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SUSTAVIANFEED

ALTERNATIVE ANIMAL FEEDS IN MEDITERRANEAN POULTRY BREEDS TO OBTAIN SUSTAINABLE PRODUCTS

ENVIRONMENTAL EVALUATION OF THE ALTERNATIVE DIET

DELIVERABLE 2.4

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SUMMARY

Poultry meat is currently the most widely consumed meat and, to satisfy the growing demand of the population, it is expected that the world production of poultry meat and eggs will continue to increase in the coming years. This has led to a rapid expansion of intensive poultry production, which has had negative effects on nature, such as the emission of greenhouse gases and the pollution of soil and water. The livestock sector needs a change towards a more sustainable production. In this sense, there is an important interest in reducing impacts with respect to feed, as the feed production is one of the elements that contribute the most to the environmental impact. So, the main goal of this project is to develop sustainable nutritional formulas as alternatives in the poultry sector able to reduce the carbon footprint. In addition, Black soldier fly larvae (*Hermetia illucens*) was considered as possible ingredient for poultry feeding. During the present document, laying hens and chicken meat in 5 different environments have been studied. Each of them was considered a Pilot study (Spain, Italy, Turkey and two in Tunisia).

To achieve the objective, each pilot provided a list of common ingredients in their broiler or layer formulas and a list of possible alternative ingredients and by-products. For each ingredient and its possible origins, environmental impact was calculated. Impact assessment was performed with the LCA software package SimaPro, using the ReCiPe 2016 Endpoint (H) V1.03 / World (2010) H/A method, and ILCD 2011 Midpoint+ V1.10 / EC-JRC Global (kgCO2-eq/t) method. As inputs, the mean of the impact of ingredient production in Europe and another mean for the American production were used, using the data from Agri-Footprint, assuming the economic allocation, and the distance from origin to the feed industry as well as the kind of transport used. For those ingredients that require drying, or grinding, the energy required for those process was imputed. In addition, the impact of a new ingredient was analyzed: Black soldier fly (BSF) larvae using the data provided by ENTOMO company.

Later, different preliminary diets were formulated according to nutrient specifications of the ingredients and nutritional requirements of the animals of each pilot. All the pilots shared the same basal experimental design regarding the feeding program as follows:

1) Control commercial diet. Common diet used by poultry farming from each pilot according to the type of chicken farming (egg-type or meat-type).

2) An experimental diet including local ingredients or by-products and fewer cereals and protein sources imported. According to the pilot, this diet may or may not contain insects.

3) An experimental diet with the inclusion of *Hermetia Illucens* larvae. Depending on the pilot, the percentage of insect used can vary.

Lastly, the environmental impact of preliminary diets was estimated considering at least 95% of the composition for each formula. Regarding the environmental impact of the diets, for Control diet the average of the impacts of each ingredient was considered when it has different origins. For alternative diets, the nearest origin of the ingredients was considered.

In terms of ingredient impacts, in all pilots, soybean derivatives (meal and oil) have the greatest impact on the carbon footprint, followed by some imported cereals, except in the Italian pilot, where fat sources such as palm oil, soybean oil or sunflower oil were the ingredients with the greatest impact. Furthermore, the alternative ingredients proposed by the different pilots, in general were less impactful than the usual ingredients and those of national origin had the least impact.

Hermetia Illucens larvae had a moderate impact, but when larvae were dried, the impact was greater. Despite this, its impact on carbon footprint is lower than that of imported soybean meal for all pilots. This makes it a potential ingredient as a protein source for more sustainable poultry diets. In addition, if they are fed with by-products, may become a possible solution for the treatment of agri-food waste, thus participating in the principles of the circular economy.

In relation to the feeding program, the Spanish pilot proposed three diets for laying hens Control diet and two alternative diets which incorporated *Hermetia Illucens* larvae at 3 and 6%, respectively. In addition, soybean meal and imported maize were decreased, and peas and DDGs were incorporated. These diets reduced by 16.9 and 28.8% kg CO_2 eq/t the carbon footprint.

Italian pilot will be carried out in meat-type chicken and feeding program involved two phases (starter: from 0 to 60 days, and grower/finisher: from 61 to 150 days). For each phase one Control and two alternative diets were provided. One alternative diet (ALTER) included alternative ingredients such as fava beans, peas, sunflower meal, and maize gluten meal. In addition, in this diet the inclusion of maize, soybean meal and soybean oil was reduced. This diet did not incorporate insect larvae. The other alternative diet (4.5-HERM) included similar ingredients to alternative ALTER plus 4.5% *Hermetia Illucens* larvae. In starter phase alternative diets reduced by 49.9 and 45.3% in the carbon footprint (kg CO_2 eq/t) compared to the Control diet. In Finisher phase, the reductions of the alternative diets were one percentage unit less than those of grower on climate change.

The Turkish pilot will be carried out in poultry meat production. The feeding program involved three phases: starter (from 0 to 14 days), grower (from 15-28 days) and finisher (from 29 days to slaughter age). In each phase three diets (1 control and 2 alternative diets) were studied. In this case, the first alternative diet (ALTER) included alternative ingredients such as Brewers´ dried grain, wheat middling, and sunflower meal. In addition, soybean meal was reduced. The other alternative diet (5-HERM) had the same ingredients to ALTER but 5% of *Hermetia Illucens* was incorporated. Thus, ALTER diet achieved a reduction of 45.9% for starter phase, 41% in grower phase and 39% kg CO_2 eq/t in finisher phase. 5-HERM reduced 43.6%, 39.5%, and 36% kg CO_2 eq/t for each phase respectively.

The pilot of Tunisia involves the ISA CM University's pilot and the RAYHANA Association's pilot. They were carried out in poultry meat and laying hens. For the meat production, a feeding program involved three phases: starter (from 1 to 28 days), grower (from 29-66 days) and finisher (from 67 days to slaughter age). In each phase three diets (1 control and 2 alternative diets) were studied. In the first alternative diet (ALTER) maize, and soybean meal were reduced, and alternative ingredients such as national triticale and pasta waste were included. The second alternative diet incorporated the same ingredients than the previous but 5% of *Hermetia Illucens* was added. These diets reduced carbon footprint by 25.7% in the case of ALTER diet, and 40.3% kg CO2 eq/t for the alternative diet 5-HERM, with respect to Control diet. In grower phase, by 40.8% and 43.2% kg CO2 eq/t, for ALTER and 5-HERM, respectively; and in finisher phase, the reduction was by 39.7% kg CO2 eq/t ALTER diet, and 41.8% 5-HERM diet. The feeding program for laying hens was in a single-phase with three diets, one Control and two alternative diets (ALTER and 5-HERM). The latter had imported maize and soybean meal reduced and alternative ingredients such as national triticale and pasta waste were included. In this case, the second alternative diet incorporated 5% *Hermetia Illucens* too. The reductions obtained were by 37.2% with ALTER diet, and 39.5% with 5-HERM diet.

In general, in all pilots, the alternative diet where the insect was incorporated as a protein source in place of soybean meal had a greater environmental impact reduction than when only alternative ingredients or by-products were incorporated.

Therefore, in the proposed scenario (one diet with alternative ingredients and reduction of imported ingredients) and other with these ingredients and *Hermetia Illucens* larvae is possible to reduce the carbon footprint by more than 15% in the poultry feeding program. In this way, we contribute to making the poultry sector more sustainable.

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Acronyms and abbreviations

Abbreviation	Description
BSF	Black Soldier Fly
DDGs	Distiller's Dried Grains with Solubles
EU	European Union
FAO	Food and Agriculture Organization
HI	*Hermetia Illucens* larvae
LCA	Life cycle assessment
Pt	points
USA	United States of America

1 Introduction

The poultry sector continues to grow and industrialize in many parts of the world. An increasing population, greater purchasing power and urbanization have been strong drivers of growth. Worldwide, chicken meat production has also increased last year (by 1.56%), reaching 100.5 million tons. EU produces 12.3% of the world's total chicken meat, and Turkey stands out with 2% of world production (MAPA, 2021). In relation to egg production, the world produces about 74 million tons of eggs per year, being EU the second largest producer with 8% of production. Tunisia, for its part, produces almost 150,000 tons of chicken meat and 103,800 tons of eggs (FAOSTAT).
Genetic advancement, development, and transfer of feeding, slaughtering, and processing technologies have improved safety and efficiency, but favoring large-scale units to the detriment of small-scale producers. This development has caused the poultry industry and the concentrated feed industry to rapidly increase in size (FAOSTAT) generating negative effects on nature, such as the emission of greenhouse gases or soil and water pollution (Cappelaere et al., 2021). Chicken meat is the most widely consumed meat currently and to meet growing demand, world production of poultry meat and eggs is expected to continue increasing (Mottet et al., 2017).
Given the importance of the poultry sector, making the transition to less harmful practices is crucial for these productions. There is an important interest in reducing impacts with respect to feed, as the feed production is one of the elements that contribute the most to the environmental impact (Abin et al., 2018; Cappelaere et al., 2021).
In addition, the EU imports a large quantity of raw materials for the livestock feeding sector, especially soybean and cereals (85% of the soybean, 24% of corn and 8% of wheat and corn consumed) (CESFAC, 2018). Therefore, the livestock sector in general needs a change towards a more sustainable production, where local raw materials take on greater importance and the dependence on imported ingredients is reduced.
In recent years, one of the most studied alternatives is the use of agro-industrial by-products. Their use in animal feed can help reducing environmental problems caused by their accumulation as the same time as the carbon footprint of animal products decreases when locally produced by-products are used while contributing to farm sustainability (Gerber et al., 2014). In addition, most byproducts are not potentially edible for humans, so they do not compete directly with human food (Bakshi, et al., 2016) which is another great advantage for its use.
On the other hand, insects seem to be an interesting resource with many environmental and health benefits. Insects could be used in poultry feed, as they are part of their natural diet. They contain between 30% and 70% protein on a dry matter basis, fats (about 35%), minerals, and vitamins and, for this reason, protein-rich insects are a promising alternative to the more harmful traditional protein sources. Some insect species have been recently included in the European regulations as possible feed ingredients for monogastric feeds (Commission Regulation (EU) 2021/1372), among them, *Hermetia illucens*, can be a suitable substitute for the diet of laying hens (Borrelli et al., 2017).
In this context, new environmentally-friendly-feeding program should be assay for poultry. In addition, the use of agriculture by-products could also be used to produce insects, favoring the principles of circular economy.
In this project, a study of environmental impact of new diets for broilers and laying hens in different contexts was carried out. The following is a description of the methodology used as well as the results and conclusions obtained in relation to this deliverable 2.4 (Environmental evaluation of the diets).

2 Methodology

2.1 Scope

The objective of SUSTAvianFEED is to reduce the impact of poultry feed, so five pilots have developed sustainable nutritional formulas as an alternative in the livestock sector able to reduce the carbon footprint. The project has worked with laying hens and chickens' meat in 5 different environments, where each of them have been considered a pilot study. The project objective is to reduce the carbon footprint of the diets by 10-15% in the egg and meat sector.
To achieve this objective, an environmental impact study has been carried out in which a control diet is compared to alternative diets. Once the impact of all ingredients is known, alternative diets will be formulated where the highest impact ingredients will be reduced and alternative ingredients such as local products, by-products, and insects will be incorporated.

2.2 Methodology

First, a database with common and alternative ingredients for poultry feeding of each pilot was developed. Each of the five pilots (Spain, Italy, Turkey, and Tunisia (ISA CM and Rayhana) provided the list of their usual ingredients for laying hens and/or chicken meat (according to the bird used in each pilot), and other list with possible alternative ingredients. Then, impacts of these ingredients were estimated.

Impact assessment was performed with the LCA software package SimaPro 9.2.0.1 developed by PRé Consultants, which classifies and combines the flows of materials, energy, and emissions into and out of each product system by the type of impact their use or release has on the environment.

To calculate the environmental impact the ReCiPe 2016 Endpoint (H) V1.03 / World (2010) H/A method (Huijbregts et al. 2016), and ILCD 2011 Midpoint+ V1.10 / EC-JRC Global (kgCO2-eq/t) method were used.

The ReCiPe method includes a global punctuation in points (pt.) and has also been employed with the aim of classifying the damage in three category indicators:

- Human health, points
- Ecosystem, points
- Resources, points

The ILCD method studies the impact on 16 category indicators, but in this study the most considerable categories were selected according to bibliography consulted (Castanheira et al., 2019; Loyola et al., 2021; Ogino et al., 2021):

- Climate change, kg CO_2eq/t
- Acidification, molc H+eq/t
- Land use, kg C deficit/t
- Marine eutrophication, kg N eq/t
- Human toxicity, non-cancer effects, CTUh/t
- Human toxicity, cancer effects, CTUh/t

Effects on the acidification and marine eutrophication categories are usually due fertilizers during crop production, and energy expenses. Land use is related to the land used change. Human toxicity is mainly related to the use of pesticides and fuel combustion.

As inputs, the mean of the impact of ingredient production in Europe and another mean for the American production, using the data from Agri-Footprint, assuming the economic allocation, and the distance from origin to the feed industry as well as the kind of transport used (truck, train, and ship) (Figure 1).

For the crop cultivation model in Agri-Footprint, the following aspects are considered:

- Crop yield (kg crop product / ha cultivated)
- Energy inputs (type and quantity / ha cultivated)
- Land use change (m^2/ ha cultivated)
- Land use change related emissions:
  - Carbon dioxide emissions
- Water use (m^3/ ha cultivated)
- Artificial fertilizer and lime inputs (type and application rate / ha cultivated)
- Animal manure inputs (type and application rate / ha cultivated)
- Fertilizer / manure related emissions:
  - Nitrous oxide emissions
  - Carbon dioxide emissions (from lime and Calcium Ammonium Nitrate)
  - Ammonia and nitrate emissions
  - Heavy metal emissions.
- Emissions from pesticides application (type and kg active ingredient / ha cultivated)

For those ingredients that require some processing stages as drying, grinding, or pelleting, and wasn´t considered of Agri-Footprint database, the energy consumption was considered (Figure 1). As outputs, the ingredient, and their byproducts, if necessary, were considered. For example, not only soybean meal but also soybean oil is produced from soybeans, and thus the environmental loads of soybean cultivation and its processing were allocated between the two products economically. A summary of data used are showed in Annex I (Table 12-16).

When a by-product did not have economic value zero environmental impact was assumed by its production.
For each ingredient and its origin, the environmental impact was estimated.

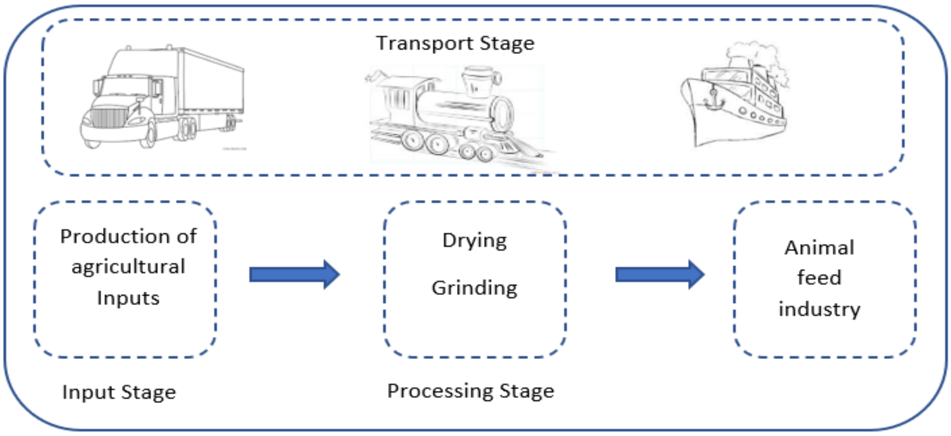


Figure 1. Life cycle stages included in the environmental impact study of ingredients

In addition, the impact of a new ingredient was analyzed: Black soldier fly (BSF) larvae (***Hermetia illucens*** **L**, **HI**) considering the production system, feeding, and transport to the pilot in Murcia according to data provided by ENTOMO company.

Insects were reared by ENTOMO company, under highly technical conditions, with controlled environmental characteristics (29°C y 70% HR). Adult colony was maintained for larvae production. Larvae at 5 days of age began to fatten for 12 days, at which time they were slaughtered by bleaching. Subsequently, the larvae will be dried to be supplied to UMU and UNITO pilots.

To continue promoting the sustainability aspects, insects were fed with authorized organic waste according to EU Regulation, by-products of the agri-food industry as well as local agriculture surpluses (broccoli and other leftovers from local agriculture, Brewer's spent grain and bakery by products). BSF can convert these substrates in high quality protein (Oonincx et al., 2015). Thus, the insects feeding was based on a circular economy and no environmental impact will be added to the process.

To calculate the environmental loads derived from water and electricity consumption for larval production and transport of by-products for feeding (Figure 2), the data provided by the company ENTOMO was used, which were entered into the LCA software SimaPro, in the same way as the rest of the ingredients. As outputs evaporation losses, the detritus or compost generated, and the production of fresh larvae were considered. Since the objective in the pilot is to provide dried insect larvae, the impact was estimated to produce fresh and dried larvae. This deliverable will also estimate the impact of the dried larvae for the Spanish pilot including transportation to the place of use.

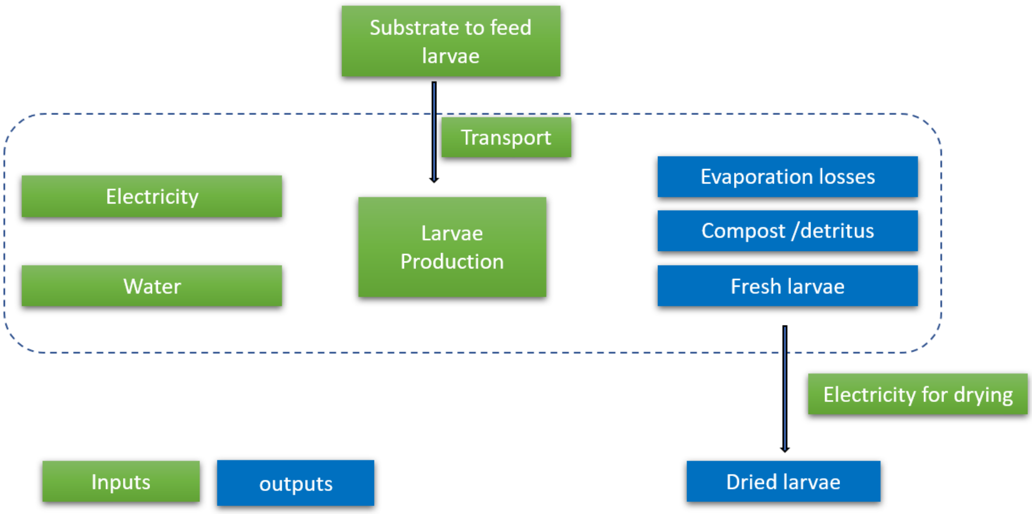


Figure 2. Input and outputs considered for the estimation of the environmental impact of the insect

Later, different preliminary diets were formulated according to data of task 2.5: Nutrient specifications of the ingredients and specifications of the nutritional requirements of the animals.

All the pilots developed in universities (Spain, Italy, Turkey, and Tunisia) shared the same basal experimental design regarding the feeding program as follows:

1) Control commercial diet. Common diet used by poultry farming from each pilot according to the type of chicken farming (egg-type or meat type).

2) An experimental diet including local ingredients or by-products and fewer cereals and protein sources imported. According to the pilot, this diet may or may not contain insects.

3) An experimental diet with the inclusion of *Hermetia Illucens* larvae. Depending on the pilot, the percentage of insect used can vary.

Lastly, environmental impact of preliminary diets was estimated considering at least 95% of the composition for each formula. This method was like the process carried out by Agri-Foodprint 2.0 (Agri-Foodprint, 2015). Impact of some micro-ingredients were not calculated. Despite this criterion for allowing components to be excluded, environmental estimation of ingredients is included when the necessary information is readily available, or a reasonable estimate can be made.

Regarding environmental impact of the diets, for Control diet the average of the impacts of each ingredient was considered when it has different origins. For alternative diets, those alternative ingredients or with high environmental impact, their nearest origin was considered for decrease the impact of formula. Therefore, it was estimated in the scenario in which the provision of the ingredient of that origin was possible.

3 Environmental impact of ingredients

In this task, the environmental evaluation of the different ingredients (usuals and alternatives) has been conducted. In a first phase, a database has been built consisting of the most usual ingredients to manufacture poultry feed, and, in addition, possible alternative ingredients have been included. This database has been made for both egg and meat production according to the information provided by each pilot.

In this section you can see the impact of ingredients with ILCD method related to climate change (expressed as kgCO_2-eq/t), and the total punctuation obtained with RECIPE method (pt) in the five pilots (one in Spain, Italy, and Turkey, and two in Tunisia). The impacts obtained with ILCD and RECIPE method in relation to other categories you can see it in the Figures from 15 to 19 in Annex I and in Figures from 20 to 50 in Annex II, respectively.

3.1 Spain

Impacts of usual and alternative ingredients provided by Spanish pilot are shown in Table 1. The usual ingredients include cereals grains (maize, wheat, and barley) and some cereals by-products (wheat middling), plant-based protein sources (soybean meal, sunflower meal, rapeseed meal), fat sources (animal fat, soybean oil), fibrous ingredients (soybean hulls) and micro-ingredients (minerals, vitamins, and amino acids). All of them are usual ingredients in animal diets in Spain. However, it is noted that many of them are imported from countries located at great distances. Thus, maize and soybean meal are entirety imported. Other ingredients, as wheat, sunflower meal and rapeseed meal are also partially imported.

Respect to environmental impact on **Climate change** expressed as kgCO_2-eq/t (Table 1) the usual ingredients with the greatest impact were soybean meal (from 3,860 to 6,550 kgCO_2-eq/t), soybean oil (7040 kgCO_2-eq/t) and imported cereals as maize (1640-2170 kgCO_2-eq/t) and wheat from Eastern Europe (1730 kgCO_2-eq/t) , while the usual ingredients with lowest impact were wheat and barley from Spain among cereals, mainly those of an origin closer to the feed mills (Murcia), 713 and 668 kgCO_2-eq/t for Murcia wheat and barley, respectively; among protein sources: Spanish sunflower meal (1190-1450 kgCO_2-eq/t) and rapeseed meal (1490 kgCO_2-eq/t), and some minerals as monocalcium phosphate (198 kgCO_2-eq/t) and sodium chloride (199 kgCO_2-eq/t) and wheat middling (from 1,360 to 386 kgCO_2-eq/t). Alternative ingredients had intermediate impacts, cereals by-products as barley rootlets (269 kgCO_2-eq/t) bakery by-products (1060 kgCO_2-eq/t) and DDGs (1190 kgCO_2-eq/t). Protein sources as soybean concentrate from USA had a very high impact (8380 kgCO_2-eq/t), but other alternative protein sources as peas (about 2000 kgCO_2-eq/t), rapeseed cake (876-1250 kgCO_2-eq/t), or sunflower cake (1420-2280 kgCO_2-eq/t) were intermediate.

