07 | 6.24E-03 | 6.00E-07 | 6.45E-03 | 6.19E-07 |
| Application of plant protection products | 6.41E-03 | 1.23E-06 | 2.86E-03 | 5.50E-07 | 2.63E-03 | 5.05E-07 | 2.76E-03 | 5.29E-07 |
| Fertilizing | 7.66E-03 | 7.36E-07 | 5.25E-03 | 5.04E-07 | 2.68E-03 | 2.57E-07 | 2.91E-03 | 2.79E-07 |
| Harvesting | 7.81E-02 | 7.50E-06 | 1.66E-02 | 1.59E-06 | 2.61E-02 | 2.50E-06 | 2.66E-02 | 2.56E-06 |
| Bailing | 3.72E-02 | 3.62E-06 | 5.68E-03 | 5.53E-07 | 1.49E-02 | 1.45E-06 | 1.93E-02 | 1.88E-06 |
| Loading bales | 1.36E-03 | 1.32E-07 | 6.81E-04 | 6.62E-08 | 5.10E-04 | 4.96E-08 | 5.34E-04 | 5.19E-08 |
| Transport, van<3.5t | 4.36E-03 | 4.18E-07 | 5.74E-04 | 5.49E-08 | 3.76E-03 | 3.60E-07 | 4.23E-03 | 4.05E-07 |
| Transport, lorry 3.5-7.5t, EURO5 | 7.03E-03 | 6.75E-07 | 2.70E-03 | 2.59E-07 | 8.97E-03 | 8.61E-07 | 1.01E-02 | 9.73E-07 |

* Damage categories are Human health (HH), Ecosystem quality (EQ), Climate change (CC), Resources (R).

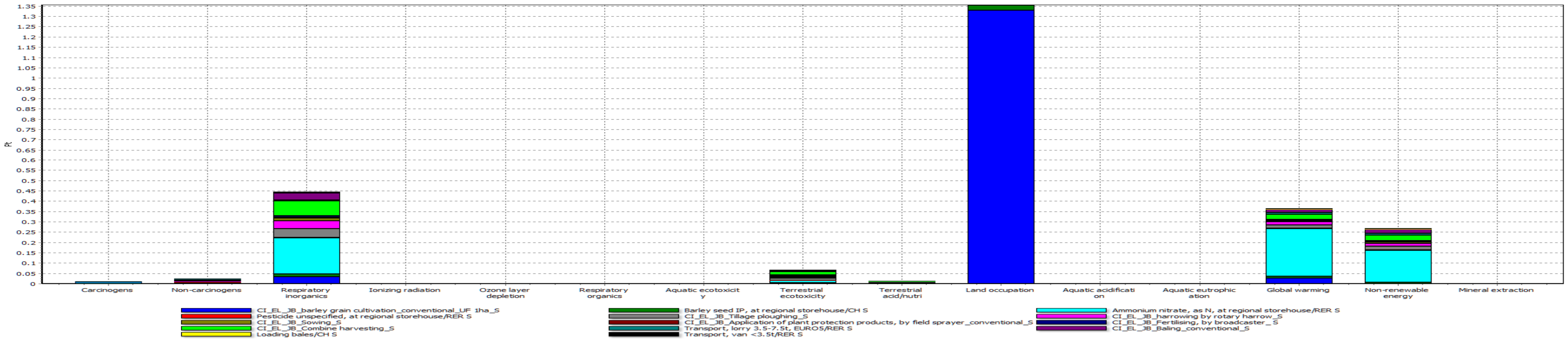


**Figure 77.** Weight evaluation per impact category for conventional barley cultivation process (with reference to 1ha FU).

**Table 45.** Weight evaluation per impact category for conventional barley cultivation process (with reference to 1ha FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Ammonium nitrate (N) | Pesticide | Ploughing | Harrowing | Sowing | Application of plant protection products | Fertilizing | Harvesting | Bailing | Loading bales | Transport, van<3.5t | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Pt | 2.55 | 1.39 | 6.10E-02 | 5.89E-01 | 5.81E-03 | 9.68E-02 | 7.06E-02 | 3.42E-02 | 1.47E-02 | 1.85E-02 | 1.47E-01 | 7.70E-02 | 3.08E-03 | 1.29E-02 | 2.88E-02 |
| CA | Pt | 1.04E-02 | 0.00 | 1.96E-04 | 5.62E-03 | 7.78E-05 | 5.23E-04 | 4.35E-04 | 1.94E-04 | 8.87E-05 | 1.04E-04 | 8.55E-04 | 1.82E-03 | 1.76E-05 | 1.97E-04 | 2.89E-04 |
| NC | Pt | 2.53E-02 | 5.58E-05 | 1.88E-03 | 4.54E-03 | 7.30E-05 | 4.34E-03 | 1.39E-03 | 1.87E-03 | 1.00E-03 | 1.87E-03 | 5.62E-03 | 1.83E-03 | 2.39E-04 | 1.33E-04 | 4.21E-04 |
| RI | Pt | 4.45E-01 | 3.32E-02 | 1.40E-02 | 1.74E-01 | 1.69E-03 | 4.42E-02 | 3.61E-02 | 1.39E-02 | 5.31E-03 | 5.67E-03 | 7.14E-02 | 3.35E-02 | 1.10E-03 | 4.00E-03 | 6.26E-03 |
| IR | Pt | 6.81E-04 | 0.00 | 4.33E-05 | 3.09E-04 | 1.64E-05 | 4.80E-05 | 4.47E-05 | 1.89E-05 | 9.68E-06 | 1.16E-05 | 7.60E-05 | 3.40E-05 | 1.81E-06 | 2.48E-05 | 4.27E-05 |
| OLD | Pt | 5.22E-05 | 0.00 | 1.16E-06 | 2.64E-05 | 4.79E-06 | 3.60E-06 | 2.84E-06 | 1.30E-06 | 5.34E-07 | 5.47E-07 | 5.41E-06 | 2.67E-06 | 1.05E-07 | 7.94E-07 | 2.06E-06 |
| RO | Pt | 3.73E-04 | 0.00 | 1.03E-05 | 9.31E-05 | 2.20E-06 | 4.25E-05 | 3.34E-05 | 1.88E-05 | 8.75E-06 | 8.41E-06 | 8.77E-05 | 3.96E-05 | 1.59E-06 | 1.02E-05 | 1.60E-05 |
| AE | Pt | 4.61E-04 | 3.96E-08 | 1.67E-05 | 2.08E-04 | 6.83E-06 | 4.29E-05 | 2.65E-05 | 1.69E-05 | 8.26E-06 | 1.24E-05 | 6.33E-05 | 2.50E-05 | 1.79E-06 | 7.81E-06 | 2.46E-05 |
| TE | Pt | 6.71E-02 | 1.57E-05 | 3.99E-03 | 1.12E-02 | 1.40E-04 | 1.18E-02 | 3.61E-03 | 5.06E-03 | 2.70E-03 | 5.09E-03 | 1.49E-02 | 5.01E-03 | 6.47E-04 | 4.29E-04 | 2.42E-03 |
| TAN | Pt | 1.31E-02 | 3.15E-03 | 6.03E-04 | 5.42E-03 | 2.65E-05 | 7.00E-04 | 5.65E-04 | 2.76E-04 | 1.11E-04 | 1.04E-04 | 1.35E-03 | 5.76E-04 | 1.97E-05 | 7.08E-05 | 1.27E-04 |
| LO | Pt | 1.36 | 1.33 | 2.57E-02 | 5.80E-04 | 5.64E-06 | 1.99E-04 | 1.37E-04 | 1.28E-04 | 4.75E-05 | 4.22E-05 | 2.25E-04 | 7.77E-05 | 1.23E-05 | 6.55E-05 | 1.27E-04 |
| AA | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | Pt | 3.65E-01 | 2.67E-02 | 8.45E-03 | 2.31E-01 | 1.58E-03 | 1.72E-02 | 1.39E-02 | 6.24E-03 | 2.63E-03 | 2.68E-03 | 2.61E-02 | 1.49E-02 | 5.10E-04 | 3.76E-03 | 8.97E-03 |
| NRE | Pt | 2.68E-01 | 0.00 | 6.14E-03 | 1.55E-01 | 2.18E-03 | 1.76E-02 | 1.43E-02 | 6.43E-03 | 2.75E-03 | 2.90E-03 | 2.66E-02 | 1.93E-02 | 5.33E-04 | 4.22E-03 | 1.01E-02 |
| ME | Pt | 5.59E-04 | 0.00 | 1.30E-05 | 3.07E-04 | 2.33E-06 | 5.26E-05 | 6.52E-05 | 1.53E-05 | 8.24E-06 | 8.24E-06 | 5.75E-05 | 1.79E-05 | 1.34E-06 | 4.84E-06 | 5.58E-06 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