If we refer to the **Total impact** in points (ReCipe method), a similar trend was observed. Soybean meal and soybean oil continue to be ingredients with a high impact (average: 173.5 and 202 pt, respectively), although maize sometimes exceeds the impact of soybean meal. For example, maize from Brazil (163 pt) and USA (159 pt) were higher than the soybean meal from USA (155 pt) and Eastern Europe (131 pt). In general, by products as wheat middling, bakery by products, citrus, carob pulp, barley rootles or DDGs have a low impact with an average of 28.9 pt.

In Annex I the impacts on other different categories of Spanish ingredients obtained with ILCD method can be seen (Figure 17). Alternative ingredients had less impact than usual ingredients for all categories studied. On acidification, the ingredients with the greatest impact were the maize from Brazil and USA followed by soybean meal. On the other hand, the high impact of the alternative ingredient peas from Canada in this category is noteworthy. In relation to land use, soybean oil and soybean concentrate were the ingredients with the greatest impact, being a usual and alternative ingredient, respectively. However, most of the alternative ingredients had very little impact, as they are considered waste, the production loads of the main ingredient are not imputed.

For marine eutrophication and on human toxicity (cancer effects or non-cancer effects), maize from Brazil and USA, were the worst impact. It is also important to highlight the harmful effects of soybean oil on human health.

In other categories assay with ReCipe method (Annex II, Figure 22-29), human health was the most prominent category, followed by ecosystem and finally resources. Therefore, in this document we will only comment on the impacts on human health category. Among the cereals, maize from USA and Brazil had the greatest impact (137.6 and 141.6 pt, respectively). Cereals from Murcia (near of feed mill) were those with the least impact (wheat and barley, with 36 pt each). If we refer to cereal by-products, DDGs had the greatest impact (49.3 pt), and wheat middling from Navarra (47.4 pt) had a greater impact than other by-products of origin closer to the feed mill. Barley rootles had the lowest impact (8.4 pt). With respect to protein sources, all the soybean meal had a high impact on the human health (more than 100 pt) especially that from Brazil (194.5 pt) and Argentina (148.7 pt) compared to sunflower products (average of 58 pt). In addition, other products from soybean as oil had a high impact not only on human health, but also on the ecosystem (more than 50 pt). Also highlight the impact of soybean hulls on human health and ecosystem.

In general, it is observed that soybean derivatives (meal, oil, and hulls) have a very high impact on carbon footprint, followed by some imported cereals. In addition, the impact of ingredients with several origins is greater the greater the distance from the origin. In this sense, it is important to note that of the alternative ingredients proposed by Spain, those of Spanish origin have the lowest impact. Transportation by road directly affects habitat, ecosystems, endangered species, and water quality through consumption, fragmentation, and replacement of natural cover with impervious surfaces (Demirel et al., 2008). On the other hand, by-products are incidental or secondary products resulting from a production process, whose main purpose is not the production of the item itself, so their environmental impact is usually low. Iit is noted that the use of imported ingredients as cereals and soybean meal and increase the use of ingredients of closer origin and by-products must be a priority.

Table 1. Environmental impact of usual and alternative ingredients estimated with ILCD (climate change, kg CO2-eq/t) and ReCipe (total impact, points) provided by Spain pilot depending on the origin.

Usual ingredients	Origin	Impact (kgCO$_2$ eq/t)[1]	Total Impact (pt)[2]	Alternative ingredients	Origin	Impact (kgCO$_2$ eq/t)	Total Impact (pt)
Maize	France	1640	83.4	Bakery by product	Spain	1060	37.1
	Brazil	2120	163	Sunflower cake	France	2280	107
	Eastern Europe	1870	102		Spain-Andalucía	1670	82.7
	USA	2170	159		Spain-Valencia	1420	73.7

Wheat	Spain-Murcia Spain-Castilla LM Eastern Europe	713 1240 1730	50.2 68.7 99.1
Barley	Spain-Castilla LM Spain-Murcia	1190 668	70.4 51.8
Wheat middling	Spain- Castilla LM Spain-Valencia Spain-Navarra Spain-Murcia	564 475 1360 386	28.9 25.7 57 22.5
Soybean meal	USA Brazil Eastern Europe Argentina	4610 6550 3860 4930	155 230 131 178
Sunflower meal	France Spain-Valencia Spain-Andalucía	1650 1190 1450	86 67 76
Rapeseed meal	Spain France	1490 2900	65.5 115
Soybean oil	Spain*	7040	202
Animal fat	Spain- Castilla LM Spain-Murcia Spain-Valencia	2710 2190 1480	96.1 77.6 88
Soybean hulls	Spain	2850	83
Sodium chloride	Spain	199	7.75
Sodium bicarbonate	Spain	1900	82.1
Monocalcium phosphate	Spain	198	6.97
Calcium carbonate	Spain	678	23.6
L- Lysine[3]		-	-
DL-Metionine[3]		-	-

Citrus Pulp	Spain	269	31.2
Carob Pulp	Spain-Murcia Spain-Andalucía Africa	97,3 645 648	3.52 22.9 26.1
Barley Rootlets	Spain	269	9.53
DDGs	Spain	1190	54.3
Rapeseed cake	France Spain	1250 876	47.3 31
Soybean concentrate	USA	8380	231
Peas	France Canada	2110 2220	120 165

[1]: Impact on climate change estimated with ILCD 2011 Midpoint+ V1.10 / EC-JRC Global method. [2]: Estimated impact obtained with ReCiPe 2016 Endpoint (H) method. [3] impact was not calculated. * Imported seed.

3.2 Italy

The impacts of ingredients provided by Italian pilot are shown in Table 2. Like Spain pilot, some of the cereal grains are totally imported, as barley. Unlike Spain, some of the maize is sourced locally, although other part must be imported. Thus, imported cereals as French maize (1180 kgCO_2-eq/t) and barley (1540 kgCO_2-eq/t) had a high impact on **Climate change**. With respect to protein sources, soybean meal is mostly imported, with high impact (1720-6210 kgCO_2-eq/t according to origin), although the ingredients with the greatest impact were fat sources as palm oil imported from

Indonesia (14700 $kgCO_2$-eq/t) and sunflower oil imported from Russia (12200 $kgCO_2$-eq/t). Soybean oil also has a very high impact, especially those imported from Brazil (9090 $kgCO_2$-eq/t), USA (4400 $kgCO_2$-eq/t), and Argentina (6000 $kgCO_2$-eq/t). All of them are usual ingredients in Italian diets. On the opposite side, the ingredients with a lower impact were Italian ingredients as Italian maize (971 $kgCO_2$-eq/t) among cereals, and sunflower meal (420 kgCO2-eq/t) as usual ingredient and by products of Italian origin (former food products, bakery by products, and hazelnut skins with an average of 258 kgCO2-eq/t) proposed as alternative ingredients. Those imported alternative ingredients, as rapeseed from Canada, peas from France, and fava beans from France, had a greater impact. However, Italian broken rice had a high impact (2180 $kgCO_2$-eq/t).

On the other hand, in the environmental impact study of soybean meal is observed that if soybean meal is imported as such from Brazil, the impact is much higher than if the seed is imported and processed in Italy (74% $kgCO_2$-eq/t plus). This appreciation is important if the second scenario is possible to reduce impacts of diets. In addition, in relation with the grape skin by product, it is observed that if the product is dried at origin the impact is lower (12,3% $kgCO_2$-eq/t less?) than if it is dried at destination, a fact that is attributed to a lower water transport in the first scenario. It is also important to note that for those alternative ingredients that have an Italian and imported origin (rapeseed meal, peas, and fava beans), the impact of the Italian products is almost half that of the imported ones, especially in terms of climate change ($kgCO_2$-eq/t). This is very important to consider for more sustainable diets. The same trend was observed in the ReCipe method study on the **total impact** expressed in points.

In relation with other categories analysed with ILCD method: acidification, land use, marine eutrophication, and human toxicity (Annex I, Figure 18). The high impact of fat sources is most striking, and alternative ingredients as peas and fava beans have a moderate impact on land use, marine eutrophication, and human toxicity.

In other categories assay with ReCipe method (Anex II Figure 30-35), among cereals and their by-products, barley had more impact on human health than maize (63.7 and 47.5 pt, respectively), and broken rice was more impact (90.8 pt) than the other cereal by products (average of 25.7 pt). According to protein sources, soybean meal obtained from Brazil seed (145.4 pt) and from Argentina seed (112.7 pt) and rapeseed meal from Canada (130.9 pt) were those with the greatest impact. Among fat sources, soybean oil when seed is from Brazil (371.9 pt) and sunflower oil if seed is from Russia (377 pt) were the most impactful. It is important to note that fat sources were the ingredients in Italy that had the greatest impact on human health, higher even than those of soybean meal. On the other hand, it is important the low impact of alternative ingredients, such as Italian sunflower meal or hazelnut skin.

In general, it is observed that in the Italian pilot, fat sources such as palm oil, soybean oil or sunflower oil are the ingredients with the highest impact on the carbon footprint. They are followed by soybean meal and some imported cereals. In addition, the impact of ingredients with several origins is greater the greater the distance from the origin. On the other hand, when possible, it is preferable to dry the ingredients at origin, thus reducing water transport and consequently environmental pollution.

Table 2. Environmental impact of usual and alternative ingredients estimated with ILCD (climate change, kg CO2-eq/t) and ReCipe (total impact, points) provided by Italian pilot depending on the origin.

Usual ingredients	Origin	Impact (kg CO_2 eq/t)[1]	Total Impact (pt)[2]	Alternative ingredients	Origin	Impact (kg CO_2 eq/t)	Total Impact (pt)
Maize	Italy	971	56.8	Wheat bran	Italy	536	27.9
	France	1180	64.1	Maize Gluten meal	Italy	1310	57.7
Barley	France	1540	82.7	Broken rice	Italy	2180	108
Soybean meal	Italy	983	66	Former food products	Italy	319	11
	Brazil (seed imported)	3560	178	Bakery by products	Italy	319	11
	USA (seed imported)	1720	108	Hazelnut skins	Italy	137	4.86
	Argentina (seed imported)	2340	141	Grape skins	Italy (wet)	137	4.86
	Brazil (meal imported)	6210	237		Italy (dried in Torino)	1780	79.2
	USA (meal imported)	3860	147		Italy (dried in origin)	1560	71.3
	Argentina (meal imported)	5250	195	Rapeseed meal	Italy	1170	54
					Canada	2360	156
Sunflower meal	Italy	420	13.1	Peas	Italy	999	77.2
	Russia	2520	87.4		France	1690	102
Palm oil	Indonesia	14700	380	Fava beans	Italy	939	74.2
Soybean oil	Italy	2510	169		France	1630	98.5
	Brazil (seed imported)	9090	456				
	USA (seed imported)	4400	277				
	Argentina (seed imported)	6000	361				

Sunflower oil	Italy	2040	63.8
	Russia	12200	425
Animal fat	Italy	14700	380
Phosphates	Maroc	-	-
Sodium bicarbonate	Italy	1260	59.4
Sodium Clhoride	Italy	2030	72.6
Calcium carbonate	Italy	177	5.84
L-lysine[3]	China	-	-
DL-Methionine[3]	China	-	-
Vitamin-mineral premix[3]	China	-	-
Pigments[3]	China	-	-
Enzymes[3]	USA	-	-

[1]: Impact on climate change estimated with ILCD 2011 Midpoint+ V1.10 / EC-JRC Global method. [2]: Estimated impact obtained with ReCiPe 2016 Endpoint (H) method. [3]: impact was not calculated.

3.3 Turkey

The estimated environmental impacts of ingredients provided by Turkish pilot are shown in Table 3. It is noteworthy that Turkish pilot hardly imports any ingredients, using mostly local products. Among cereals, maize and wheat are the cereals usually used, Turkish wheat and maize from Russia and Turkey. As expected, imported maize from Russia had the greatest impact (3580 kgCO_2- eq/t) on **Climate change** and **Total impact** (151 pt). Soybean meal, fish meal and sunflower meal were the usual protein sources. The largest impact was that of imported soybean meal (from Brazil: 8000 kgCO_2- eq/t and 293 pt, and from Eastern Europe 4480 kgCO_2- eq/t and 157 pt). Fish meal is an animal protein source of Tunisian origin, which has a greater impact (1.5 times more) than Turkish soybean meal. However, sunflower meal, other vegetal source protein, has similar impact to soybean meal when both were from Turkey.

It is also noted that if a same ingredient sourced from Turkey, the impact is considerably reduced. For example, maize from Turkey has 39% and 34% less environmental impact than Russia maize if we refer to climate change (kg CO_2-eq/t) or total impact (points). In the same way Turkish soybean meal has 77% and 68% less than Brazil soybean meal for climate change (kg CO_2-eq/t) and total impact (pt), respectively.

With respect to the alternative ingredients, all of them of Turkish origin. It is important to note the high impact of whey powder (5120 kgCO_2- eq/t, and 233 pt), due to the dehydration process to which it must be subjected, which means that although it is an alternative ingredient, its use is not recommended to reduce environmental impact. Wheat middling was the lowest impact ingredient

(317 kgCO_2- eq/t, and 21.4 pt). Also, some alternative ingredients as grape pomace and beer pulp had a lower impact if they are transported dry than wet, almost 3% less, due to the volume of water transported in the latter scenario. This fact is important if you can choose when to dehydrate the product.

In Annex I other environmental categories studied with the ILCD method are shown (Figure 19). Soybean meal was the ingredient with the highest impact on all studied categories (acidification, land use, marine eutrophication, and human toxicity). The low impact of alternative ingredients on land use, marine eutrophication and human toxicity, cancer and non-cancer effects is striking.

In other parameters analyzed with the ReCipe method (Figure 36-39 in Annex II), on human health, origin of ingredients has a high importance. Thus, maize from Turkey has 35.9% less impact than Russian maize, and Turkish wheat much less impact than the previous ones. Soybean meal from Brazil was the ingredient with highest impact on human health, with 1.9 times more impact than that of Eastern European and 3.6 times more than Turkish soybean meal. In this category, fish meal has less impact than imported soybean meal. And sunflower meal is even less than fish meal. Also, it is observed a high impact of some alternative ingredients (brewers' dried grain) when it is transported wet. Mineral sources had a very low impact on human health.

In summary, imported soybean meal and maize are the ingredients with the highest impact on carbon footprint. Fishmeal of Turkish origin has a greater impact than soybean meal of the same origin. In addition, imported ingredients had a greater environmental impact than local ingredients. On the other hand, if it is possible, it is preferable drying the ingredient at origin, before transport, to reduce the environmental impact.

Table 3. Environmental impact of usual and alternative ingredients estimated with ILCD (climate change, kg CO2-eq/t) and ReCipe (total impact, points) provided by Turkish pilot depending on the origin.

Usual ingredients	Origin	Impact (kg CO_2 eq/t)[1]	Total Impact (pt)[2]	Alternative ingredients	Origin	Impact (kg CO_2 eq/t)	Total Impact (pt)
Maize	Russia	3580	151	Tomato pomace	Turkey	1610	70.9
	Turkey	2170	99.3	Grape pomace (wet transport)	Turkey	1440	63.1
Soybean meal	Brazil	8000	293	Grape pomace (dry transport)	Turkey	1230	55.8
	Turkey	1790	94.6	Whey powder	Turkey	5120	233
	Eastern Europe	4480	157	Whey powder high protein	Turkey	3040	121
Fish meal	Turkey	2670	91	Sunflower oil	Turkey	3380	111
Sunflower meal	Turkey	1800	88.6	Beer pulp (wet transport)	Turkey	4600	186
Wheat	Turkey	751	51.6	Beer pulp (dry transport)	Turkey	2800	122

Calcium sources	Turkey	78.1	2.34	Wheat middling	Turkey	317	21.4
Sodium chloride	Turkey	169	6.69				
Marble dust	Turkey	102	3.6				
Vitamin premix[3]		-	-				
Mineral premix[3]		-	-				
Aminoacids (DL-methionine, L-lysine) [3]		-	-				

[1]: Impact on climate change estimated with ILCD 2011 Midpoint+ V1.10 / EC-JRC Global method. [2]: Estimated impact obtained with ReCiPe 2016 Endpoint (H) method. [3]: impact was not calculated

3.4 Tunisia

3.4.1. ISA-CM University

Table 4 shows impacts of ingredients (usual ingredients, subproducts, and other by-products) provided by ISA CM University. In relation of usual ingredients, a high dependence is observed on imported cereals (maize, wheat, and barley), mainly from Eastern European countries such as Romania, Ukraine, Bulgaria, and Russia. They also import cereals from Finland, Argentina, Germany, and United States of America (USA). The cereal with highest impact on **Climate change** was Russian barley (4010 kg CO_2-eq/t) followed by maize from Argentina (2730 kg CO_2-eq/t). The cereals with the least impact were Italian wheat and Bulgarian barley with 1170 and 1240 kg CO_2-eq/t, respectively. The rest of cereals had an intermediate impact. As protein sources they mainly use fava beans, soybean meal, and rapeseed meal, the latter two are common sub-products. Fava beans are of Tunisian origin, from different localities, which makes them moderately impacted (about 1000-1100 kg CO_2-eq/t). Nevertheless, Soybean meal is partially imported from Argentina with 2.3 times more impact than when coming from Tunisia (5210 and 2250 kg CO_2-eq/t, respectively).
There are other sub-products of Tunisian origin with intermediate impacts such as wheat bran, tomato pulp, brewer's grain, and molasses. Fat sources as soybean oil and animal fat are imported too with very high impact (about 7800 and 3000 kg CO_2-eq/t, respectively). However, it should be noted that all alternative ingredients are produced in Tunisia whose impact is considerably low: olive pomace (51 kg CO_2-eq/t), grape marc (192 kg CO_2-eq/t), carob pulp (192 kg CO_2-eq/t), pasta waste (184 kg CO_2-eq/t). Other alternative ingredients as by-products of the date palm and triticale had a greater impact (865 and 1160 kg CO_2-eq/t, respectively). As was observed for other ingredients in the Turkish pilot, some sub-products have less impact if they are transported dry from the origin, such as dried tomato, brewer's grain and beer pulp which decreased by 15%, 25% and 26%, respectively, when they are dried transported respect to wet transport. In ReCipe study, a similar trend was observed on the **Total impact** expressed in points.

In other categories analyzed with ILCD (Annex I, Figure 20), alternative ingredients were, in general, less impactful than the usual ingredients. Especially noteworthy is the negligible impact of almost all alternative ingredients, except for triticale, which showed a low impact. With respect to subproduct, they had an intermediate impact between usual and alternative ingredients, so, they could be used as ingredients in more sustainable diets, and thus increase the availability of possible ingredients for sustainable diets.

According to ReCipe method (Annex II, Figure 40-48), maize was the cereal with the greatest impact on human health, above wheat and barley. Among their different origins, maize from Argentina had the greatest impact and maize from Romania had the least. Barley was like wheat impact, except for Russia, the impact of which was much greater. Respect to protein sources, soybean meal had the greatest impact, especially that of Argentina with more than 160 points. Rapeseed and fava beans had a moderate impact (about 60 and 50 pt, respectively). Soybean oil was the worst ingredient in relation with human health. In general, alternative ingredients had a low impact.

In conclusion, it is observed that imported soybean meal from Argentina was the ingredient with the greatest impact on carbon footprint, followed by some imported cereals. In addition, the impact of ingredients with several origins is greater the distance from the origin. In this sense, it is important to note that all alternative ingredients proposed by Tunisia are Tunisian origin and they have a moderate-low impact.

Table 4. Environmental impact of usual and alternative ingredients estimated with ILCD (climate change, kg CO2-eq/t) and ReCipe (total impact, points) provided by Tunisian pilot (ISA CM University) depending on the origin.

Usual ingredients	Origin	Impact (kg CO_2 eq/t)[1]	Total Impact (pt)[2]	Other Alternative ingredients	Origin	Impact (kg CO_2 eq/t)	Total Impact (pt)
Maize	Argentina	2730	196	Olive pomace fresh	Tunisia	51	1.78
	Romania	1530	84.9	Grape marc fresh	Tunisia	192	6.81
	Ukraine	1670	90,6	Caroube Pulp	Tunisia	192	6.89
	USA	2040	158	By-products of the date palm	Tunisia	865	30.6
Wheat	Ukraine	1710	95	Pasta waste	Tunisia	184	6.27
	Italy	1170	70.3	Triticale	Tunisia	1160	77.2
	Bulgaria	1250	77.1				
Barley	Russia	4010	180				
	Germany	1700	105				
	Bulgaria	1210	78.8				
	Finland	1460	102				
	Ukraine	1480	89.9				
	Rumania	1340	84				
Fava beans	Tunisia-Beja	1170	82.4				
	Tunisia-Jendouba	1170	82.4				
	Tunisia–Gran Tunisia	1020	77,1				

	Tunisia–Siliana	1020	77,1
	Tunisia–Kef	1120	80,5
	Tunisia-Zaghouan	946	74.4
	Tunisia–Governorate Nabeoul	980	75.6
	Tunisia-Bizerte	1100	80
Soybean oil	Spain	7870	237
	France	7730	231
Animal Fat	Spain	3030	112
	France	2890	106
Vitamins[3]		-	-
Minerals[3]		-	-
Premixed additives[3]		-	-
Enzymes[3]		-	-
Antioxidants, acidifiers[3]		-	-
Yeasts[3]		-	-
Pigments[3]		-	-
Anticoccidial[3]		-	-
Amino-Acids[3]		-	-
Usual subproducts/alternative			
Wheat bran	Tunisia	650	32
	Italy	851	43.2
Soybean meal	Tunisia	2250	128
	Argentina	5210	195
Soybeans hulls	Argentina	3530	152
Rapeseed meal	Tunisia	1240	58.6
Tomato pulp (fresh)	Tunisia	178	6.32

Dried Tomato pulp (wet transport)	Tunisia	1630	71.2	
Dried Tomato pulp (dry transport)	Tunisia	1380	62.5	
Brewer's grain (fresh)	Tunisia	343	12.2	
Dried Brewer's grain (wet transport)	Tunisia	2600	110	
Dried Brewer's grain (dry transport)	Tunisia	1960	87.7	
Beer pulp (fresh)	Tunisia	384	13.6	
Dried Beer pulp (wet transport)	Tunisia	2670	112	
Dried Beer pulp (dry transport)	Tunisia	1970	87.5	
Molasses	Tunisia–Béja	343	12.2	
	Tunisia Bou Salem	385	13.6	
Rapessed	Tunisia wet	1880	101	
	Tunisia dried	1970	106	

[1]: Impact on climate change estimated with ILCD 2011 Midpoint+ V1.10 / EC-JRC Global method. [2]: Estimated impact obtained with ReCiPe 2016 Endpoint (H) method. [3]: impact was not calculated.