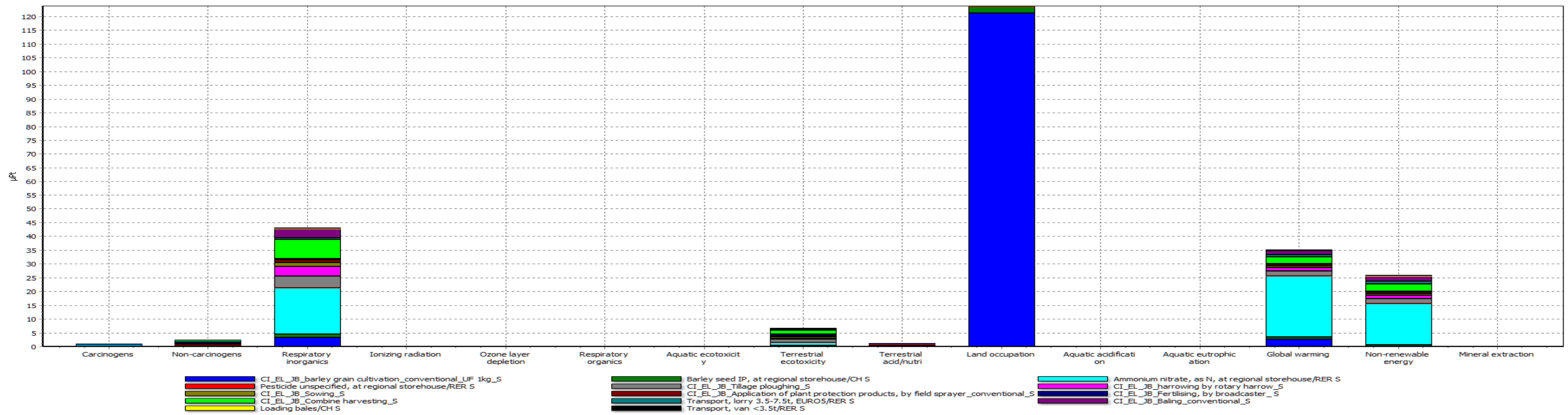


**Figure 78.** Weight evaluation per impact category for conventional barley cultivation process (with reference to 1kg FU).

**Table 46.** Weight evaluation per impact category for conventional barley cultivation process (with reference to 1kg FU).

| IMPACT CATEGORY* | Unit | Total | Cultivation | Seed | Ammonium nitrate (N) | Pesticide | Ploughing | Harrowing | Sowing | Application of plant protection products | Fertilizing | Harvesting | Bailing | Loading bales | Transport , van<3.5t | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | Pt | 2.40E-04 | 1.27E-04 | 5.86E-06 | 5.66E-05 | 2.65E-07 | 9.30E-06 | 6.78E-06 | 3.28E-06 | 2.82E-06 | 1.78E-06 | 1.41E-05 | 7.49E-06 | 3.00E-07 | 1.24E-06 | 2.77E-06 |
| CA | Pt | 1.01E-06 | 0.00 | 1.88E-08 | 5.40E-07 | 3.55E-09 | 5.02E-08 | 4.18E-08 | 1.87E-08 | 1.70E-08 | 9.99E-09 | 8.21E-08 | 1.77E-07 | 1.71E-09 | 1.89E-08 | 2.78E-08 |
| NC | Pt | 2.52E-06 | 5.36E-09 | 1.81E-07 | 4.36E-07 | 3.33E-09 | 4.17E-07 | 1.34E-07 | 1.80E-07 | 1.92E-07 | 1.79E-07 | 5.39E-07 | 1.78E-07 | 2.32E-08 | 1.27E-08 | 4.04E-08 |
| RI | Pt | 4.32E-05 | 3.19E-06 | 1.34E-06 | 1.67E-05 | 7.71E-08 | 4.25E-06 | 3.47E-06 | 1.34E-06 | 1.02E-06 | 5.44E-07 | 6.86E-06 | 3.25E-06 | 1.07E-07 | 3.83E-07 | 6.01E-07 |
| IR | Pt | 6.55E-08 | 0.00 | 4.16E-09 | 2.97E-08 | 7.50E-10 | 4.60E-09 | 4.29E-09 | 1.82E-09 | 1.86E-09 | 1.12E-09 | 7.30E-09 | 3.30E-09 | 1.76E-10 | 2.37E-09 | 4.10E-09 |
| OLD | Pt | 4.82E-09 | 0.00 | 1.11E-10 | 2.53E-09 | 2.19E-10 | 3.46E-10 | 2.73E-10 | 1.25E-10 | 1.03E-10 | 5.26E-11 | 5.19E-10 | 2.59E-10 | 1.02E-11 | 7.60E-11 | 1.98E-10 |
| RO | Pt | 3.66E-08 | 0.00 | 9.92E-10 | 8.94E-09 | 1.00E-10 | 4.08E-09 | 3.21E-09 | 1.81E-09 | 1.68E-09 | 8.08E-10 | 8.42E-09 | 3.85E-09 | 1.55E-10 | 9.74E-10 | 1.54E-09 |
| AE | Pt | 4.47E-08 | 3.80E-12 | 1.60E-09 | 2.00E-08 | 3.12E-10 | 4.12E-09 | 2.54E-09 | 1.62E-09 | 1.59E-09 | 1.19E-09 | 6.08E-09 | 2.43E-09 | 1.74E-10 | 7.48E-10 | 2.36E-09 |
| TE | Pt | 6.70E-06 | 1.51E-09 | 3.83E-07 | 1.07E-06 | 6.38E-09 | 1.14E-06 | 3.47E-07 | 4.85E-07 | 5.18E-07 | 4.89E-07 | 1.43E-06 | 4.87E-07 | 6.29E-08 | 4.11E-08 | 2.33E-07 |
| TAN | Pt | 1.27E-06 | 3.02E-07 | 5.79E-08 | 5.20E-07 | 1.21E-09 | 6.72E-08 | 5.43E-08 | 2.65E-08 | 2.14E-08 | 9.95E-09 | 1.30E-07 | 5.60E-08 | 1.91E-09 | 6.78E-09 | 1.22E-08 |
| LO | Pt | 1.24E-04 | 1.21E-04 | 2.46E-06 | 5.57E-08 | 2.58E-10 | 1.91E-08 | 1.32E-08 | 1.23E-08 | 9.12E-09 | 4.05E-09 | 2.16E-08 | 7.56E-09 | 1.19E-09 | 6.27E-09 | 1.22E-08 |
| AA | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | Pt | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | Pt | 3.52E-05 | 2.56E-06 | 8.11E-07 | 2.22E-05 | 7.22E-08 | 1.65E-06 | 1.34E-06 | 6.00E-07 | 5.05E-07 | 2.57E-07 | 2.50E-06 | 1.45E-06 | 4.96E-08 | 3.60E-07 | 8.61E-07 |
| NRE | Pt | 2.60E-05 | 0.00 | 5.90E-07 | 1.49E-05 | 9.97E-08 | 1.69E-06 | 1.37E-06 | 6.18E-07 | 5.28E-07 | 2.78E-07 | 2.55E-06 | 1.87E-06 | 5.18E-08 | 4.05E-07 | 9.72E-07 |
| ME | Pt | 5.43E-08 | 0.00 | 1.25E-09 | 2.94E-08 | 1.06E-10 | 5.05E-09 | 6.26E-09 | 1.47E-09 | 1.58E-09 | 7.91E-10 | 5.52E-09 | 1.74E-09 | 1.31E-10 | 4.64E-10 | 5.36E-10 |