3.4.2. Rayhana

The Association Rayhana is a non-governmental Organization whose aim is to develop a transformative movement for women by practicing participatory and democratic associationism, will engage rural women for the poultry breeding. This association will work common pilot with ISA-CM in Tunisia, in a real context which will engage rural women of Jendouba region. Rayhana developed a list of available ingredients as shown in the Table 5. Rayhana will basically work with similar ingredients as ISA CM.

For the estimation of impacts, the average distance from the origins of the ISA-CM ingredients was considered. As previous pilots imported ingredients have greater environmental impact than local ingredients, sometimes up to twice as much as in the case of maize and barley. It should be noted that this association uses protein raw materials such as fish meal and peas with less impact than soybean meal (1570, 1130, and 3730 kg CO_2 eq/t, respectively), which is important for use in more sustainable diets, although raw materials are often used based on the lowest cost. In Annex I Figure 21 impacts on other categories obtained with ILC method are shown, and in Figures 49-52 of Annex II impacts on other categories obtained with ReCipe method are shown. Soybean meal and imported maize are the ingredients with the greatest impact in general, except for land use where Trigonella foenum-graecum and peas had the greatest impact.

Table 5. Environmental impact of usual and alternative ingredients estimated with ILCD (climate change, kg CO2-eq/t) and ReCipe (total impact, points) provided by Tunisia pilot (RAYHANA) depending on the origin.

Available ingredients	Origin	Impact (kg CO_2 eq/t)[1]	Total Impact (pt)[2]
Fava beans	Tunisia	1065.8	78.7
	Tunisia, nearest origin	836	70.5
Maize	Tunisia	1030	59
	Imported	1992.5	132.4
Wheat	Tunisia	890	56.5
	Imported	1376.7	80.8
Barley	Tunisia	845	58.1
	Imported	2082.5	113
Wheat bran	Tunisia	574	29.3
	Imported	851	43.2
Soybean meal	Imported	3730	161.5
Marble dust	Tunisia	30.2	1.1
Fish meal	Tunisia	1570	51.9
Trigonella foenum-graecum	Tunisia	1130	81.8
Peas	Tunisia	1130	81.8
	Imported (Italy)	1800	109
Triticale	Tunisia	963	70.3
Pasta waste	Tunisia	319	11
Vitamins[3]		-	-
Minerals[3]		-	-
Oligoelements[3]		-	-

[1]: Impact on climate change estimated with ILCD 2011 Midpoint+ V1.10 / EC-JRC Global method. [2]: Estimated impact obtained with ReCiPe 2016 Endpoint (H) method. [3]: impact was not calculated.

4 Evaluation of impact of *Hermetia Illucens* larvae

The use of insects for feed is widely recognized as one of the potential solutions for the environmental problem of livestock sector and to cope with the expected growth of consumer demand (Sogari et al., 2019). Recently, it has been included in the European regulations as possible feed ingredients for animal feed (Commission Regulation (EU) 2021/1372). They are suitable as feed for livestock, fish, poultry, and pigs. In poultry nutrition, *Hermetia illucens* larvae is one of the most promising because of its nutritional composition and high digestibility rate (De Marco et al., 2015), which gets similar animal performance when compared to conventional soybean-meal-based diets. Another advantage of BSF is that, unlike many pests that consume waste, BSF do not carry bacteria or diseases and larvae are capable of inactivating Escherichia coli and Salmonella enterica Erickson et al., 2004).

One of the aims of this project is to use insect by replacing part of imported protein sources such as soybean meal, and for this we first conducted a study of its environmental impact.

4.1 Environmental Impact of *Hermetia Illucens*

The impact of HI estimated with ILCD (**Climate change**, kg CO_2-eq/t) and ReCipe (**Total impact**, points) method on environmental are shown in Table 6. As expected, the impact of fresh larvae was much lower than that of dried larvae (819 kg CO_2-eq/t - 29.6 pt and 2,860 kg CO_2-eq/t - 104 pt, respectively) since dried larvae had 3.5 times more impact both with ILCD and ReCipe method than fresh larvae. The impact of *H. Illucens* obtained is according to the literature consulted (Bava et al., 2019; Bosch et al., 2019). However, the potential global warming impacts of insect production reared with by-products (food waste) vary over a wide range from -6.420 to 5.300 kg CO_2 eq/t according to the review by Smetana et al. (2021) because the impact depends on the type of insect, compositions of the diet, optimization of growing conditions, level of processing, type of distribution, etc.

Despite this moderate impact of dried insect, its impact on carbon footprint is lower than that of imported soybean meal for all pilots. This makes it a potential ingredient for more sustainable poultry diets to reduce environmental impact.

The greatest contribution to the impact of fresh insect production was due to the transport of the feeding substrate (927 kg CO_2-eq/t), which accounts for 48% of the total carbon footprint, followed by the larval fattening phase (805 kg CO_2-eq/t), and finally the maintenance of the colony (172 kg CO_2-eq/t) (Figure 3). However, the distribution phase will also increase the environmental impact.

Table 6. Environmental impact of insect larvae provided by ENTOMO company

Insect	Impact (kg CO_2 eq/t)[1]	Impact (pt)[2]
Fresh HI larvae[3]	819	29.6
Dried HI larvae	2860	104

[1]: Impact on climate change estimated with ILCD 2011 Midpoint+ V1.10 / EC-JRC Global method.
[2]: Estimated impact obtained with ReCiPe 2016 Endpoint (H) method.[3] HI: *Hermetia Illucens*

In the assumption for the LCA, insects were reared on agro-industrial by-products, which has several advantages such as reduced waste production, and compliance with sustainable circular economy, which makes it a great advantage over other substrates.

The other environmental categories studied with ILCD method are showed in Figure 4. For human toxicity, acidification, marine eutrophication and land use, dried larvae were from 62% to 78% more contaminant than the fresh ones. This is due to the drying process. When data are normalized (Figure 5), we can observe that fresh larvae production have a very low impact on these categories. Dried larvae production has a greater impact. Human toxicity and, especially, cancer effects, is the most affected category. However, marine eutrophication and land use are little impacted.

Respect the other categories studied with ReCipe method (Figure 6). Human health was the most affect category where dried larvae production had a 71% higher impact than fresh larvae.

In any case, the larvae could be offered fresh, but the objective of the project is to propose their use in dried form, as this has many advantages over fresh larvae in terms of preservation and distribution. Another possible form of administration would be in meal, but in this case the natural behavior of birds to ingest the insect would not be exercised with the associated loss of added value.

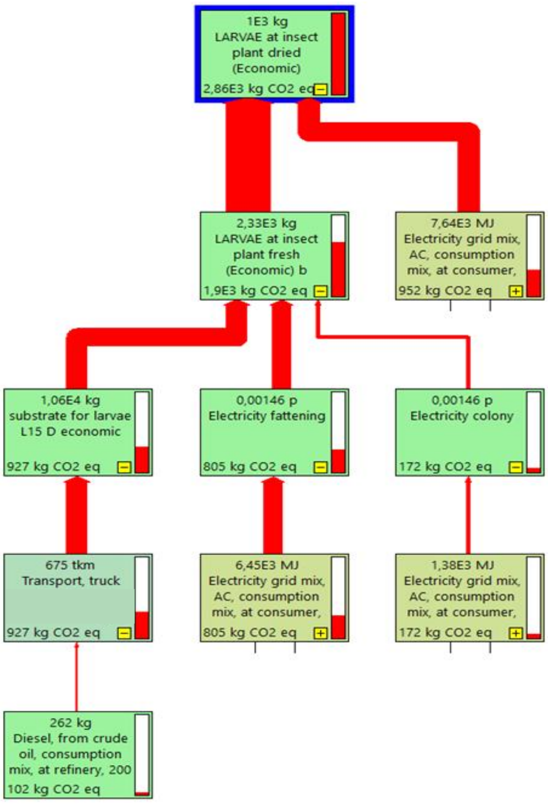


Figure 3. Carbon footprint contribution analysis of production of dried Hermetia Illucens larvae (ILCD 2011 Midpoint+ V1.10 / EC-JRC method).

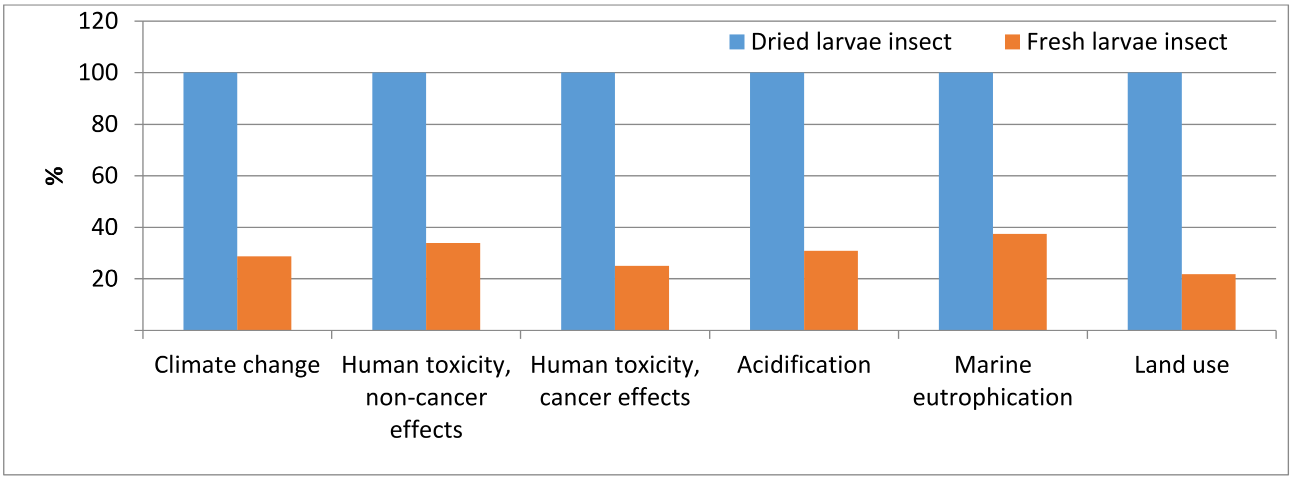


Figure 4. Environmental impact of production of fresh and dried Hermetia Illucens larvae on different categories obtained with ILCD method.

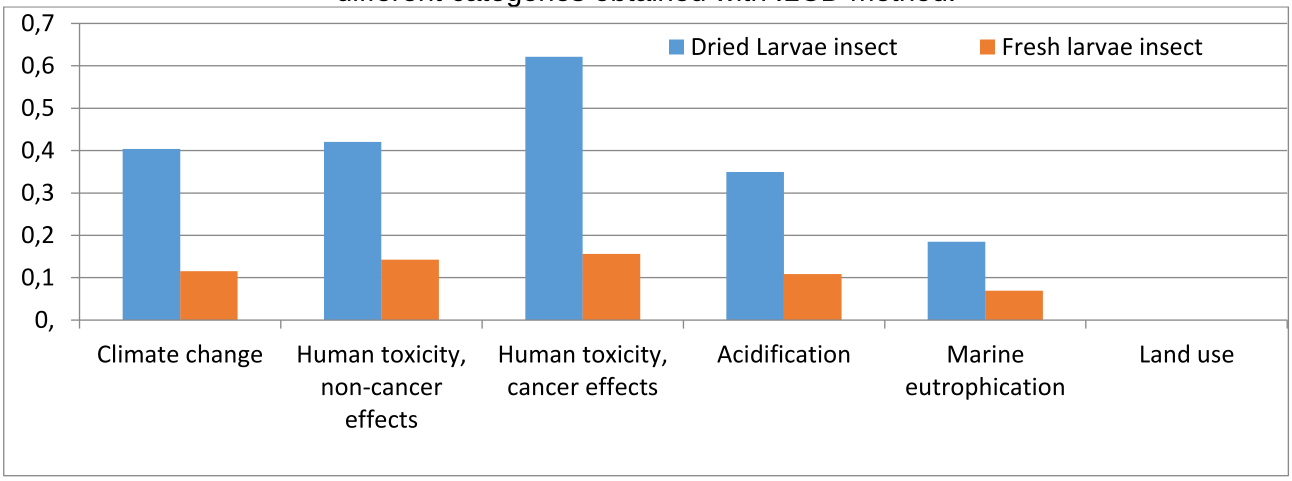


Figure 5. Environmental impact of production of fresh and dried Hermetia Illucens larvae on different categories obtained with ILCD method when data are normalized.

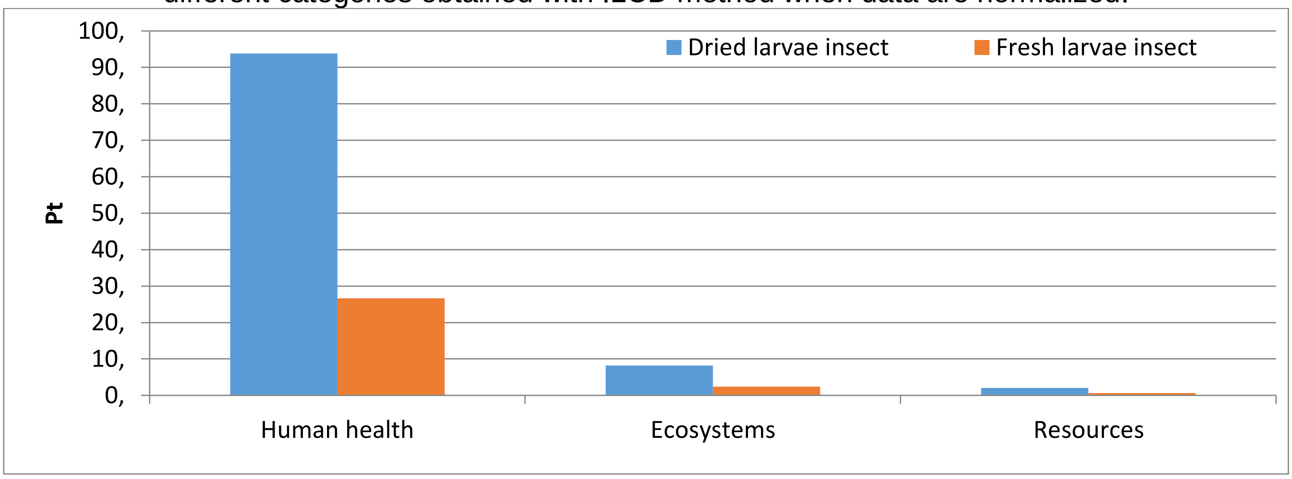


Figure 6. Environmental impact of production of fresh and dried Hermetia Illucens larvae on human health, ecosystem, and resources obtained with ReCipe method.

According to these results, insects may become not only a possible solution to the high dependence on imported protein sources, such as soybean meal, for animal feed, but also for the treatment of food waste and the recirculation of nutrients in food systems, as suggested by other authors (Gold et al., 2020; Smetana, 2020).

If insects are produced close to feed mills, as this project proposes, their environmental impact will be even lower, in addition, when its production is on a larger scale, they will become even more competitive as protein sources than they are today. If we want the generalized utilization of insects in animal diets, Insect mass production will be necessary but must be environmentally optimized and economically efficient.

5 Environmental impact of diets

One of the objectives of this project is to reduce carbon footprint by 10-15%/kg poultry feeding and decrease imported ingredients by 10-15%, so it was estimated environmental impact of each preliminary diet provided by pilots.

The impacts of diets were calculated by aggregating the life cycle impacts of the various ingredients of the rations of each pilot. The contributions of the different diets from each pilot in relation to climate change (kg CO_2 eq/t) and total punctuation on environmental impact obtained with ILCD and ReCipe methods, respectively were examinate. In addition, other categories were studied with both methods, and they are shown in Annex I and II.

5.1 Spain

Spanish pilot (UMU University and ALIA) will work with laying hens, crossing with breeds adapted to western-Mediterranean, for first phase of lay production, up to 40 weeks approximately.
The pilot developed a single-phase feeding program with a Control diet and two alternative diets according to the project proposal:

- **Control diet**. This diet included usual ingredients for laying hens in this area of Spain. In this pilot, Control diet incorporate imported maize and soybean meal by high proportion (55% and 22%, respectively). In addition, incorporated soybean oil, an ingredient with high environmental impact.
- **Alternative diet** 1 (**3-HERM**). In this diet maize was reduced and wheat grain with less impact was incorporated. The soybean meal decreased and other ingredient with very high impact, as soybean oil was reduced too. In addition, peas and DDGs were incorporated as alternative ingredients. In this diet 3% of HI larvae was incorporated.
- **Alternative diet** 2 (**6-HERM**). This diet followed similar criteria to the previous alternative diet, imported maize, soybean meal, and soybean oil were reduced. In addition, peas, and rapeseed meal as two alternative ingredients were used) and in this case the insect larvae were incorporated at 6%.

For more precision of the diets see deliverable 2.5.

The main environmental impacts of diets of Spanish pilot considering >99% of their compositions are shown in Table 7.

Table 7. Environmental impact of preliminary diets from Spanish pilot

Treatment[1]	Impact (kg CO_2 eq/t)[2]	Total Impact (pt)[3]
Control	2600	124
3-HERM	2160	92.6
6-HERME	1850	83.1

[1]Treatment: Control: feed with inclusion of usual ingredients; 3-HERM: diet with alternative ingredients and 3% dried larvae; 6-HERM: diet with alternative ingredients and 6% dried larvae.

[2]: Impact on climate change estimated with ILCD 2011 Midpoint+ V1.10 / EC-JRC Global method.
[3]: Estimated impact obtained with ReCiPe 2016 Endpoint (H) method.

In the study conducted with ILCD method, a total impact of 2600, 2160, and 1850 kg CO_2-eq/t for Control, 3%-HERME and 6%-HERME diet, respectively, was obtained. This meant a reduction of 16.9 in the case of 3%-HERME alternative diet, and 28.8% for the 6%-HERME alternative diet, respect to Control diet. In relation to other categories studied with this method, the Figure 7 shows impacts on climate change, human toxicity (cancer and non-cancer effects), acidification, marine eutrophication, and land use. The 3-HERM diet reduced the impacts on these categories by 16%, 51%, 35%, 37%, 28% and 3.2%, respectively. The 6-HERME diet reduced them by 29%, 41%, 36%, 43%, 31% and 4.4%, respectively.

One of the objectives of the project is to reduce the carbon footprint by at least 10% with more sustainable diets. In this pilot this objective has in principle been met with these preliminary diets. It should be kept in mind that when the pilot starts, some of the ingredients used in these diets may not be available, especially in the current uncertain situation, where imported materials from Ukraine and Russia will probably not be available. In any case, the reduction has been much larger than the proposed minimum, so it is to be expected that the final diets used in the project will also comply with this reduction.

The study conducted with ReCipe method, in addition to the total point, studied the impacts on human health, ecosystems and resources. The impacts for these categories are shown in Figure 8.

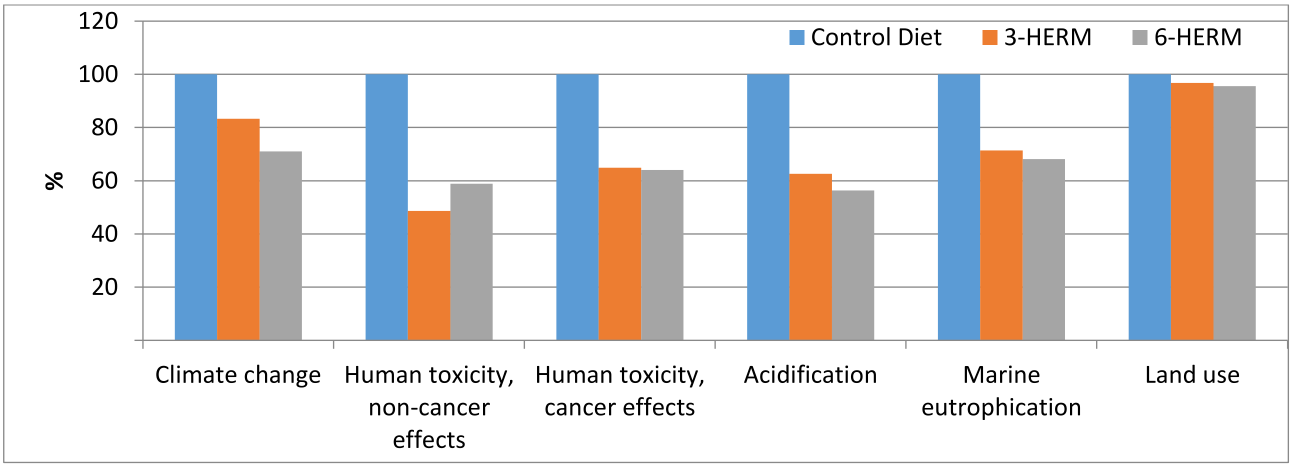


Figure 7. Environmental impact obtained with ILCD Method of the three preliminary diets from Spanish pilot.

Control diet had an impact on human health of 104 pt, 3-HERM of 74.4 pt and 6-HERM of 65.4 pt, which represented a reduction of 28.5% and 37.1% FOR 3-HERM and 6-HERM, respectively, in relation to Control diet. With respect to the impact on the ecosystem, the scores were 18.8, 17.1 and 16.7 pt for Control, 3-HERM, and 6-HERM diets, respectively. The reductions on this category were by 9% and 11.2% for two alternative diets respectively, respect to Control diet. Finally, the impacts on resources were 1.37, 1.16 and 0.987 pt for Control, 3-HERM, and 6-HERM, respectively, which mean a reduction by 15 and 28% for two alternative diets respectively, respect to Control diet.