[*] Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

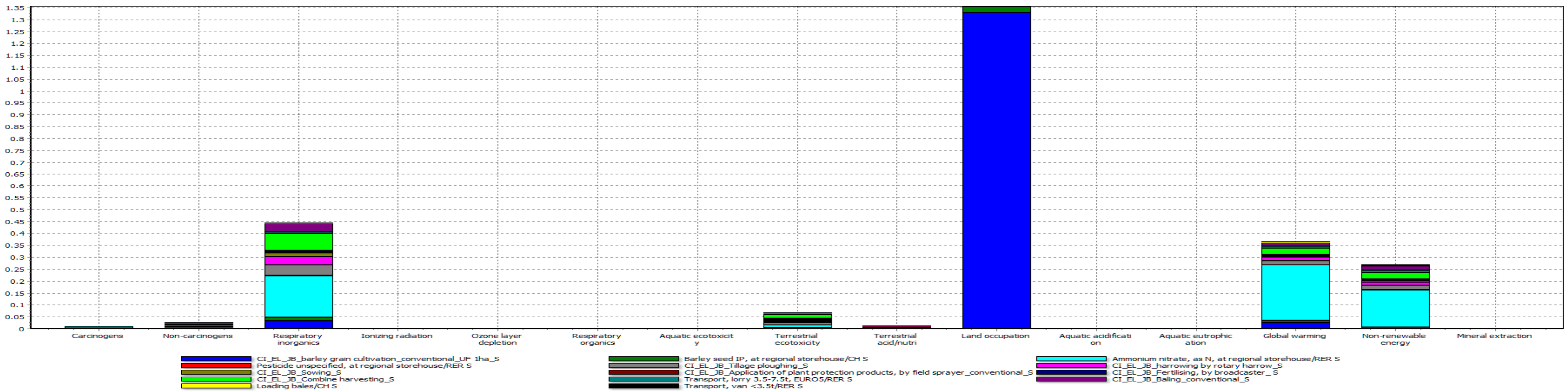


**Figure 79.** Normalization of impact categories for conventional barley cultivation process (with reference to 1ha FU).

**Table 47.** Normalization of impact categories for conventional barley cultivation process (with reference to 1ha FU).

| IMPACT CATEGORY* | Total | Cultivation | Seed | Ammonium nitrate (N) | Pesticide | Ploughing | Harrowing | Sowing | Application of plant protection products | Fertilizing | Harvesting | Bailing | Loading bales | Transport, van<3.5t | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | 1.04E-02 | 0.00 | 1.96E-04 | 5.62E-03 | 7.78E-05 | 5.23E-04 | 4.35E-04 | 1.94E-04 | 8.87E-05 | 1.04E-04 | 8.55E-04 | 1.82E-03 | 1.76E-05 | 1.97E-04 | 2.89E-04 |
| NC | 2.53E-02 | 5.58E-05 | 1.88E-03 | 4.54E-03 | 7.30E-05 | 4.34E-03 | 1.39E-03 | 1.87E-03 | 1.00E-03 | 1.87E-03 | 5.62E-03 | 1.83E-03 | 2.39E-04 | 1.33E-04 | 4.21E-04 |
| RI | 4.45E-01 | 3.32E-02 | 1.40E-02 | 1.74E-01 | 1.69E-03 | 4.42E-02 | 3.61E-02 | 1.39E-02 | 5.31E-03 | 5.67E-03 | 7.14E-02 | 3.35E-02 | 1.10E-03 | 4.00E-03 | 6.26E-03 |
| IR | 6.81E-04 | 0.00 | 4.33E-05 | 3.09E-04 | 1.64E-05 | 4.80E-05 | 4.47E-05 | 1.89E-05 | 9.68E-06 | 1.16E-05 | 7.60E-05 | 3.40E-05 | 1.81E-06 | 2.48E-05 | 4.27E-05 |
| OLD | 5.22E-05 | 0.00 | 1.16E-06 | 2.64E-05 | 4.79E-06 | 3.60E-06 | 2.84E-06 | 1.30E-06 | 5.34E-07 | 5.47E-07 | 5.41E-06 | 2.67E-06 | 1.05E-07 | 7.94E-07 | 2.06E-06 |
| RO | 3.73E-04 | 0.00 | 1.03E-05 | 9.31E-05 | 2.20E-06 | 4.25E-05 | 3.34E-05 | 1.88E-05 | 8.75E-06 | 8.41E-06 | 8.77E-05 | 3.96E-05 | 1.59E-06 | 1.02E-05 | 1.60E-05 |
| AE | 4.61E-04 | 3.96E-08 | 1.67E-05 | 2.08E-04 | 6.83E-06 | 4.29E-05 | 2.65E-05 | 1.69E-05 | 8.26E-06 | 1.24E-05 | 6.33E-05 | 2.50E-05 | 1.79E-06 | 7.81E-06 | 2.46E-05 |
| TE | 6.71E-02 | 1.57E-05 | 3.99E-03 | 1.12E-02 | 1.40E-04 | 1.18E-02 | 3.61E-03 | 5.06E-03 | 2.70E-03 | 5.09E-03 | 1.49E-02 | 5.01E-03 | 6.47E-04 | 4.29E-04 | 2.42E-03 |
| TAN | 1.31E-02 | 3.15E-03 | 6.03E-04 | 5.42E-03 | 2.65E-05 | 7.00E-04 | 5.65E-04 | 2.76E-04 | 1.11E-04 | 1.04E-04 | 1.35E-03 | 5.76E-04 | 1.97E-05 | 7.08E-05 | 1.27E-04 |
| LO | 1.36 | 1.33 | 2.57E-02 | 5.80E-04 | 5.64E-06 | 1.99E-04 | 1.37E-04 | 1.28E-04 | 4.75E-05 | 4.22E-05 | 2.25E-04 | 7.77E-05 | 1.23E-05 | 6.55E-05 | 1.27E-04 |
| AA | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | 3.65E-01 | 2.67E-02 | 8.45E-03 | 2.31E-01 | 1.58E-03 | 1.72E-02 | 1.39E-02 | 6.24E-03 | 2.63E-03 | 2.68E-03 | 2.61E-02 | 1.49E-02 | 5.10E-04 | 3.76E-03 | 8.97E-03 |
| NRE | 2.68E-01 | 0.00 | 6.14E-03 | 1.55E-01 | 2.18E-03 | 1.76E-02 | 1.43E-02 | 6.43E-03 | 2.75E-03 | 2.90E-03 | 2.66E-02 | 1.93E-02 | 5.33E-04 | 4.22E-03 | 1.01E-02 |
| ME | 5.59E-04 | 0.00 | 1.30E-05 | 3.07E-04 | 2.33E-06 | 5.26E-05 | 6.52E-05 | 1.53E-05 | 8.24E-06 | 8.24E-06 | 5.75E-05 | 1.79E-05 | 1.34E-06 | 4.84E-06 | 5.58E-06 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

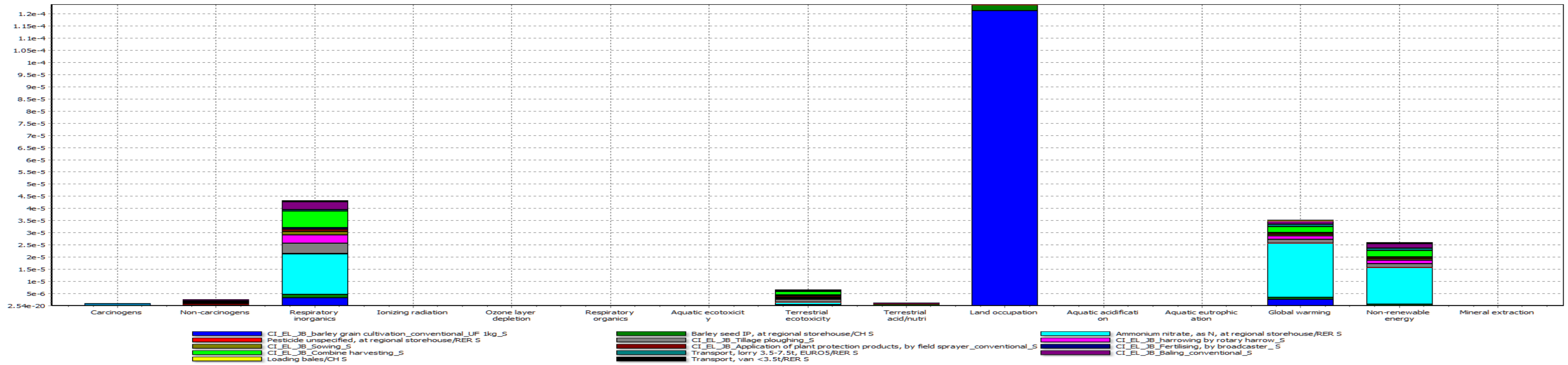


**Figure 80.** Normalization of impact categories for conventional barley cultivation process (with reference to 1kg FU).