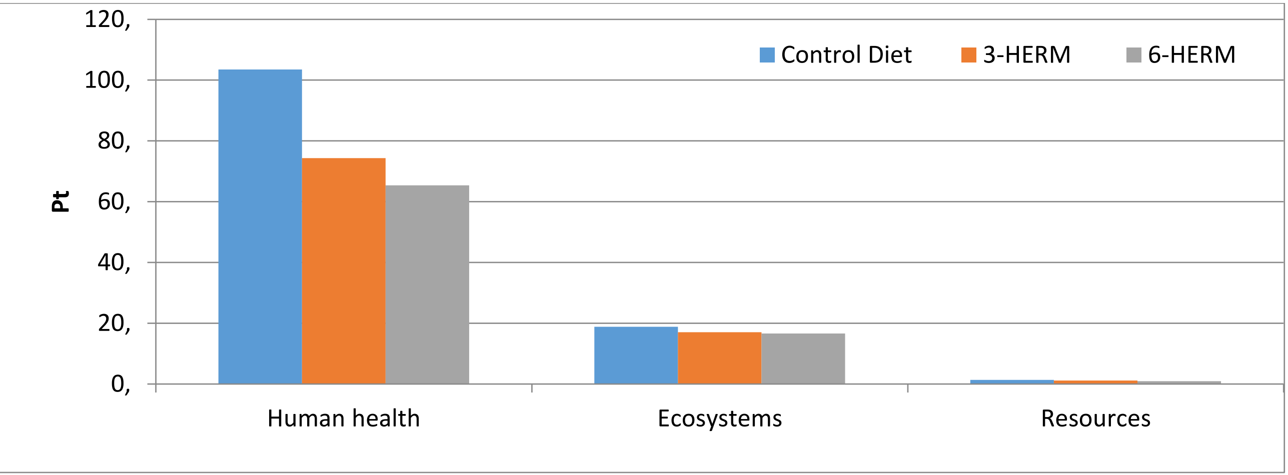


Figure 8. Environmental impact obtained with ReCipe Method of the three preliminary diets from Spanish pilot.

In conclusion, in the proposed scenario where alternative diets incorporated by-products, with the reduction of the most impactful ingredients, and the addition of *Hermetia Illucens* larvae is possible to reduce the carbon footprint by more than 15% in laying hens feeding program as proposed. Considering that in this scenario the lowest impact origin of each ingredient was considered for the alternative diets, in the case of not having enough of all the ingredients, ingredients could be incorporated from other origins achieving significant reductions in environmental impact with respect to the Control diet.

5.2. Italy

Italian pilot (University of UNITO) will be carried out in meat-type chicken, using *Bianca di Saluzzo* male. This is an autochthonous local breed with low growing. The feeding program involved two phases: starter: from 0 to 60 days, and grower/finisher: from 61 to 150 days.
In each phase, 3 diets (1 control and 2 alternative diets) were studied.

- **Control diet** is a wheat and soybean meal-based diet (usual ingredients in feeding poultry in Italy). Both ingredients have a high environmental impact. Furthermore, this diet incorporated soybean oil which has a high impact too.
- **Alternative diet 1 (ALTER)** include alternative ingredients such as fava beans, peas, sunflower meal, and maize gluten meal. These ingredients, when of Italian origin, have a lower impact than the ingredients in the control diet. In addition, in this diet the inclusion of maize, soybean meal and soybean oil were reduced. This diet did not incorporate insect larvae.
- **Alternative diet 2 (4.5-HERM)** include ALTER diets plus *Hermetia illucens* dried larvae, so a reduction in intake of the alternative diet is expected between 3 and 6%. This diet is called 4.5-HERM considering the average insect ingestion. Therefore, in this diet incorporation of maize, soybean meal and soybean oil were reduced, and other alternative ingredients were incorporated (fava beans, peas, sunflower meal, and maize gluten meal).

For more precision of the diets see deliverable 2.5.

The main environmental impacts of preliminary diets of Italian pilot considering >97% of their compositions, are shown in **Table** 8. In Starter phase, Control diet had an impact on climate change of 1940 kg CO2 eq/t, while ALTER and 4.5-HERM diets had 972 and 1063 kg CO2 eq/t, respectively. This represented a reduction by 49.9 and 45.3% in the carbon footprint compared to the Control diet. Respect to total impact (obtained with ReCipe method) the scores were 95.3, 57.6, and 59.8 pt. respectively, which represented a reduction of 39.5 and 37.2% for ALTER and 4.5-HERM respectively, respect to control.

In Finisher phase, the reductions of the alternative diets were one percentage unit less than those of grower in both climate change and total score. Therefore, the reductions obtained by the alternative diets are higher than the 10-15% target set by the project.

Table 8. Environmental impact of preliminary diets from Italian pilot.

Phase	Treatment[1]	Impact (kg CO_2 eq/t)[2]	Total Impact (pt)[3]
Grower (0-60d)	Control	1940	95.3
	ALTER	972	57.6
	4.5-HERM	1063	59.8
Finisher (61-150d)	Control	1910	94.9
	ALTER	980	58.4
	4.5-HERM	1070	60.5

[1] Treatment: Control: feed with inclusion of usual ingredients; ALTER: diet with alternative ingredients; 4.5-HERM: diet with alternative ingredients plus extra-supplemented *Hermetia illucens* dried larvae a reduction in intake of the alternative diet is expected between 3 and 6%.
[2]: Impact on climate change estimated with ILCD 2011 Midpoint+ V1.10 / EC-JRC Global method.
[3]: Estimated impact obtained with ReCiPe 2016 Endpoint (H) method.

Impacts obtained with ILCD method on other categories are shown in Figure 9. In grower phase, the two alternative diets achieved reductions of over 38% respect to Control diet in Acidification. Human toxicity (cancer and non-cancer effects) were the least affected categories (from 4 to 8% of reduction with alternative diets), although it is noteworthy that on cancer effects, the ALTER diet achieved more impact than the control diet: 6.3%. On marine eutrophication alternative diets reduced by 20% and 22% the impact respect to Control diet. Land use was reduced by 12.7% and 16.7% with ALTER and 4.5 HERM, respectively.

In finisher phase, the reductions achieved with the proposed alternative diets were like the grower phase with a difference of 1 to 2 percentage units.

Other environmental impacts obtained with ReCipe method are shown in Figure 10. On human health, alternative diets obtained a reduction of 44 to 40% in both phases for ALTER and 4.5 HERM respectively, with respect to the control diet. On ecosystems the reductions were about 16-19% in both phases for the two alternative diets, and on resources the reductions were about 45-50% for alternative diets respect Control diet.

Therefore, in the proposed scenario (one diet with alternative ingredients and reduction of imported ingredients) and other with these ingredients and *Hermetia Illucens* larvae is possible to reduce the carbon footprint by more than 15% in poultry feeding program in Italy. Considering that in this scenario the lowest impact origin of each ingredient has considered for the alternative diets, in the case of not having enough of all the ingredients, they could probably be incorporated from other origins achieving significant reductions in environmental impact with respect to the Control diet.

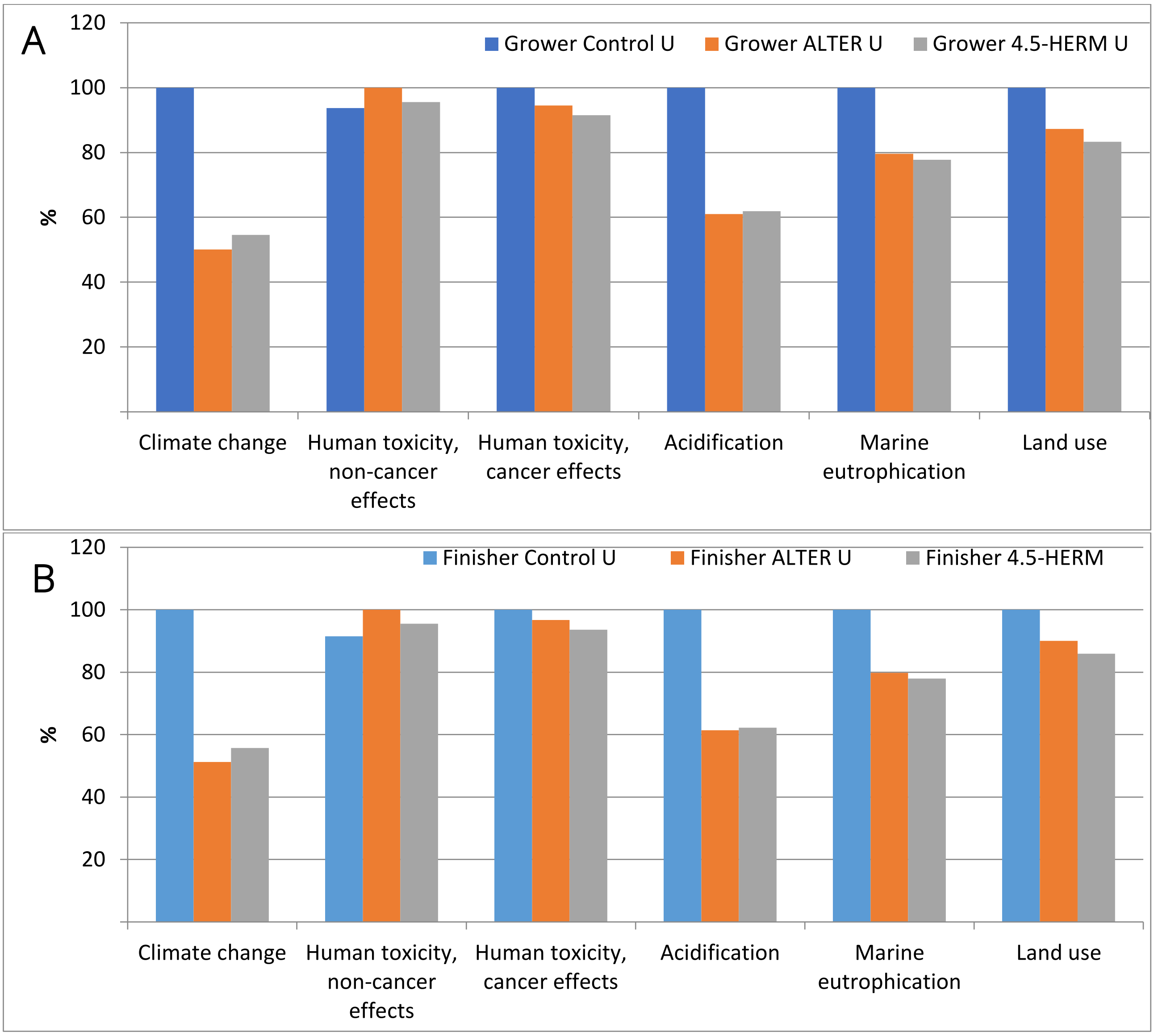


Figure 9. Environmental impact obtained on other categories with ILCD method of the three preliminary grower (A) and finisher diets (B) from Italian pilot.

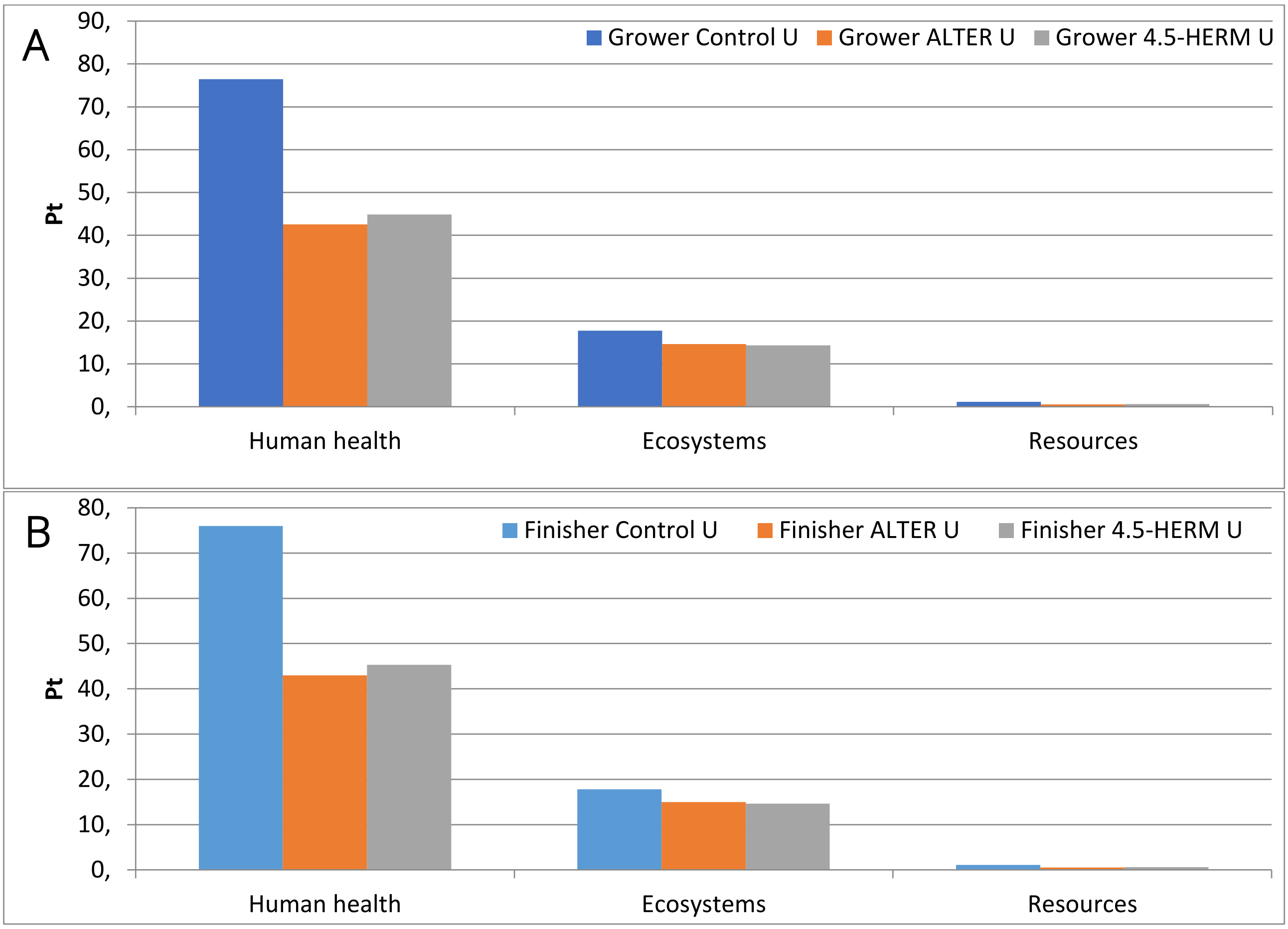


Figure 10. Environmental impact obtained on other categories with ReCipe method of the three preliminary grower (A) and finisher diets (B) from Italian pilot.

5.3 Turkey

The pilot of Turkey (University of EGE) will be carried out in poultry meat production, using an ecotype of adapted broiler and a commercial broiler strain. The feeding program involved three phases: starter (from 0 to 14 days), grower (from 15-28 days) and finisher (from 29 days to slaughter age). In each phase, three diets (1 control and 2 alternative diets) were studied.

- **Control diet** is a maize, wheat, and soybean meal-based diet. They are usual ingredients in Turkey with high impact.
- **Alternative diet 1 (ALTER)** where maize and soybean meal were reduced, and it included alternative ingredients such as Brewers´ dried grain, wheat middling, and sunflower meal. In addition, soybean meal was reduced.
- **Alternative diet 2 (5-HERM),** maize and soybean meal were reduced and alternative ingredients such us Brewers´ dried grain, wheat middling, and sunflower meal were included. In this diet dried *Hermetia illucens* larvae were incorporated at 5%.

For more precision of the diets see deliverable 2.5.

The main environmental impacts of preliminary diets of Turkish pilot considering >97% of their compositions are shown in Table 9. The most affected environmental category was climate change. Control diet had an impact on carbon footprint of 3460, 3360 and 3080 kg CO_2 eq/t for starter, grower, and finisher phase respectively. ALTER diet achieved a reduction of 45.9% for starter phase, 41% in grower phase and 39% in finisher phase. 5-HERM reduced 43.6%, 39.5%, and 36% kg CO_2 eq/t for each phase respectively.

Regarding the total impact obtained with ReCipe method, Control diet had 138,135 and 126 pt for starter, grower, and finisher phase, respectively. ALTER diet had 36%, 32% and 31% less for starter, grower, and finisher phase, respectively, and 5-HERM diet reduced the impact by 34.9%, 31.4%, and 28.7% kg CO_2 eq/t respectively respect Control diet.

Therefore, in the proposed scenario, where the ingredients of the alternative diets would be sourced with less impact, the carbon footprint in poultry Italian feeding program could be reduced by more than 15% at each phase as the project proposed.

Impacts obtained with ILCD method on other categories are shown in Figure 11. After climate change category where the alternative diets showed the greatest reductions in the three phases studied, the impacts on acidification were the next most affected, the two alternative diets managed to reduce from 29 to 35% of the impact, the reductions being greater in starter than in grower, and the latter greater than in finisher. Human toxicity (cancer effects) was reduced about 14-19% for ALTER diet and about 18-21% for 5-HERM diet respectively respect Control diet. It is noteworthy that ALTER diet increased the impact on human toxicity non-cancer effects in starter and grower phases (1.8-4% respectively) and in finisher decreased by 3.5% the impact respect to Control diet. On marine eutrophication alternative diets reduced from 22 to 28% the impact respect to Control diet, and Land use impact was reduced by 19-27% with alternative diets.

Other environmental impacts obtained with ReCipe method are shown in Figure 10. On human health, alternative diets obtained a reduction of 39.2%, 34% and 33% with ALTER diet, and of 37%, 33% and 30% with 5-HERM in starter, grower, and finisher phase, respectively. The reductions on ecosystems were about 20% with ALTER diet and about 20-23% with 5-HERM.The reductions on resources were slightly higher with both diets.

In conclusion, in the proposed scenario (one diet with alternative ingredients and reduction of imported ingredients and other with these ingredients and *Hermetia Il*lucens larvae) is possible to reduce the carbon footprint by much more than 15% in poultry feeding program in Turkey. Considering that in this scenario the lowest impact origin of each ingredient has been considered for the alternative diets, if not enough of all the ingredients are available, they could probably be incorporated from other origins, achieving significant reductions in the environmental impact with respect to the Control diet.

Table 9. Environmental impact of preliminary diets from Turkish pilot.

Phase	Treatment[1]	Impact (kg CO_2 eq/t)[2]	Total Impact (pt)[3]
Starter (0-14d)	Control	3460	138
	ALTER	1870	87.6
	5-HERM	1950	89.8
Grower (15-28d)	Control	3360	135
	ALTER	1980	91.8
	5-HERM	2030	92.5
Finisher (29d-slaughter)	Control	3080	126
	ALTER	1870	86.8
	5-HERM	1970	89.8

[1]Control: feed with inclusion of usual ingredients; ALTER: diet with alternative ingredients; 5-HERM: diet with alternative ingredients and 5% dried larvae.
[2]: Impact on climate change estimated with ILCD 2011 Midpoint+ V1.10 / EC-JRC Global method.
[3]: Estimated impact obtained with ReCiPe 2016 Endpoint (H) method.

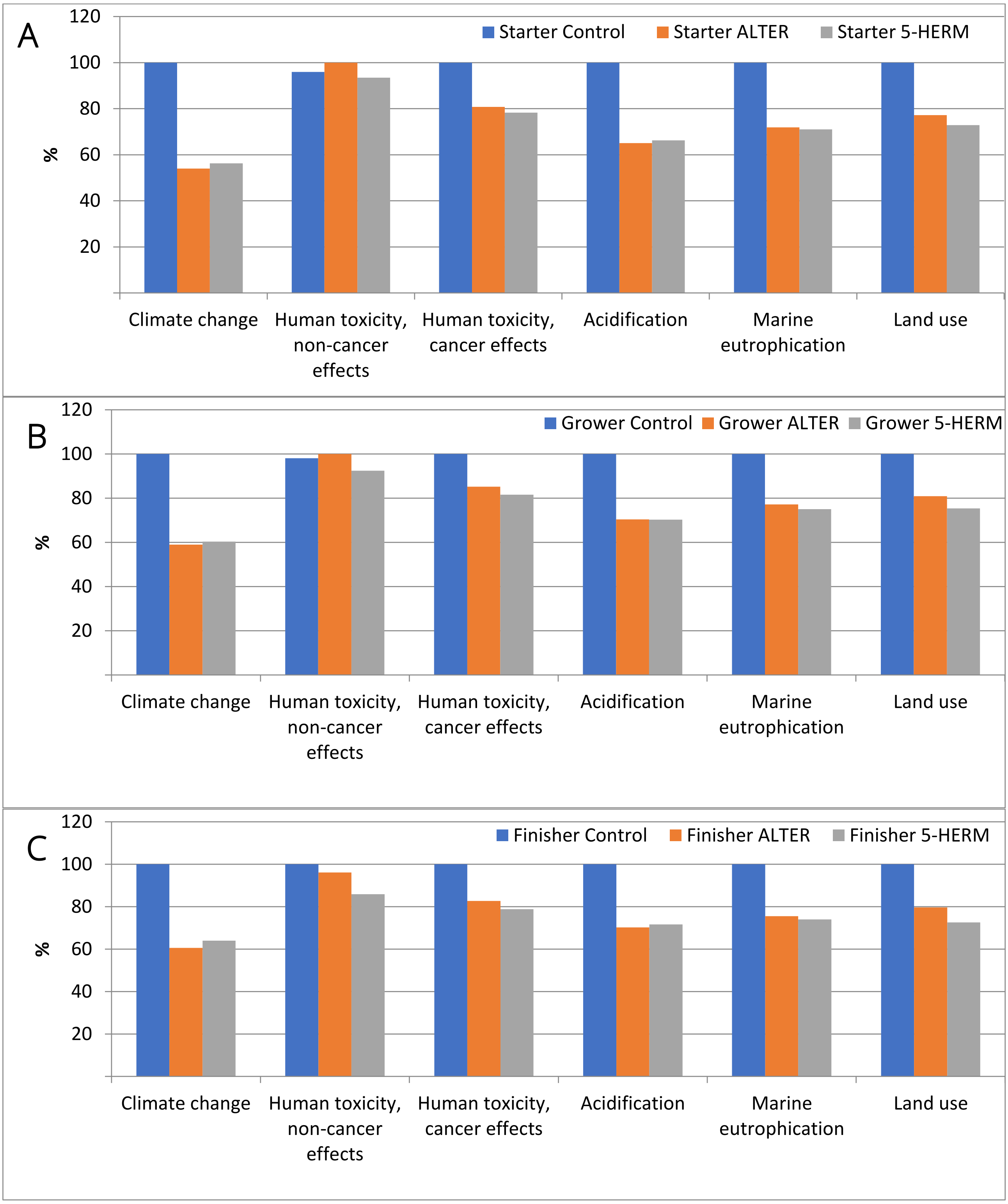


Figure 11. Environmental impact obtained on other categories with ILCD method of the three preliminary starter (A), grower (B), and finisher diets (B) from Turkish pilot.

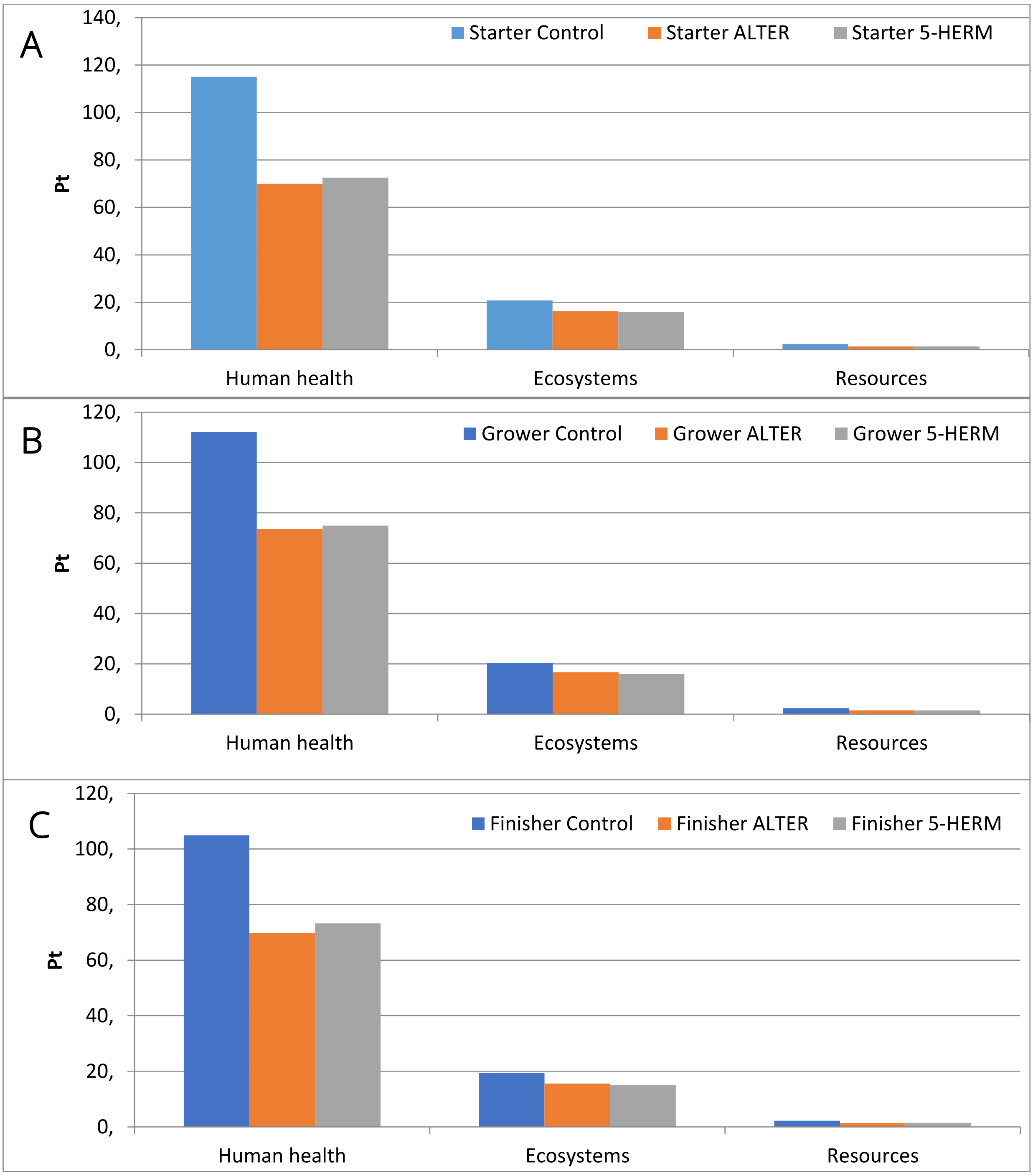


Figure 12. Environmental impact obtained on other categories with ReCipe method of the three preliminary starter (A), grower (B), and finisher diets (B) from Turkish pilot.

5.4 Tunisia

The pilot of Tunisia involves the ISA CM University's pilot and the RAYHANA Association's pilot. They will be carried out in poultry meat (slow-growing chicken) and laying eggs production, using ecotypes of adapted birds.

For the meat production, feeding program involved three phases: starter (from 1 to 28 days), grower (from 29-66 days) and finisher (from 67 days to slaughter age). In each phase three diets (1 control and 2 alternative diets) were studied:

- **Control diet** with usual ingredients. In this case, imported maize and soybean meal were used.
- **Alternative diet 1 (ALTER)** where maize, and soybean meal were reduced, alternative ingredients such as national triticale and pasta waste were included. This diet did not incorporate insects.
- **Alternative diet 2 (5-HERM),** maize and soybean meal were reduced and alternative ingredients such us such as national triticale and pasta waste were included. In this diet dried *Hermetia illucens* larvae were incorporated at 5%.

First, we will comment on the results obtained for the **poultry feeding program**. The main environmental impacts obtained with preliminary diets of Tunisian pilot considering >98% of their compositions are shown in Table 10. In the study conducted with ILCD method, in starter phase a total impact of 2600, 1930, and 1550 kg CO_2-eq/t for Control, ALTER and 5-HERME, respectively, was obtained. This meant a reduction of 25.7% in the case of ALTER diet, and 40.3% for the alternative diet 5-HERME, respect to Control diet. In grower phase, the impacts were of 2450, 1450, and 1390 kg CO_2-eq/t for Control, ALTER and 5-HERME, respectively. In this phase, the reductions with alternative diets were of 40.8% and 43.2%, for ALTER and 5-HERM, respectively. In finisher phase, Control diet had an impact of 2390 kg CO_2-eq/t, while alternative diets reached a reduction by 39.7% ALTER diet, and 41.8% 5-HERM diet.

On total impact (ReCipe method), alternative diets Control diet had 140, 138 and 137 pt for starter, grower, and finisher phase, respectively. ALTER diet reduced by 41%, 42.2% and 41.7% these impacts respectively for each phase, and 5-HERM reduced them by 37.7%, 44%, and 44% for starter, grower, and finisher phase, respectively.

Therefore, in the proposed scenario, where the ingredients of the alternative diets would be sourced with less impact, the carbon footprint in poultry Tunisian feeding program could be reduced by much more than 15% at each phase as the project proposed.

In relation to other categories studied with ILCD method, the Figure 13 shows impacts on climate change, human toxicity (cancer and non-cancer effects), acidification, marine eutrophication, and land use. Human toxicity and acidification were the categories more reduced by alternative diets as they achieved reductions of over 50%. Land use was the least affected category where ALTER diet reduced impact was below 10% and 5-HERM around 10%.

In other categories studied with ReCipe method (Figure 14), human health was the most prominent category, followed by ecosystem and finally resources. ALTER diet reduced the impact on human health between 34% and 46% depending on the phase, and 5-HERM reduced slightly more, between 42 and 48% depending on the phase. Ecosystems were reduced about 10-17% with ALTER diet, and about 15-23% with 5-HERM. Reductions for resources were in the middle range among the above (about 29-42% with ALTER diet and about 32-38% with 5-HERM).

In short, poultry feeding program provided by Tunisian pilot where the usual high impact ingredients are reduced, and the ingredients of national origin and insect larvae are used allow a very important reduction of the impact.

Table 10. Environmental impact of preliminary diets of meat chickens from Tunisian pilot.

Phase	Treatment[1]	Impact (kg CO_2 eq/t)[2]	Total Impact (pt)[3]
Starter (0-14d)	Control	2600	140
	ALTER	1900	96.4
	5-HERM	1550	87.1
Grower (15-28d)	Control	2450	138
	ALTER	1450	79.8
	5-HERM	1390	77.2
Finisher (29d-slaughter)	Control	2390	137
	ALTER	1440	79.9
	5-HERM	1390	76.7

[1]: Control: feed with inclusion of usual ingredients; ALTER: diet with alternative ingredients; 5-HERM: diet with alternative ingredients and 5% dried larvae.
[2]: Impact on climate change estimated with ILCD 2011 Midpoint+ V1.10 / EC-JRC Global method.
[3]: Estimated impact obtained with ReCiPe 2016 Endpoint (H) method.

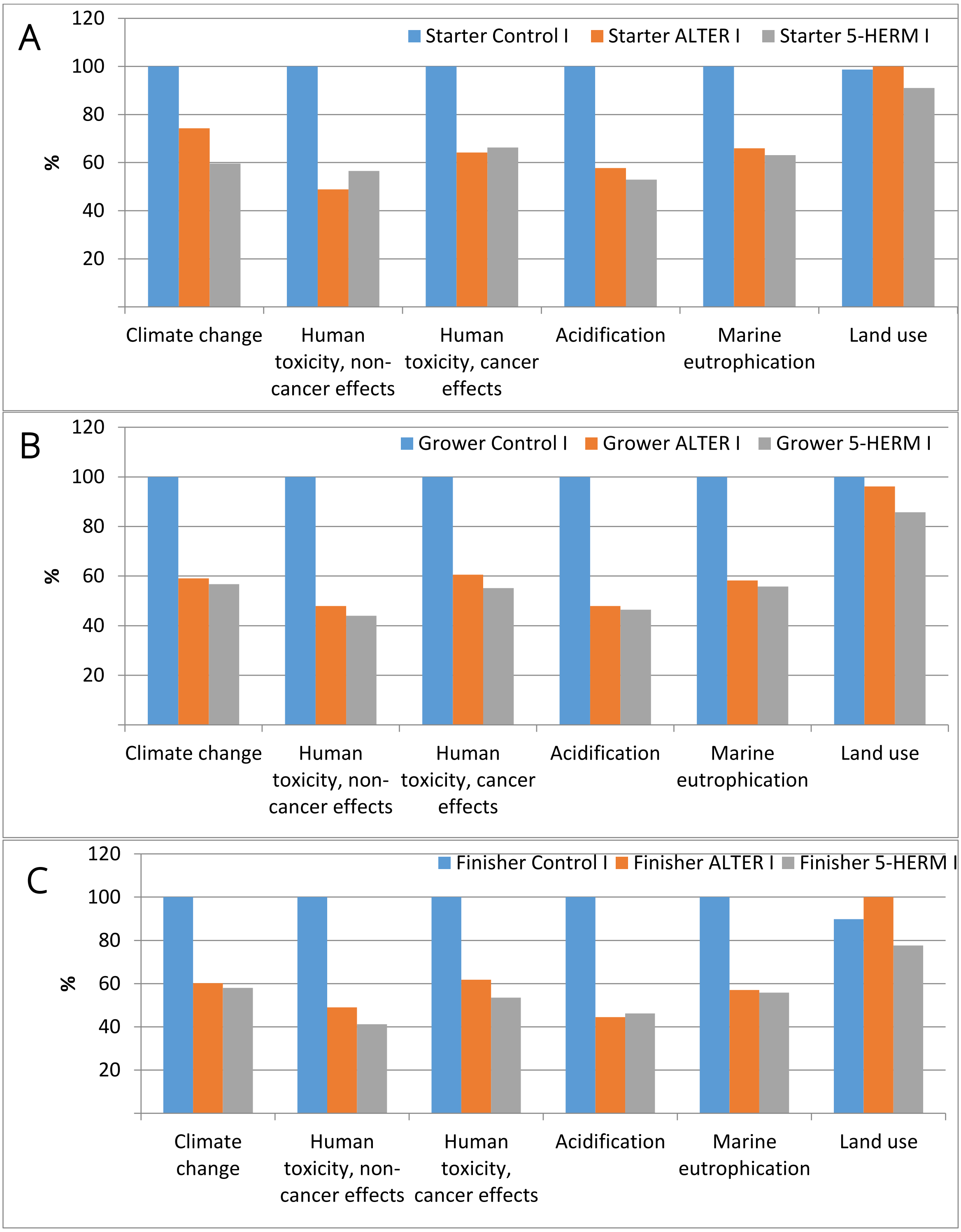


Figure 13. Environmental impact obtained on other categories with ILCD method of the three preliminary starter (A), grower (B), and finisher diets (B) for poultry from Tunisian pilot**.**

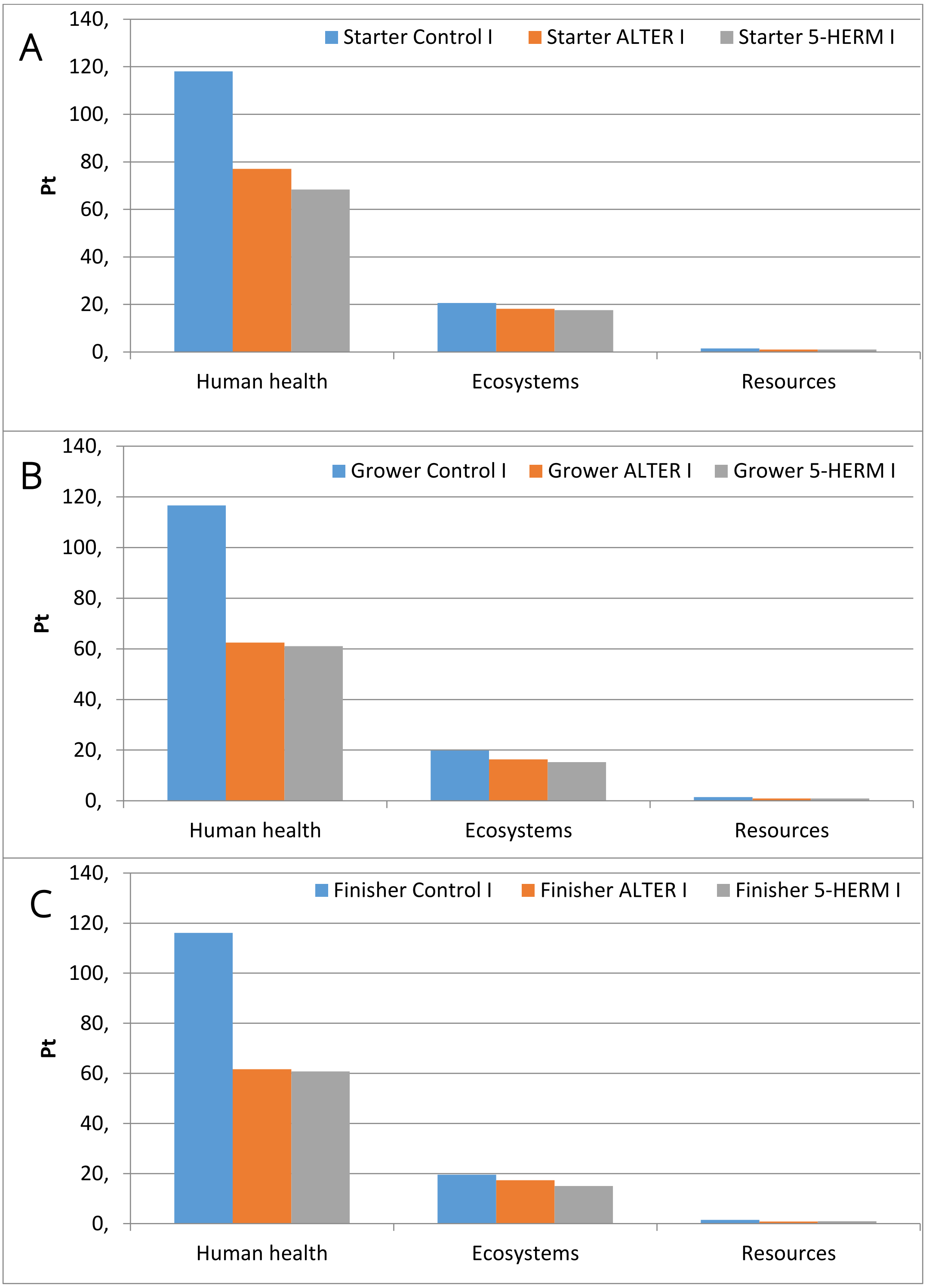


Figure 14. Environmental impact obtained on other categories with ReCipe method of the three preliminary starter (A), grower (B), and finisher diets (B) for poultry from Tunisian pilot.

Ion the other hand, in Tunisian pilot the production of **laying hen eggs** was evaluated in a single-phase program (from 17 to 40 week). In this phase, three diets were studied.

- **Control diet** is a maize, wheat, and soybean meal-based diet. These ingredients have a high environmental impact because they are mostly imported.
- **Alternative diet 1 (ALTER)** where the inclusion of maize and soybean meal were reduced. In addition, alternative ingredients such as national triticale and pasta waste were included. This diet did not incorporate insects.
- **Alternative diet 2 (5-HERM)** where maize and soybean meal were reduced and alternative ingredients such as national triticale and pasta waste were included. In this diet dried *Hermetia illucens* larvae were incorporated at 5%.

For more precision of the diets see deliverable 2.5.

The main environmental impacts obtained with preliminary diets of Tunisian pilot considering >99% of their compositions are shown in Table 11. In the study conducted with ILCD method, Control diet obtained an impact on carbon footprint of 2.2 kg CO_2-eq/t, while alternative diets reached a reduction by 37.2% ALTER diet, and 39.5% 5-HERM diet. In total impact (ReCipe method), Control diet had 124 pt versus 92.6 pt and 83.1 pt obtained with ALTER and 5-HERM, respectively. This meant a reduction as the previous ones, of 37.2 and 39.5 % in total score with alternative diets (ALTER and 5-HERM, respectively).

The reductions obtained with the alternative diets of laying hens Tunisian feeding program on carbon footprint are therefore greater than those proposed in the project.

Table 11. Environmental impact of preliminary diets of laying hens from Tunisian pilot.

Treatment[1]	Impact (kg CO_2 eq/t)[2]	Total Impact (pt)[3]
Control	2600	124
ALTER	2160	92.6
5-HERME	1850	83.1

[1]: Treatment: Control: feed with inclusion of usual ingredients; ALTER: diet with alternative ingredients; 5-HER: diet with alternative ingredients and 5% dried larvae.
[2]: Impact on climate change estimated with ILCD 2011 Midpoint+ V1.10 / EC-JRC Global method.
[3]: Estimated impact obtained with ReCiPe 2016 Endpoint (H) method.

The Figure 15 shows the impacts on climate change, human toxicity (cancer and non-cancer effects), acidification, marine eutrophication, and land use from Control and alternative diets.

Human toxicity was the category where alternative diets reduced more the impact respect Control diet. ALTER diet reduce by 55% and 5-HERM by 62%. Acidification was reduced by 44% and 50% with ALTER and 5-HERM respectively in relation to Control diet. On marine eutrophication alternative diets reduced by 36.7% and 43.7% the impact respect to Control diet. Land use was reduced by 15.5% and 27.8% with ALTER and 5-HERM, respectively.

The study conducted with ReCipe method, in addition to the total point, studied the impacts on human health, ecosystems and resources. The impacts for these categories are shown in Figure 16. Human health was reduced by 40% and 44.6% with ALTER and 5-HERM respectively. Ecosystems by 20% and 29% with ALTER and 5-HERM respectively. Reductions for resources were in the middle range among the above (about 28% with ALTER diet and about 29% with 5-HERM diet.

Therefore, the feeding of laying hens in Turkey can be more sustainable with the formulation of alternative diets such as those proposed in this project.

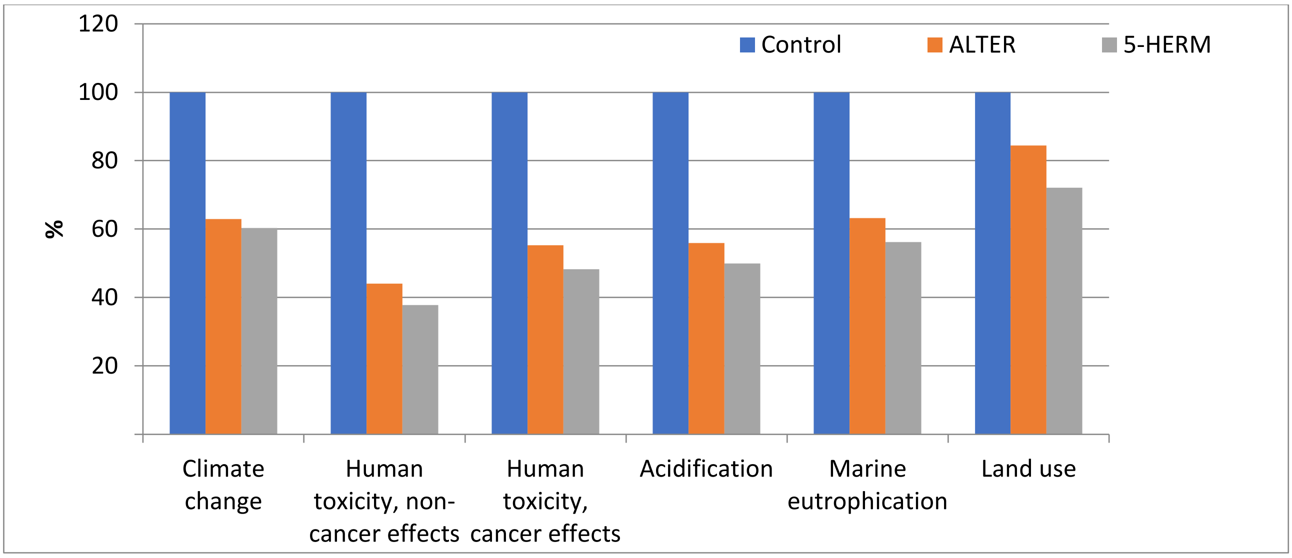


Figure 15. Environmental impact obtained on other categories with ILCD method of the three preliminary diets for laying hens from Tunisian pilot.

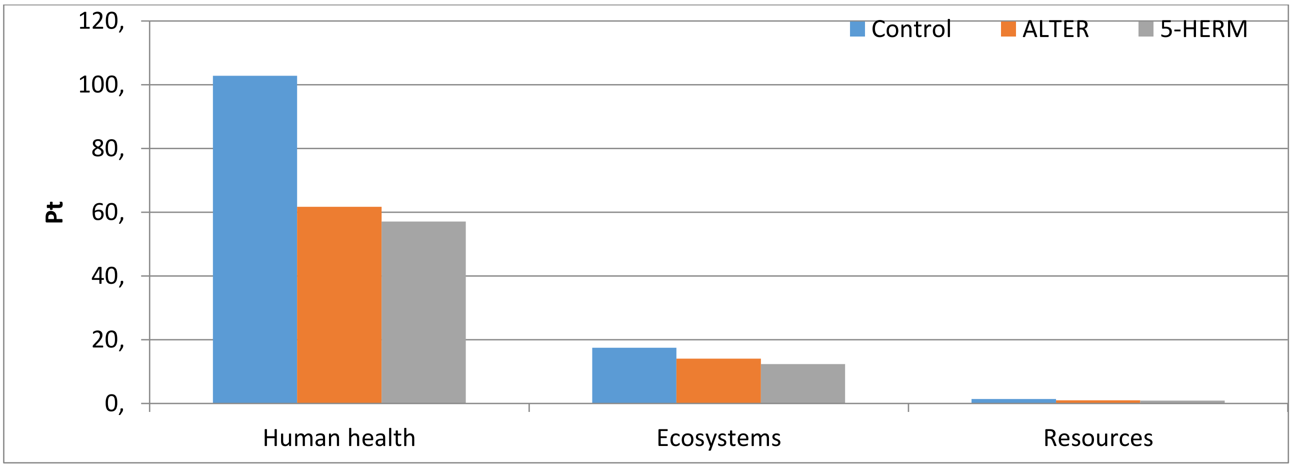


Figure 16. Environmental impact obtained on other categories with ReCipe method of the three preliminary diets for laying hens from Tunisian pilot.