**Table 48.** Normalization of impact categories for conventional barley cultivation process (with reference to 1kg FU).

| IMPACT CATEGORY* | Total | Cultivation | Seed | Ammonium nitrate (N) | Pesticide | Ploughing | Harrowing | Sowing | Application of plant protection products | Fertilizing | Harvesting | Bailing | Loading bales | Transport, van<3.5t | Transport, lorry 3.5-7.5t, EURO5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CA | 1.01E-06 | 0.00 | 1.88E-08 | 5.40E-07 | 3.55E-09 | 5.02E-08 | 4.18E-08 | 1.87E-08 | 1.70E-08 | 9.99E-09 | 8.21E-08 | 1.77E-07 | 1.71E-09 | 1.89E-08 | 2.78E-08 |
| NC | 2.52E-06 | 5.36E-09 | 1.81E-07 | 4.36E-07 | 3.33E-09 | 4.17E-07 | 1.34E-07 | 1.80E-07 | 1.92E-07 | 1.79E-07 | 5.39E-07 | 1.78E-07 | 2.32E-08 | 1.27E-08 | 4.04E-08 |
| RI | 4.32E-05 | 3.19E-06 | 1.34E-06 | 1.67E-05 | 7.71E-08 | 4.25E-06 | 3.47E-06 | 1.34E-06 | 1.02E-06 | 5.44E-07 | 6.86E-06 | 3.25E-06 | 1.07E-07 | 3.83E-07 | 6.01E-07 |
| IR | 6.55E-08 | 0.00 | 4.16E-09 | 2.97E-08 | 7.50E-10 | 4.60E-09 | 4.29E-09 | 1.82E-09 | 1.86E-09 | 1.12E-09 | 7.30E-09 | 3.30E-09 | 1.76E-10 | 2.37E-09 | 4.10E-09 |
| OLD | 4.82E-09 | 0.00 | 1.11E-10 | 2.53E-09 | 2.19E-10 | 3.46E-10 | 2.73E-10 | 1.25E-10 | 1.03E-10 | 5.26E-11 | 5.19E-10 | 2.59E-10 | 1.02E-11 | 7.60E-11 | 1.98E-10 |
| RO | 3.66E-08 | 0.00 | 9.92E-10 | 8.94E-09 | 1.00E-10 | 4.08E-09 | 3.21E-09 | 1.81E-09 | 1.68E-09 | 8.08E-10 | 8.42E-09 | 3.85E-09 | 1.55E-10 | 9.74E-10 | 1.54E-09 |
| AE | 4.47E-08 | 3.80E-12 | 1.60E-09 | 2.00E-08 | 3.12E-10 | 4.12E-09 | 2.54E-09 | 1.62E-09 | 1.59E-09 | 1.19E-09 | 6.08E-09 | 2.43E-09 | 1.74E-10 | 7.48E-10 | 2.36E-09 |
| TE | 6.70E-06 | 1.51E-09 | 3.83E-07 | 1.07E-06 | 6.38E-09 | 1.14E-06 | 3.47E-07 | 4.85E-07 | 5.18E-07 | 4.89E-07 | 1.43E-06 | 4.87E-07 | 6.29E-08 | 4.11E-08 | 2.33E-07 |
| TAN | 1.27E-06 | 3.02E-07 | 5.79E-08 | 5.20E-07 | 1.21E-09 | 6.72E-08 | 5.43E-08 | 2.65E-08 | 2.14E-08 | 9.95E-09 | 1.30E-07 | 5.60E-08 | 1.91E-09 | 6.78E-09 | 1.22E-08 |
| LO | 1.24E-04 | 1.21E-04 | 2.46E-06 | 5.57E-08 | 2.58E-10 | 1.91E-08 | 1.32E-08 | 1.23E-08 | 9.12E-09 | 4.05E-09 | 2.16E-08 | 7.56E-09 | 1.19E-09 | 6.27E-09 | 1.22E-08 |
| AA | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| AEU | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| GW | 3.52E-05 | 2.56E-06 | 8.11E-07 | 2.22E-05 | 7.22E-08 | 1.65E-06 | 1.34E-06 | 6.00E-07 | 5.05E-07 | 2.57E-07 | 2.50E-06 | 1.45E-06 | 4.96E-08 | 3.60E-07 | 8.61E-07 |
| NRE | 2.60E-05 | 0.00 | 5.90E-07 | 1.49E-05 | 9.97E-08 | 1.69E-06 | 1.37E-06 | 6.18E-07 | 5.28E-07 | 2.78E-07 | 2.55E-06 | 1.87E-06 | 5.18E-08 | 4.05E-07 | 9.72E-07 |
| ME | 5.43E-08 | 0.00 | 1.25E-09 | 2.94E-08 | 1.06E-10 | 5.05E-09 | 6.26E-09 | 1.47E-09 | 1.58E-09 | 7.91E-10 | 5.52E-09 | 1.74E-09 | 1.31E-10 | 4.64E-10 | 5.36E-10 |