6 Conclusions

After conducting the impact study of preliminary broiler and layer programs, the following conclusions can be drawn from this deliverable:

- Environmental impacts of ingredients vary quite widely. Soybean meal and imported cereals were the ingredients with the highest impact on carbon footprint among all the usual ingredients of the different pilots, except in Italy, where they were the sources of fat. On the opposite side it is interesting to note how little impact the alternative ingredients have in general compared to the usual ones.
- The same ingredient with different origins is more impactful the greater the distance of origin, so, local crops should be favoured in each country to reduce the importation of feed ingredients.
- When possible, it is preferable to dry the ingredients at origin, thus reducing water transport and consequently environmental pollution.
- *Hermetia Illucens* larvae had a moderate impact, but when larvae were dried, the impact was greater. Despite this, its impact on carbon footprint is lower than that of imported soybean meal for all pilots. This makes it a potential ingredient as protein source for more sustainable poultry diets with less environmental impact. So, importing protein sources from remote areas can be reduced when insect larvae is used in poultry feeding.
- Insects may become not only a possible solution to the high dependence on imported protein sources for animal feed, but also for the treatment of agri-food waste, thus participating in the principles of the circular economy.
- If we want the generalized utilization of insects in animal diets, mass production is necessary. In addition, environmental optimization and economic efficiency should be applied.
- Reduction of soybean meal and imported cereals in poultry diets is possible in the proposed scenario of alternative diets where less impactful ingredients and agricultural by-products allow reducing the carbon footprint associated with those ingredients.
- The reductions in carbon footprint obtained by the preliminary alternative diets provided by all pilots are higher than the 10-15% target set by the project.
- In general, in all pilots, the alternative diet where the insect was incorporated as a protein source in place of soybean meal had a greater environmental impact reduction than when only alternative ingredients or by-products were incorporated.
- Poultry feed can be more sustainable if we use diets with less soybean meal and imported grains, while increasing the use of alternative ingredients, by-products and insects. Although it is necessary to study the effect of these diets on the performance of the animals.

7 References

Agri-footprint 2.0 – Part 2: Description of data (2015). In: www.agri-footprint.com. Accessed 01/03/2022.

Abín, R., Laca, A., Laca, A., & Díaz, M. (2018). Environmental assesment of intensive egg production: A Spanish case study. Journal of cleaner production, 179, 160-168.

Bava, L., Jucker, C., Gislon, G., Lupi, D., Savoldelli, S., Zucali, M., & Colombini, S. (2019). Rearing of Hermetia illucens on different organic by-products: Influence on growth, waste reduction, and environmental impact. *Animals*, *9*(6), 289.

Bakshi, M. P. S., Wadhwa, M., & Makkar, H. P. (2016). Waste to worth: Vegetable wastes as animal feed. Cab Rev, 11(012), 1-26.

Borrelli, L., Coretti, L., Dipineto, L., Bovera, F., Menna, F., Chiariotti, L., ... & Fioretti, A. (2017). Insect-based diet, a promising nutritional source, modulates gut microbiota composition and SCFAs production in laying hens. Scientific reports, 7(1), 1-11.

Bosch, G., Van Zanten, H. H. E., Zamprogna, A., Veenenbos, M., Meijer, N. P., Van der Fels-Klerx, H. J., & Van Loon, J. J. A. (2019). Conversion of organic resources by black soldier fly larvae: legislation, efficiency and environmental impact. Journal of Cleaner Production, 222, 355-363.

Cappelaere, L., Le Cour Grandmaison, J., Martin, N., & Lambert, W. (2021). Amino acid supplementation to reduce environmental impacts of broiler and pig production: a review. Frontiers in veterinary science, 799.

Castanheira, É. G., Grisoli, R., Coelho, S., da Silva, G. A., & Freire, F. (2015). Life-cycle assessment of soybean-based biodiesel in Europe: comparing grain, oil and biodiesel import from Brazil. Journal of Cleaner Production, 102, 188-201.

CESFAC. Española de Fabricantes de Alimentos Compuestos Para Animales. Mercados y estadísticas 2018. https://ec.europa.eu/commission/presscorner/detail/en/IP_19_161.

Commission Regulation (EU) 2021/1372 of 17 August 2021 amending Annex IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council as regards the prohibition to feed non-ruminant farmed animals, other than fur animals, with protein derived from animals (Text with EEA relevance)

De Marco, M., Martínez, S., Hernandez, F., Madrid, J., Gai, F., Rotolo, L., ... & Schiavone, A. (2015). Nutritional value of two insect larval meals (Tenebrio molitor and Hermetia illucens) for broiler chickens: Apparent nutrient digestibility, apparent ileal amino acid digestibility and apparent metabolizable energy. Animal Feed Science and Technology, 209, 211-218.

Demirel, H., Sertel, E., Kaya, S., & Seker, D. Z. (2008). Exploring impacts of road transportation on environment: a spatial approach. Desalination, 226(1-3), 279-288.

Erickson, M. C., Islam, M., Sheppard, C., Liao, J., & Doyle, M. P. (2004). Reduction of Escherichia coli O157: H7 and Salmonella enterica serovar Enteritidis in chicken manure by larvae of the black soldier fly. Journal of food protection, 67(4), 685-690.

FAOSTAT. https://www.fao.org/faostat/es/#data/QCL. Accessed 06/03/2022.

Gerber, P. J., Uwizeye, A., Schulte, R. P., Opio, C. I., & De Boer, I. J. M. (2014). Nutrient use efficiency: a valuable approach to benchmark the sustainability of nutrient use in total livestock production?. Current opinion in environmental sustainability, 9, 122-130.

Gold, M., Cassar, C. M., Zurbrügg, C., Kreuzer, M., Boulos, S., Diener, S., & Mathys, A. (2020). Biowaste treatment with black soldier fly larvae: Increasing performance through the formulation of biowastes based on protein and carbohydrates. Waste Management, 102, 319-329.

Huijbregts MAJ, Steinmann ZJN, Elshout PMF, Stam G, Verones F,Vieira M, Zijp M, Hollander A, van Zelm R (2016) ReCiPe2016. A harmonized life cycle impact assessment method at midpoint and endpoint level. Report I: Characterization. RIVM Report 2016- 0104. National Institute for Human Health and the Environment, Bilthoven.

Loyola C, Papadimitriou C & Dettling J. (2021). LCA of waste-to-feed diets for laying hens. For: World Wildlife Fund (WWF). Quantis US MA. USA.

MAPA. Ministerio de Agricultura, Pesca y Alimentación. El sector de la avicultura de carne en cifras. https://www.mapa.gob.es/es/ganaderia/estadisticas/indicadoreseconomicossectoravicoladecarne2020. Consultado el 07/03/2022.

Mottet A, Tempio G. Global poultry production: current state and future outlook and challenges. Worlds Poult Sci J. (2017) 73:245–56. doi: 10.1017/S0043933917000071.

Ogino, A., Oishi, K., Setoguchi, A., & Osada, T. (2021). Life Cycle Assessment of Sustainable Broiler Production Systems: Effects of Low-Protein Diet and Litter Incineration. Agriculture, 11(10), 921.

Oonincx DGAB, van Broekhoven S, van Huis A, van Loon JJA. Feed conversion, survival and development, and composition of four insect species on diets composed of food by-products. PLoS One. 2015;10(12):e0144601.

Smetana, S. (2020). Life cycle assessment of specific organic waste–based bioeconomy approaches. Current Opinion in Green and Sustainable Chemistry, 23, 50-54.

Smetana, S., Spykman, R., & Heinz, V. (2021). Environmental aspects of insect mass production. Journal of Insects as Food and Feed, 7(5), 553-571.

Sogari G, Amato M, Biasato I, Chiesa S, Gasco L. 2019. The potential role of insects as feed: A multi-perspective review. Animals 9:119

8 Annex I. Environmental Impact with Europe ILCD 2011 Midpoint method on different categories of the ingredients of the five pilot.

The data used for the environmental impact study in each pilot are presented in Tables 12-16. The background data of each ingredient were obtained from Agri-Footprint database, except those marked on the tables. In addition, the distance and type of transport used for the environmental impact were calculated based on the information given from the pilots.

Table 12. (Annex I). Foreground data for environmental impact study in Spanish pilot.

Ingredients*	Origin	Transport (km)		
		Lorry**	Ship	Train
Maize	France	576	828.89	-
	Brazil	1694.6	8526	-
	Eastern Europe	550.6	3532	-
	USA	375.6	6680	1706
Wheat	Spain-Murcia	65.8	-	-
	Spain-Castilla LM	447	-	-
	Eastern Europe	550.6	3532	-
Barley	Spain-Castilla LM	447	-	-
	Spain-Murcia	65.8	-	-
Wheat middling	Spain- Castilla LM	196	-	-
	Spain-Valencia	131	-	-
	Spain-Navarra	774	-	-
	Spain-Murcia	65.8	-	-
Soybean meal	USA	375.6	6680	1706
	Brazil	1694.6	8526	-
	Eastern Europe	550.6	3532	-
	Argentina	417.6	9922.8	-
Sunflower meal	France	849.6	828.9	-
	Spain-Valencia	280	-	-
	Spain-Andalucía	465	-	-
Rapeseed meal	Spain	636	-	-
	France	1663	-	-

Soybean oil	Spain	75.6	-	
Animal fat	Spain- Castilla LM	447	-	-
	Spain-Murcia	65.8	-	-
	Spain-Valencia	280	-	-
Soybean hulls	Spain	75.6	-	-
Sodium chloride	Spain	65.8	-	-
Sodium bicarbonate	Spain	867	-	-
Monocalcium phosphate	Spain	75.6	-	-
Calcium carbonate	Spain	465	-	-
Bakery by-product[1,2]	Spain	637	-	-
Sunflower cake	France	849.6	828.88	
	Spain-Andalucía	465	-	-
	Spain-Valencia	280	-	-
Citrus Pulp[3]	Spain	465	-	-
Carob Pulp[2]	Spain-Murcia	65.8	-	-
	Spain-Andalucía	465	-	-
	Africa	405.6	843.9	-
Barley Rootlets	Spain	196	-	-
DDGs[1,3]	Spain	34	-	-
Rapeseed cake	France	1663	-	-
	Spain	637	-	-
Soybean concentrate	USA	75.6	6680	1706
Peas	France	849.6	828.9	-
	Canada	75.6	12100	1247.3
Dried H. Illucens[1]	Spain-Murcia	69	-	-
Feed for insects	Spain-Murcia	63.55	-	-

*: The background data of each ingredient were obtained from Agri-Footprint database, except those marked on the tables.
**: Average estimated from commercial routes origin plus destination or local route by lorry.
[1]: Average Energy for drying when it is not specified in database: 1.6 Kw/kg evaporated water.
[2]: Average energy for milling when it is not specified in database: 12.8 kwh/t.
[3]: Average energy for pelletizing when it is not specified in database: 25.5 kwh/t electric energy and 42.9 kwh/t thermal energy.

Table 13. (Annex I). Foreground data for environmental impact study in Italian pilot.

Ingredients*	Origin	Transport (km)		
		Lorry**	Ship	Train
Maize	Italy	150	-	-
	France	300	-	-
Barley	France	700	-	-
Soybean meal	Italy	175	-	-
	Brazil (seed imported)	1819	9695	-
	USA (seed imported)	200	7769.8	1706
	Argentina (seed imported)	542	11677.1	-
	Brazil (meal imported)	1819	9695	-
	USA (meal imported)	200	7769.8	1706
	Argentina (meal imported)	542	11677.1	-
Sunflower meal	Italy	350	-	-
	Russia	3000	-	-
Palm oil	Indonesia	1036	11129.3	-
Soybean oil	Italy	175	-	-
	Brazil (seed imported)	1819	9695	-
	USA (seed imported)	200	7769.8	1706
	Argentina (seed imported)	542	11677	-
Sunflower oil	Italy	350	-	-
	Russia	3000	-	-
Animal fat	Italy	200	-	-
Phosphates	Maroc			-
Sodium bicarbonate	Italy	400	-	-
Sodium Chloride	Italy	1400	-	-
Calcium carbonate	Italy	100	-	-
Wheat bran	Italy	175	-	-
Maize Gluten meal	Italy	150	-	-
Broken rice	Italy	150	-	-
Former food products[1]	Italy	100	-	-

Bakery by products[1]	Italy	100	-	-
Hazelnut skins	Italy	100	-	-
Grape skins[1]	Italy (wet)	100	-	-
	Italy (dried in Torino)[1]	100	-	-
	Italy (dried in origin)	100	-	-
Rapeseed meal	Italy	400	-	-
	Canada	200	12239.2	1247
Peas	Italy	100	-	-
	France	600	-	-
Fava beans	Italy	100	-	-
	France	600	-	-

*: The background data of each ingredient were obtained from Agri-Footprint database, except those marked on the tables.
**: Average estimated from commercial routes origin plus destination or local route by lorry.
1: Average Energy for drying when it is not specified in database: 1.6 Kwh/kg evaporated water.

Table 14. (Annex I). Foreground data for environmental impact study in Turkish pilot.

Ingredients*	Origin	Transport (km)		
		Lorry**	Ship	Train
Maize	Russia	2024	410.3	-
	Turkey	1024	-	-
Soybean meal	Brazil	2521	11703	-
	Turkey	24	-	-
	Eastern Europe	1499	740	-
Fish meal	Turkey	1000	-	-
Sunflower meal	Turkey	724	-	-
Wheat	Turkey	94	-	-
Calcium sources	Turkey	28	-	-
Sodium chloride	Turkey	44	-	-
Marble dust	Turkey	74	-	-
Tomato pomace[1]	Turkey	124	-	-
Grape pomace (wet transport)[1]	Turkey	124	-	-
Grape pomace (dry transport)[1]	Turkey	124	-	-

Whey powder[1]	Turkey	134	-	-
Whey powder high protein	Turkey	108	-	-
Sunflower oil	Turkey	700	-	-
Beer pulp (wet transport)[1]	Turkey	561	-	-
Beer pulp (dry transport)[1]	Turkey	561	-	-
Wheat middling	Turkey	32	-	-

*: The background data of each ingredient were obtained from Agri-Footprint database, except those marked on the tables.

**: Average estimated from commercial routes origin plus destination or local route by lorry.

1: Average Energy for drying when it is not specified in database: 1.6 Kwh/kg evaporated water.

Table 15. (Annex I). Foreground data for environmental impact study in Tunisian pilot (ISA CM).

Ingredients*	Origin	Transport (km)		
		Lorry[1]	Ship[2]	Train[3]
Maize	Argentina	466.3	11684	-
	Romania	390	2295	-
	Ukraine	476	2511	-
	USA	216	7604	1706
Wheat	Ukraine	609	2565	-
	Italy	316	1113	-
	Bulgaria	304	2143	-
Barley	Russia	2300	2721	-
	Germany	1404	1113	-
	Bulgaria	304	2143	-
	Finland	1439	19715	-
	Ukraine	476	2510	-
	Romania	390	2295	-
Fava beans	Tunisia-Beja	270	-	-
	Tunisia-Jendouba	270	-	-
	Tunisia–Gran Tunisia	160	-	-
	Tunisia– Siliana	160	-	-
	Tunisia–Kef	230	-	-

	Tunisia-Zaghouan	105	-	-
	Tunisia–Governorate Nabeoul	130	-	-
	Tunisia- Bizerte	220	-	-
Soybean oil	Spain	584	1348	-
	France	495	1131	-
Animal Fat	Spain	584	1348	-
	France	494	1131	
Wheat bran	Tunisia	250	-	-
	Italy	316	1112	-
Soybean meal	Tunisia	103	-	-
	Argentina	476	11887	-
Soybeans hulls	Argentina	476	11887	-
Rapeseed meal	Tunisia	280	-	-
Tomato pulp (fresh)	Tunisia	130	-	-
Dried Tomato pulp (wet transport)[4]	Tunisia	130	-	-
Dried Tomato pulp (dry transport)[4]	Tunisia	130	-	-
Brewer's grain (fresh)	Tunisia	250	-	-
Dried Brewer's grain (wet transport)[4]	Tunisia	250	-	-
Dried Brewer's grain (dry transport)[4]	Tunisia	250	-	-
Beer pulp (fresh)	Tunisia	280	-	-
Dried Beer pulp (wet transport)[4]	Tunisia	280	-	-
Dried Beer pulp (dry transport)	Tunisia	280	-	-
Molasses	Tunisia-Béja	250	-	-
	Tunisia -Bou Salem	280	-	-
Rapessed[4]	Tunisia wet	280	-	-
	Tunisia dried	280	-	-
Olive pomace fresh	Tunisia	60	-	-
Grape marc fresh	Tunisia	140	-	-
Caroube Pulp[5]	Tunisia	135	-	-

By-products of the date palm	Tunisia	630	-	-
Pasta waste	Tunisia	2	-	-
Triticale	Tunisia	2.70	-	-

*: The background data of each ingredient were obtained from Agri-Footprint database, except those marked on the tables.
[1]: Segregation of reference km provided by ISA-CM according to means of transport. Average estimated from commercial routes origin plus destination or local route by lorry.
[2]: Segregation of reference km provided by ISA-CM according to means of transport. Average estimated from commercial routes origin by ship.
[3]: Segregation of reference km provided by ISA-CM according to means of transport. Average estimated from commercial routes origin by train.
[4]: Average energy for drying when it is not specified in database: 1.6Kw/kg evaporated water.
[5]: Average energy for milling when it is not specified in database: 12.8 kwh/t.

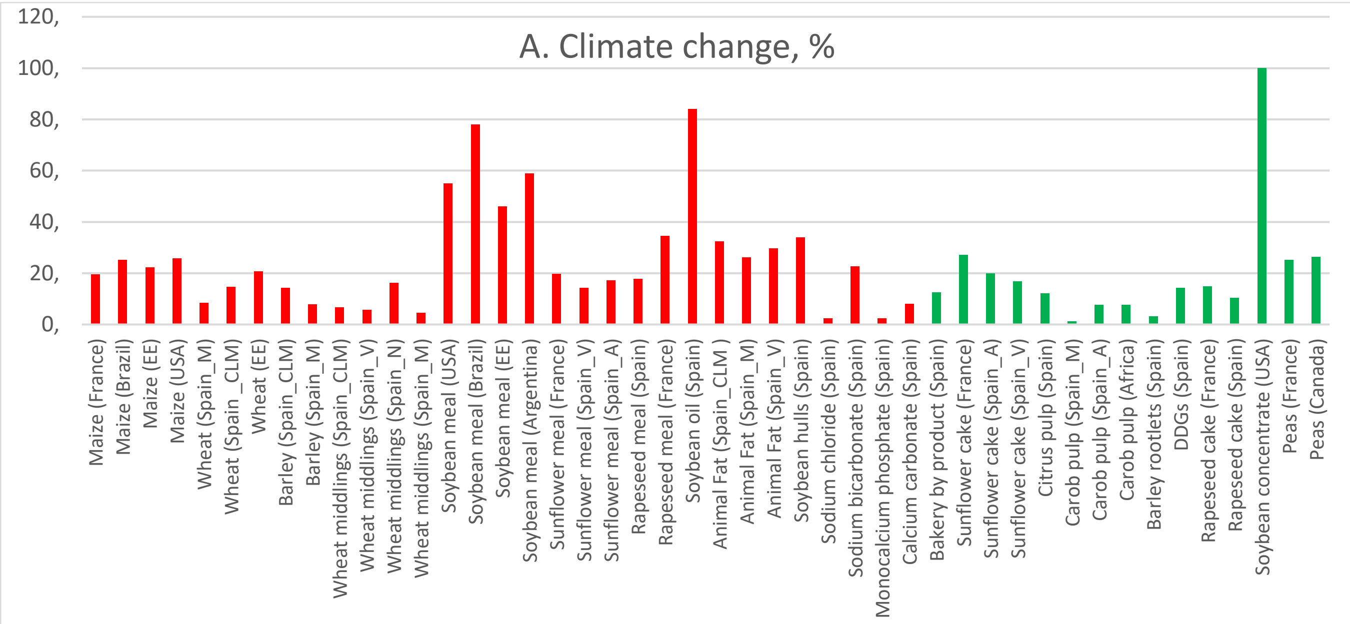
Table 16. (Annex I). Foreground data for environmental impact study in Ryahana.

Ingredients*	Origin	Transport (km)		
		Lorry[1]	Ship[2]	Train[3]
Fava beans	Tunisia	195	-	-
	Tunisia, nearest origin	25	-	-
Maize	Tunisia	195	-	-
	Imported	390	6023.3	426.5
Wheat	Tunisia			
	Imported	410	1940	-
Barley	Tunisia	195		-
	Imported	873	5169	-
Wheat bran	Tunisia	195		-
	Imported	316	112.59	-
Soybean meal	Imported	289.5	5943.1	-
Marble dust	Tunisia	22	-	-
Fish meal	Tunisia	195	-	-
Trigonella foenum-graecum	Tunisia	195	-	-
Peas	Tunisia	195	-	-
	Imported (Italy)	600	112.59	-
Triticale	Tunisia	128	-	-
Pasta waste[4]	Tunisia	100	-	-

*: The background data of each ingredient were obtained from Agri-Footprint database, except those marked on the tables.
[1]: Average estimated from commercial routes of imported ingredients or local route by lorry.
[2]: Average estimated from commercial routes of imported ingredients by ship.
[3]: Average estimated from commercial routes of imported ingredients by train.
[4]: Average energy for drying when it is not specified in database: 1.6 Kwh/kg evaporated water.

SPANISH PILOT

Figure 17. (Annex I). Environmental impact obtained with ILCD method on Climate change (A), Acidification (B), Land use (C), Marine eutrophication (D), Human toxicity, cancer effects € and non-cancer effects (F) from ingredients provided by Spanish pilot. Origin is indicated in parentheses: EE: Eastern Europe; Spain_M: from Murcia; Spain_CLM: from Castilla La Mancha; Spain_V: from Valencia; Spain_N: from Navarra; Spain_A: from Andalucía. The units are percentages with respect to the highest impact, which is considered 100%. Red: Usual ingredients. Green: alternative ingredients.



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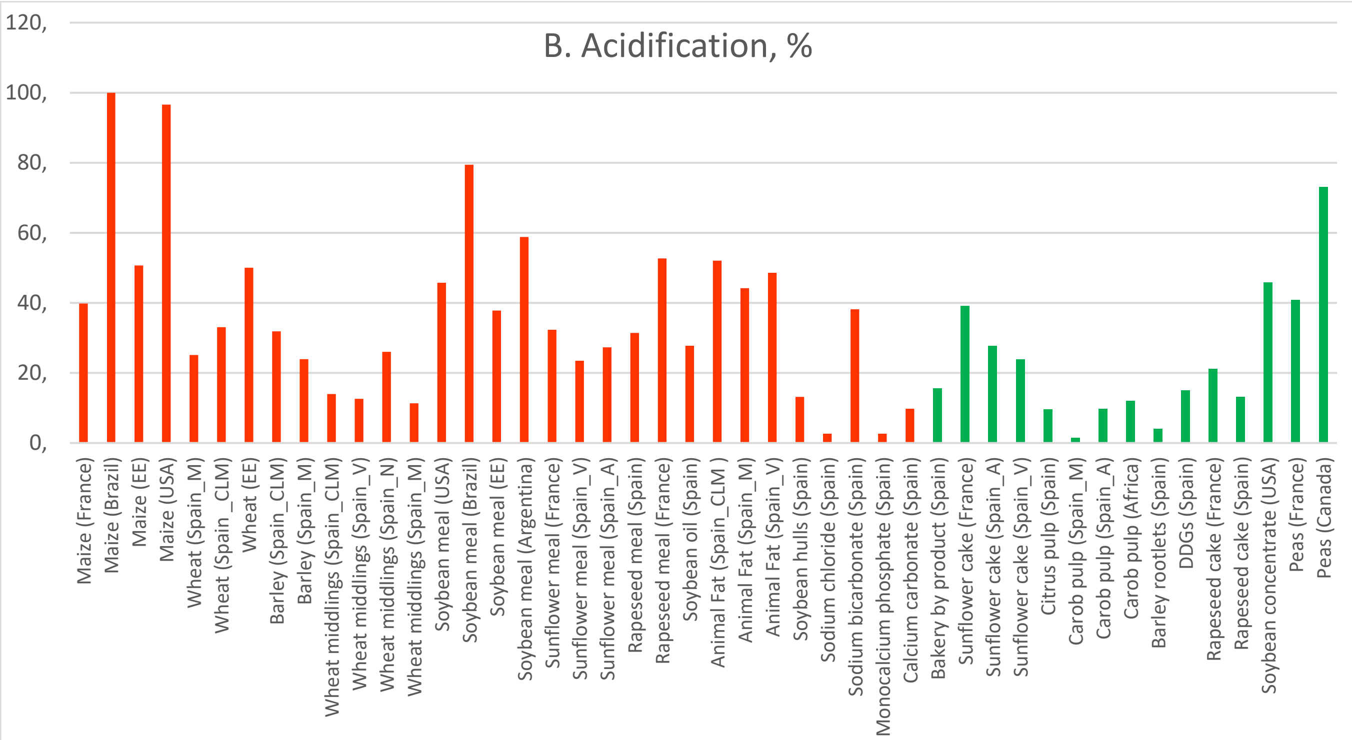
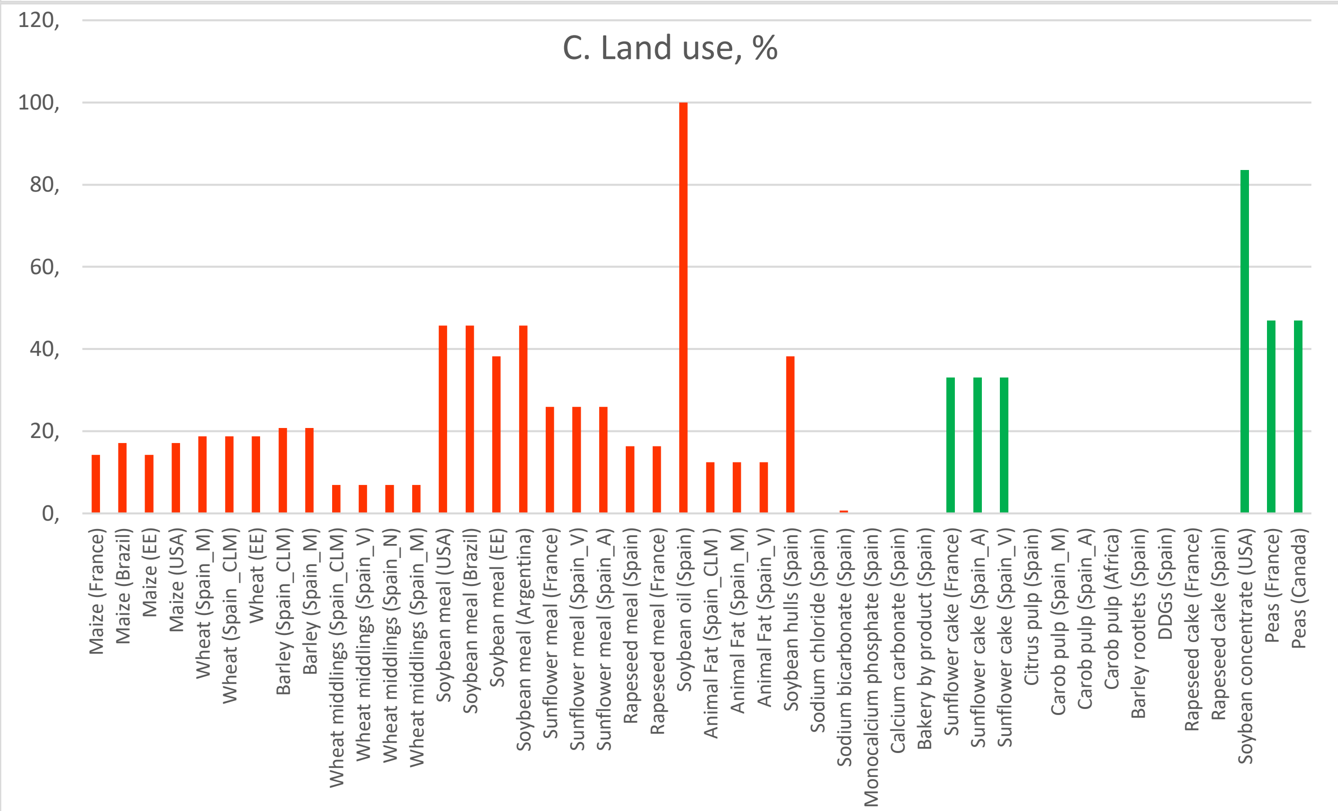
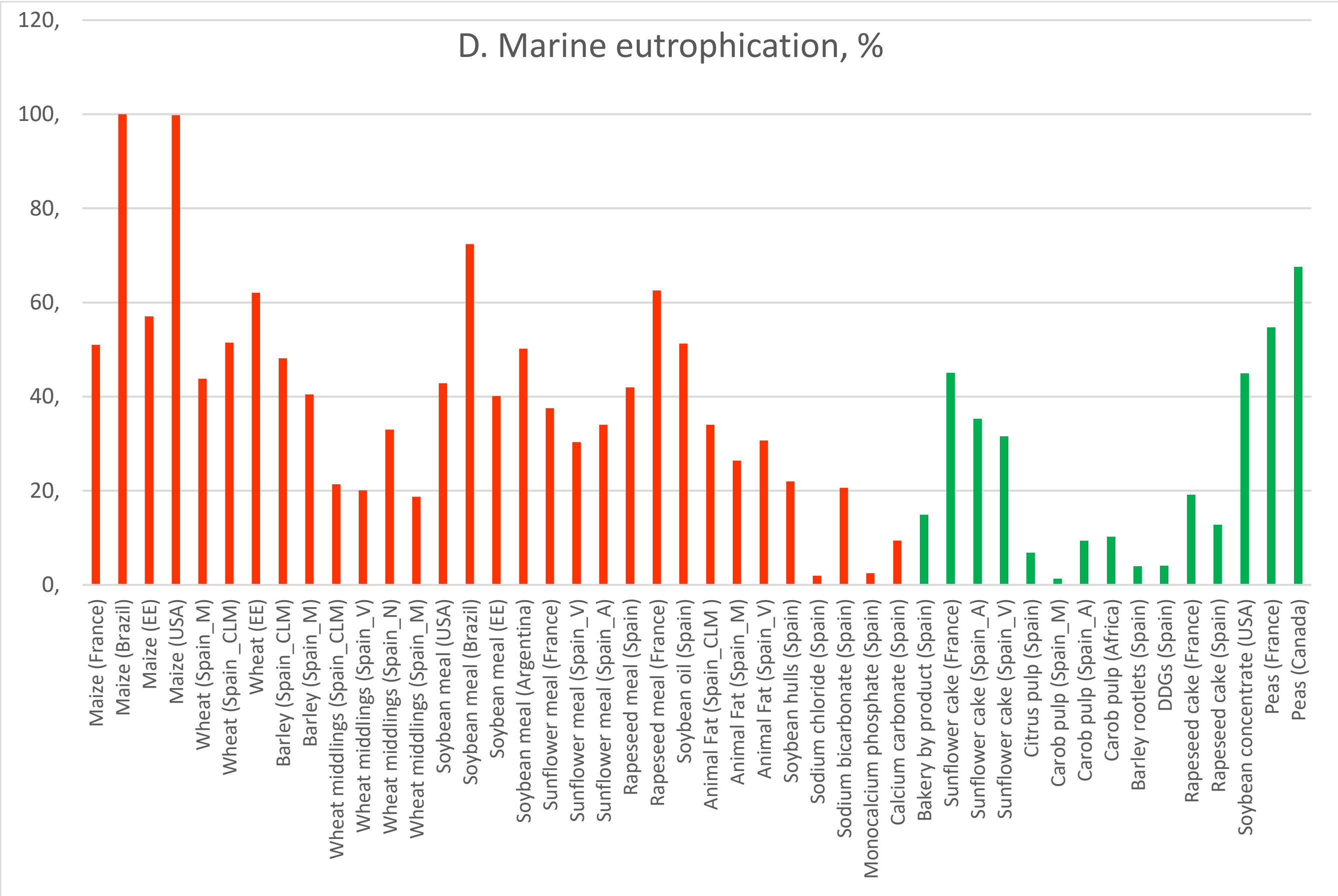
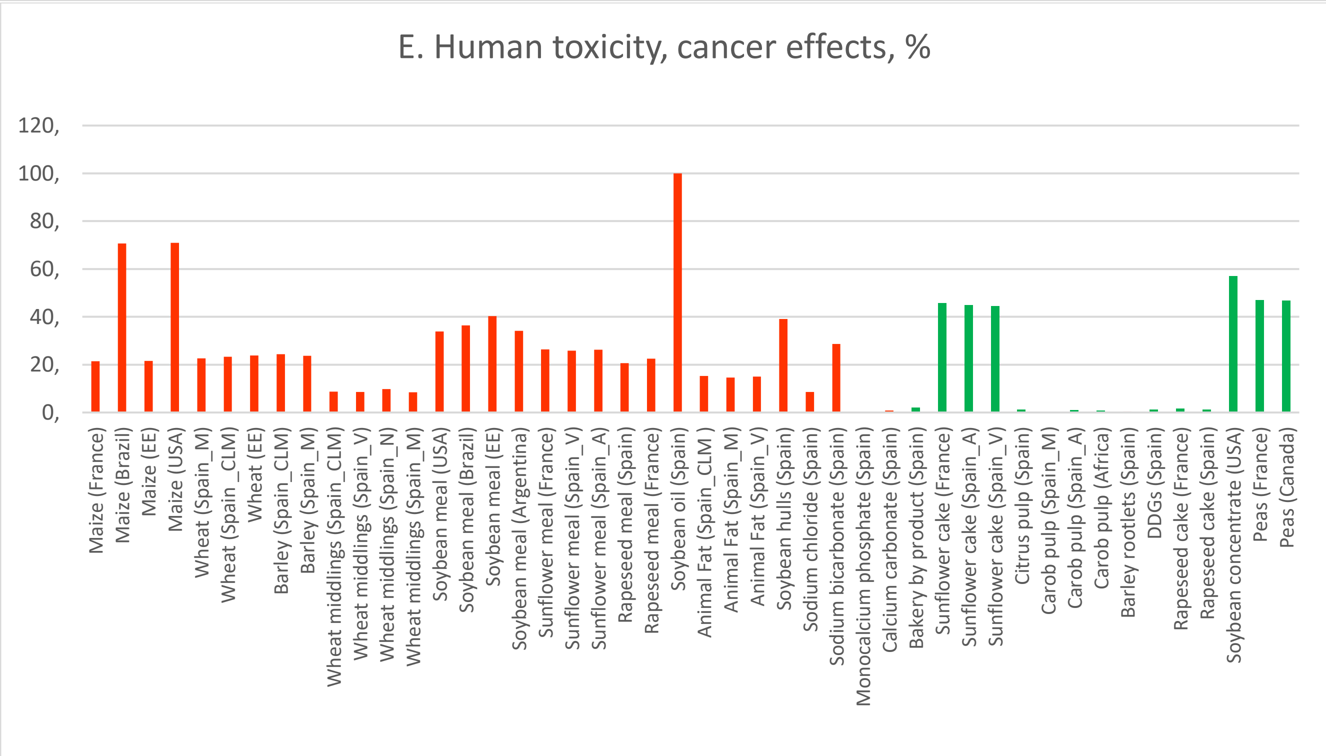
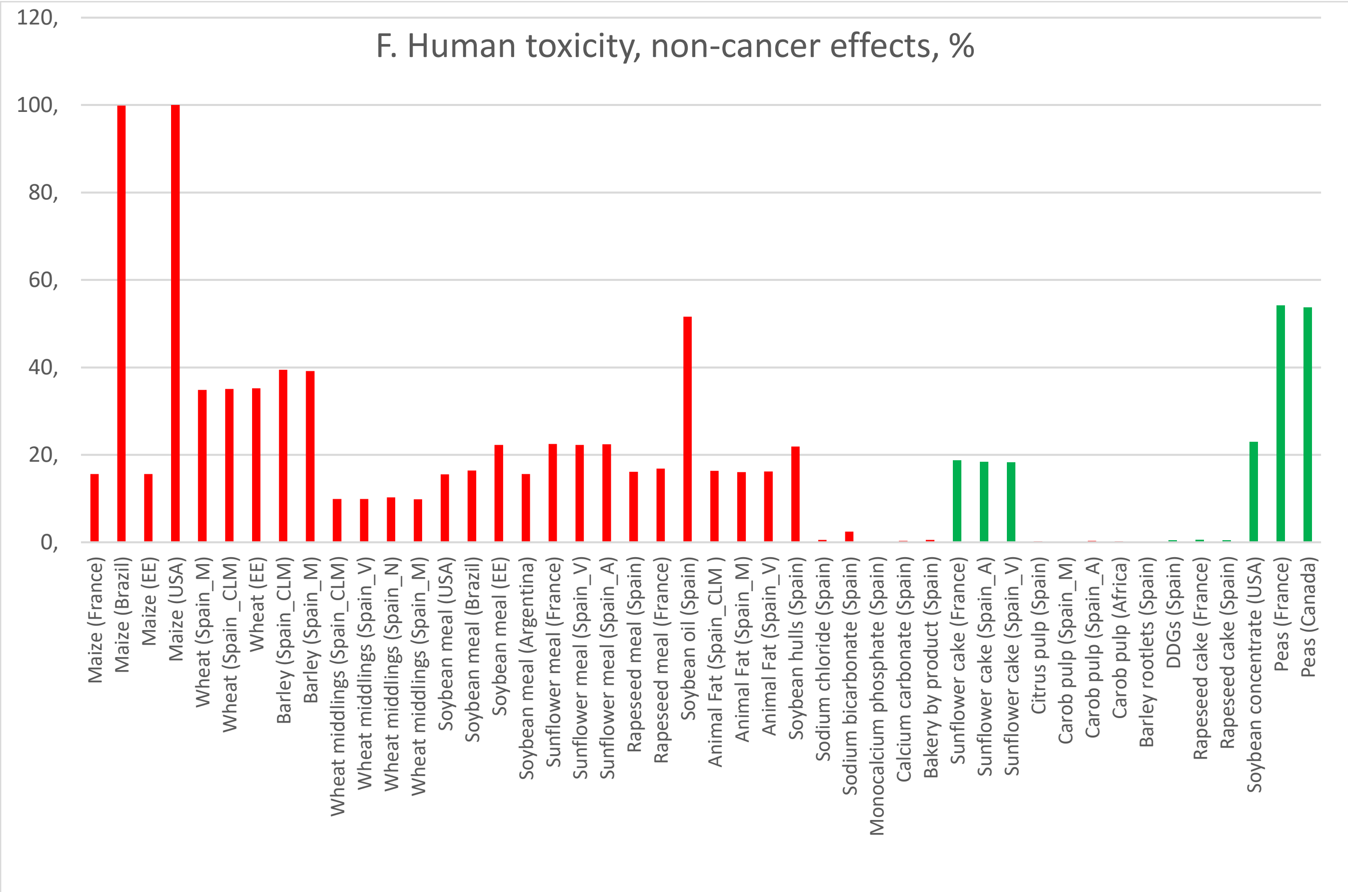

B. Acidification, %
120,
100,
80,
60,
40,
20,
0,
Maize (France)
Maize (Brazil)
Maize (EE)
Maize (USA)
Wheat (Spain_M)
Wheat (Spain _CLM)
Wheat (EE)
Barley (Spain_CLM)
Barley (Spain_M)
Wheat middlings (Spain_CLM)
Wheat middlings (Spain_V)
Wheat middlings (Spain_N)
Wheat middlings (Spain_M)
Soybean meal (USA)
Soybean meal (Brazil)
Soybean meal (EE)
Soybean meal (Argentina)
Sunflower meal (France)
Sunflower meal (Spain_V)
Sunflower meal (Spain_A)
Rapeseed meal (Spain)
Rapeseed meal (France)
Soybean oil (Spain)
Animal Fat (Spain_CLM)
Animal Fat (Spain_M)
Animal Fat (Spain_V)
Soybean hulls (Spain)
Sodium chloride (Spain)
Sodium bicarbonate (Spain)
Monocalcium phosphate (Spain)
Calcium carbonate (Spain)
Bakery by product (Spain)
Sunflower cake (France)
Sunflower cake (Spain_A)
Sunflower cake (Spain_V)
Citrus pulp (Spain)
Carob pulp (Spain_M)
Carob pulp (Spain_A)
Carob pulp (Africa)
Barley rootlets (Spain)
DDGs (Spain)
Rapeseed cake (France)
Rapeseed cake (Spain)
Soybean concentrate (USA)
Peas (France)
Peas (Canada)


C. Land use, %
120,
100,
80,
60,
40,
20,
0,
Maize (France)
Maize (Brazil)
Maize (EE)
Maize (USA)
Wheat (Spain_M)
Wheat (Spain _CLM)
Wheat (EE)
Barley (Spain_CLM)
Barley (Spain_M)
Wheat middlings (Spain_CLM)
Wheat middlings (Spain_V)
Wheat middlings (Spain_N)
Wheat middlings (Spain_M)
Soybean meal (USA)
Soybean meal (Brazil)
Soybean meal (EE)
Soybean meal (Argentina)
Sunflower meal (France)
Sunflower meal (Spain_V)
Sunflower meal (Spain_A)
Rapeseed meal (Spain)
Rapeseed meal (France)
Soybean oil (Spain)
Animal Fat (Spain_CLM)
Animal Fat (Spain_M)
Animal Fat (Spain_V)
Soybean hulls (Spain)
Sodium chloride (Spain)
Sodium bicarbonate (Spain)
Monocalcium phosphate (Spain)
Calcium carbonate (Spain)
Bakery by product (Spain)
Sunflower cake (France)
Sunflower cake (Spain_A)
Sunflower cake (Spain_V)
Citrus pulp (Spain)
Carob pulp (Spain_M)
Carob pulp (Spain_A)
Carob pulp (Africa)
Barley rootlets (Spain)
DDGs (Spain)
Rapeseed cake (France)
Rapeseed cake (Spain)
Soybean concentrate (USA)
Peas (France)
Peas (Canada)

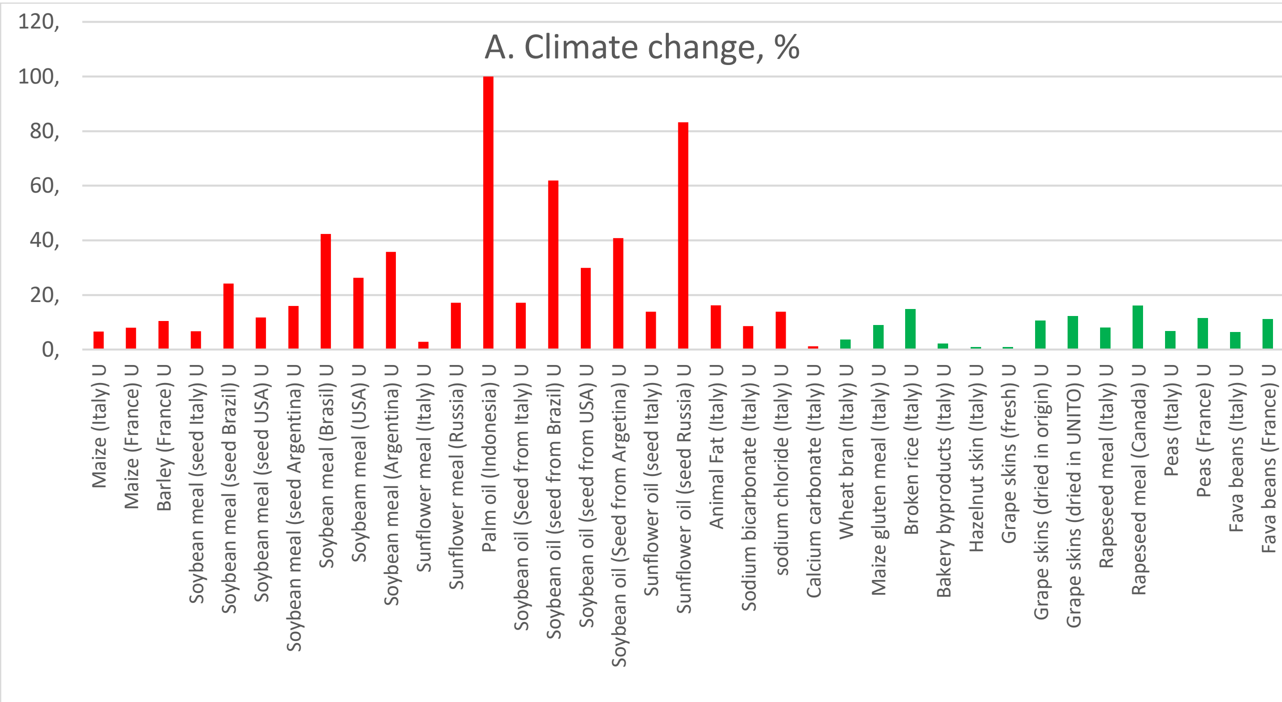

D. Marine eutrophication, %
120,
100,
80,
60,
40,
20,
0,
Maize (France)
Maize (Brazil)
Maize (EE)
Maize (USA)
Wheat (Spain_M)
Wheat (Spain _CLM)
Wheat (EE)
Barley (Spain_CLM)
Barley (Spain_M)
Wheat middlings (Spain_CLM)
Wheat middlings (Spain_V)
Wheat middlings (Spain_N)
Wheat middlings (Spain_M)
Soybean meal (USA)
Soybean meal (Brazil)
Soybean meal (EE)
Soybean meal (Argentina)
Sunflower meal (France)
Sunflower meal (Spain_V)
Sunflower meal (Spain_A)
Rapeseed meal (Spain)
Rapeseed meal (France)
Soybean oil (Spain)
Animal Fat (Spain_CLM)
Animal Fat (Spain_M)
Animal Fat (Spain_V)
Soybean hulls (Spain)
Sodium chloride (Spain)
Sodium bicarbonate (Spain)
Monocalcium phosphate (Spain)
Calcium carbonate (Spain)
Bakery by product (Spain)
Sunflower cake (France)
Sunflower cake (Spain_A)
Sunflower cake (Spain_V)
Citrus pulp (Spain)
Carob pulp (Spain_M)
Carob pulp (Spain_A)
Carob pulp (Africa)
Barley rootlets (Spain)
DDGs (Spain)
Rapeseed cake (France)
Rapeseed cake (Spain)
Soybean concentrate (USA)
Peas (France)
Peas (Canada)