* Impact categories are Carcinogens (CA), Non-carcinogens (NC), Respiratory inorganics (RI), Ionizion radiation (IR), Ozone layer depletion (OLD), Respiratory organics (RO), Aquatic ecotoxicity (AE), Terrestrial ecotoxicity (TE), Terrestrial acidification and nutrition (TAN), Land occupation (LO), Aquatic acidification (AA), Aquatic eutrophication (AEU), Global warming (GW), Non-renewable Energy (NRE), Mineral extraction (ME).

## III. Nomenclature

| Symbol | Definition | Unit |
|---|---|---|
| $NH_3$ | Ammonia | g |
| $N_2O$ | Dinitrogen monoxide | g |
| N | Nitrogen | kg/ha |
| $NH_4NO_3$ | Ammonium nitrate | kg |
| $CO_2$ | Carbon dioxide | kg |
| HH* | Human health | DALY |
| EQ* | Ecosystem quality | PDF*m$^2$*yr |
| CC* | Climate change | kg $CO_2$ eq |
| R* | Resources | MJ primary |
| CA* | Carcinogens | DALY (kg $C_2H_3Cl$ eq) |
| NC* | Non-carcinogens | DALY (kg $C_2H_3Cl$ eq) |
| RI* | Respiratory inorganics | DALY (kg PM2.5 eq) |
| IR* | Respiratory organics | DALY (kg $C_2H_4$ eq) |
| OLD* | Ionizing radiation | DALY (Bq C-14 eq) |
| RO* | Ozone layer depletion | DALY (kg CFC-11 eq) |
| AE* | Aquatic ecotoxicity | PDF*m2*yr (kg TEG water) |
| TE* | Terrestrial ecotoxicity | PDF*m2*yr (kg TEG soil) |
| TAN* | Terrestrial acidification/nutrition | PDF*m2*yr (kg $SO_2$ eq) |
| LO* | Land occupation | PDF*m2*yr (m$^2$org.arable) |
| AA* | Aquatic acidification | kg $SO_2$ eq |
| AEU* | Aquatic eutrophication | kg $PO_4$ P-lim |
| GW* | Global warming | kg $CO_2$ eq |
| NRE* | Non-renewable energy | MJ primary |
| ME* | Mineral extraction | MJ surplus |

* Source: Jolliet *et al.* (2003)

## IV. Acronyms

| Abbreviation | Definition |
|---|---|
| CAP | Common Agricultural Policy |
| ha | Hectare |
| $m^2$ | Squared meter |
| yr | Year |
| g | Gram |
| kg | Kilogramm |
| Gt | Giga tons |
| Mt | Mega tons |
| EU-28 | European Union (28 Countries) |
| LCA | Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| LCIA | Life Cycle Impact Assessment |
| FU | Functional Unit |
| DM | Dry matter |
| S | System process |
| U | Unit process |
| pt | Point |
| CI_EL | Processes related to barley cultivation in organic farming. They were created to describe the complex process of organic barley cultivation and involve the baseline sub-processes. Currently, they are stored in SimaPro v.7.3.3 software, in use by the Department of Economics at the University of Foggia (Italy). |
| CI_EL_JB | Processes related to barley cultivation in conventional farming. They were created to describe the complex process of conventional barley cultivation and involve the baseline sub-processes. Currently, they are stored in SimaPro v.7.3.3 software, in use by the Department of Economics at the University of Foggia (Italy). |
| PDF | Potential Damage Fraction: the fraction of species that have a high probability of not surviving in the affected area due to unfavorable living conditions. |
| DALY | Disability-Adjusted Life Year: a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death. |
| $CO_2$ eq | Carbon dioxide equivalent |
| MJ primary | Mega Joule of nonrenewable primary energy |