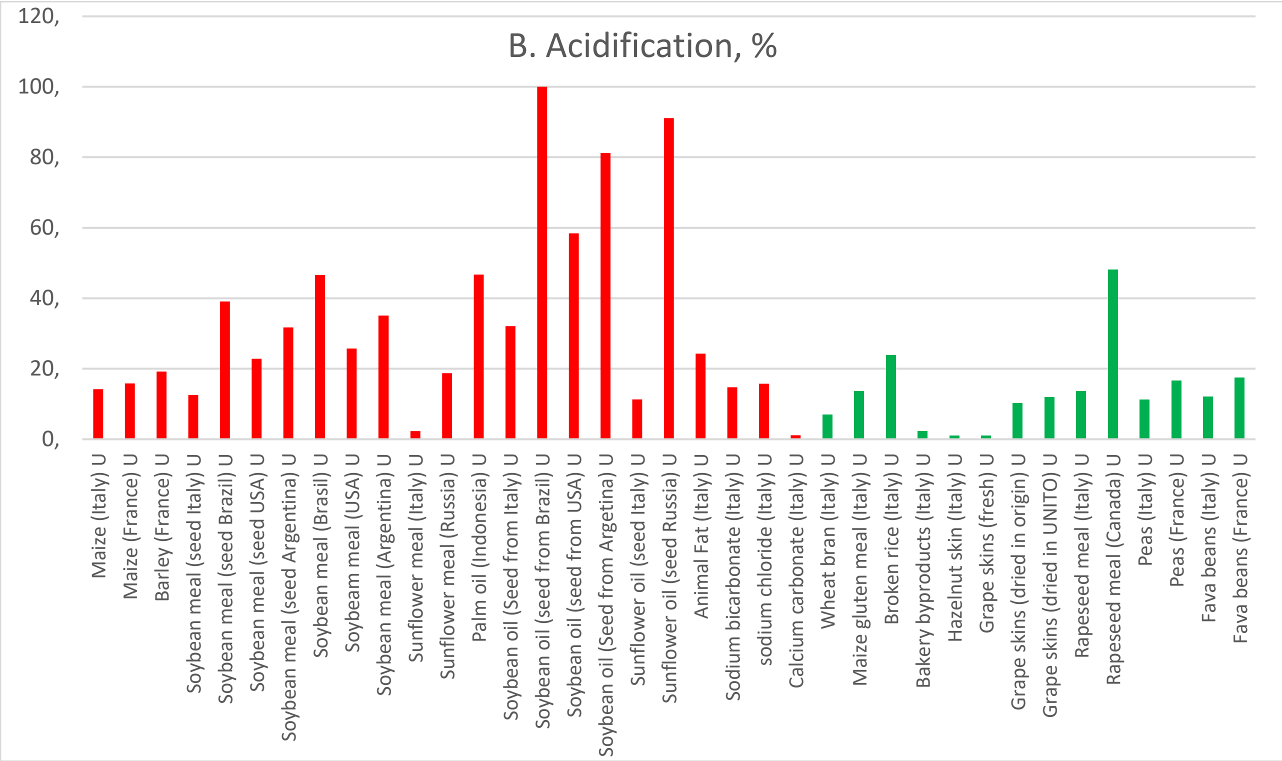

E. Human toxicity, cancer effects, %
120,
100,
80,
60,
40,
20,
0,
Maize (France)
Maize (Brazil)
Maize (EE)
Maize (USA)
Wheat (Spain_M)
Wheat (Spain _CLM)
Wheat (EE)
Barley (Spain_CLM)
Barley (Spain_M)
Wheat middlings (Spain_CLM)
Wheat middlings (Spain_V)
Wheat middlings (Spain_N)
Wheat middlings (Spain_M)
Soybean meal (USA)
Soybean meal (Brazil)
Soybean meal (EE)
Soybean meal (Argentina)
Sunflower meal (France)
Sunflower meal (Spain_V)
Sunflower meal (Spain_A)
Rapeseed meal (Spain)
Rapeseed meal (France)
Soybean oil (Spain)
Animal Fat (Spain_CLM)
Animal Fat (Spain_M)
Animal Fat (Spain_V)
Soybean hulls (Spain)
Sodium chloride (Spain)
Sodium bicarbonate (Spain)
Monocalcium phosphate (Spain)
Calcium carbonate (Spain)
Bakery by product (Spain)
Sunflower cake (France)
Sunflower cake (Spain_A)
Sunflower cake (Spain_V)
Citrus pulp (Spain)
Carob pulp (Spain_M)
Carob pulp (Spain_A)
Carob pulp (Africa)
Barley rootlets (Spain)
DDGs (Spain)
Rapeseed cake (France)
Rapeseed cake (Spain)
Soybean concentrate (USA)
Peas (France)
Peas (Canada)

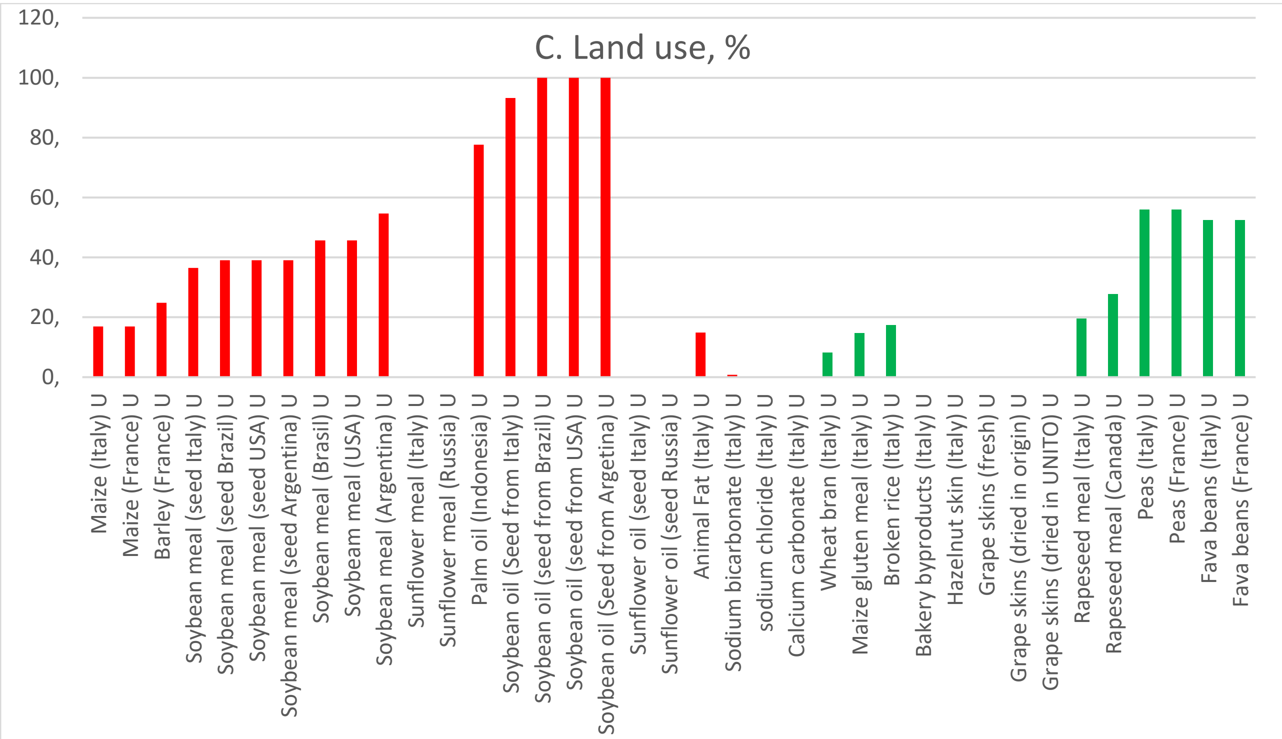

F. Human toxicity, non-cancer effects, %
120,
100,
80,
60,
40,
20,
0,
Maize (France)
Maize (Brazil)
Maize (EE)
Maize (USA)
Wheat (Spain_M)
Wheat (Spain _CLM)
Wheat (EE)
Barley (Spain_CLM)
Barley (Spain_M)
Wheat middlings (Spain_CLM)
Wheat middlings (Spain_V)
Wheat middlings (Spain_N)
Wheat middlings (Spain_M)
Soybean meal (USA)
Soybean meal (Brazil)
Soybean meal (EE)
Soybean meal (Argentina)
Sunflower meal (France)
Sunflower meal (Spain_V)
Sunflower meal (Spain_A)
Rapeseed meal (Spain)
Rapeseed meal (France)
Soybean oil (Spain)
Animal Fat (Spain_CLM)
Animal Fat (Spain_M)
Animal Fat (Spain_V)
Soybean hulls (Spain)
Sodium chloride (Spain)
Sodium bicarbonate (Spain)
Monocalcium phosphate (Spain)
Calcium carbonate (Spain)
Bakery by product (Spain)
Sunflower cake (France)
Sunflower cake (Spain_A)
Sunflower cake (Spain_V)
Citrus pulp (Spain)
Carob pulp (Spain_M)
Carob pulp (Spain_A)
Carob pulp (Africa)
Barley rootlets (Spain)
DDGs (Spain)
Rapeseed cake (France)
Rapeseed cake (Spain)
Soybean concentrate (USA)
Peas (France)
Peas (Canada)

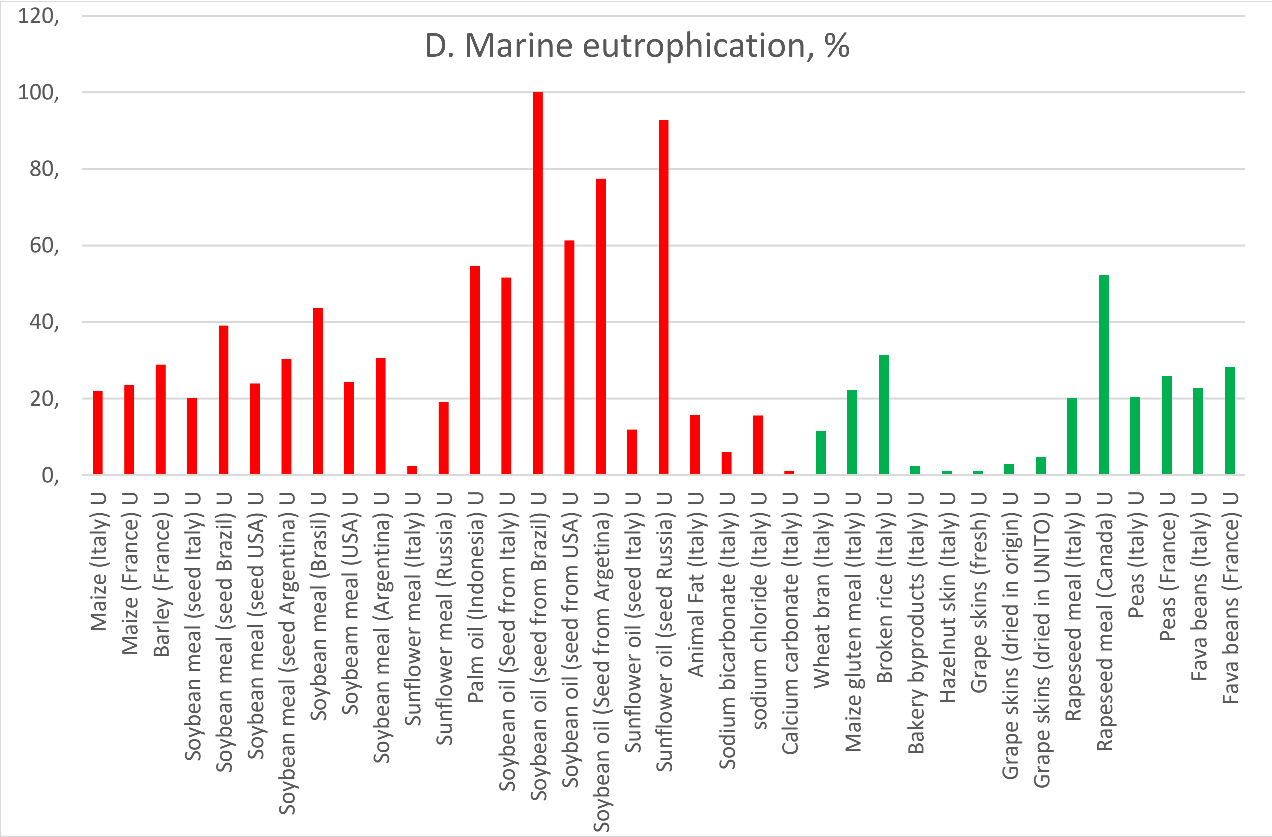
ITALIAN PILOT

Figure 18. (Annex I). Environmental impact obtained with ILCD method on Climate change (A), Acidification (B), Land use (C), Marine eutrophication (D), Human toxicity, cancer effects € and non-cancer effects (F) from ingredients provided by Italian pilot. Origin is indicated in parentheses. The units are percentages with respect to the highest impact, which is considered 100%. Red: Usual ingredients. Green: alternative ingredients.

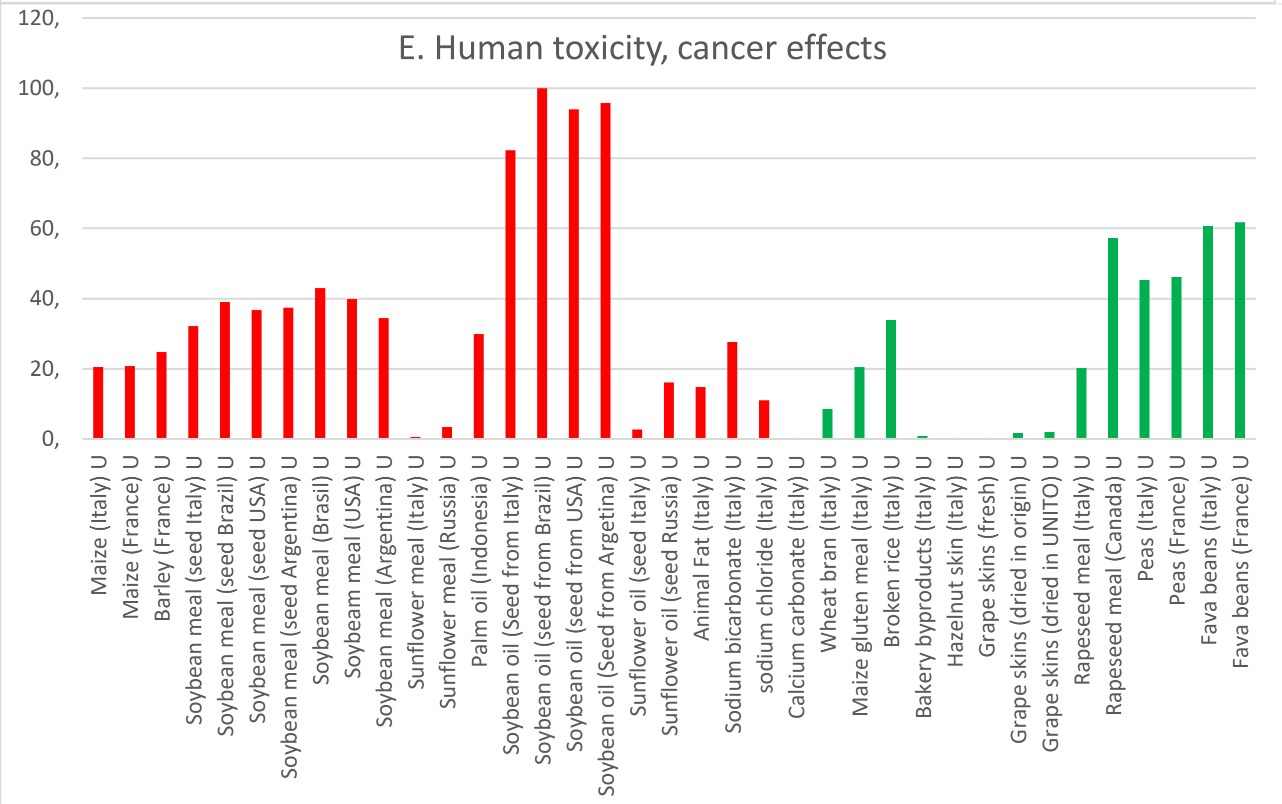



B. Acidification, %
120,
100,
80,
60,
40,
20,
0,
Maize (Italy) U
Maize (France) U
Barley (France) U
Soybean meal (seed Italy) U
Soybean meal (seed Brazil) U
Soybean meal (seed USA) U
Soybean meal (seed Argentina) U
Soybean meal (Brasil) U
Soybeam meal (USA) U
Soybean meal (Argentina) U
Sunflower meal (Italy) U
Sunflower meal (Russia) U
Palm oil (Indonesia) U
Soybean oil (Seed from Italy) U
Soybean oil (seed from Brazil) U
Soybean oil (seed from USA) U
Soybean oil (Seed from Argetina) U
Sunflower oil (seed Italy) U
Sunflower oil (seed Russia) U
Animal Fat (Italy) U
Sodium bicarbonate (Italy) U
sodium chloride (Italy) U
Calcium carbonate (Italy) U
Wheat bran (Italy) U
Maize gluten meal (Italy) U
Broken rice (Italy) U
Bakery byproducts (Italy) U
Hazelnut skin (Italy) U
Grape skins (fresh) U
Grape skins (dried in origin) U
Grape skins (dried in UNITO) U
Rapeseed meal (Italy) U
Rapeseed meal (Canada) U
Peas (Italy) U
Peas (France) U
Fava beans (Italy) U
Fava beans (France) U

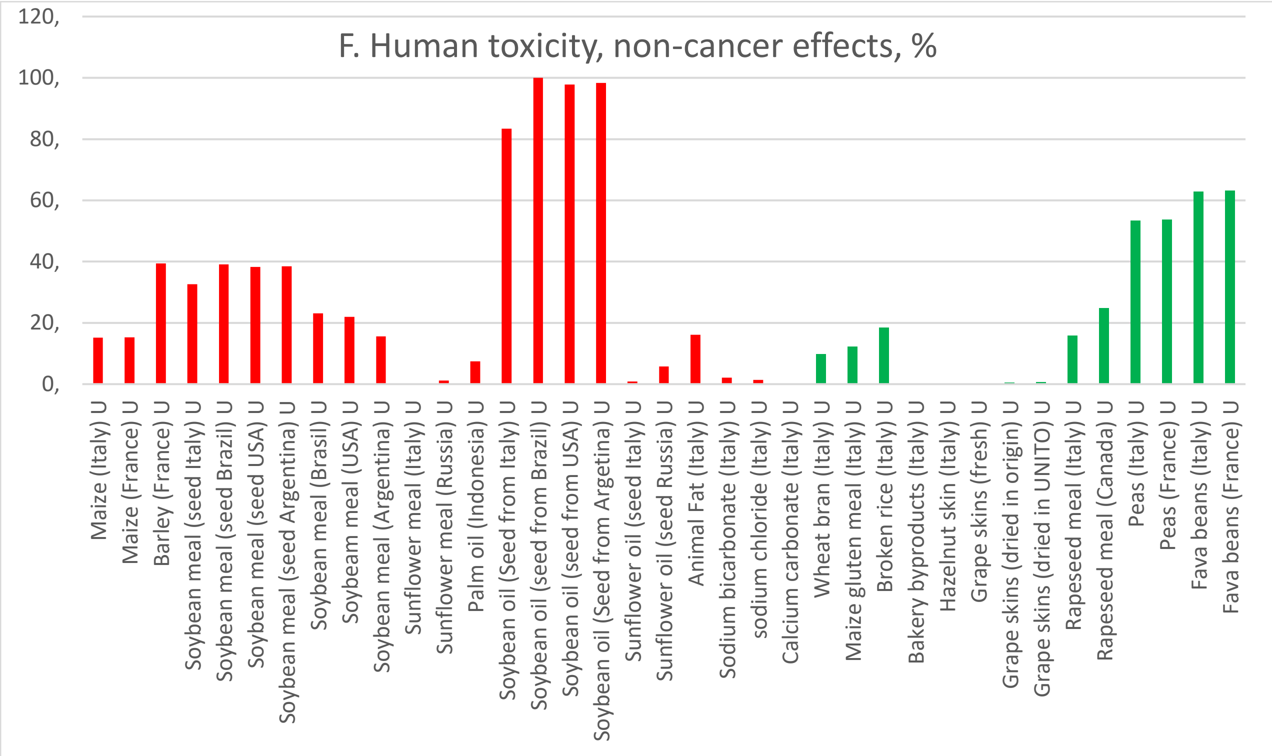

C. Land use, %
120,
100,
80,
60,
40,
20,
0,
Maize (Italy) U
Maize (France) U
Barley (France) U
Soybean meal (seed Italy) U
Soybean meal (seed Brazil) U
Soybean meal (seed USA) U
Soybean meal (seed Argentina) U
Soybean meal (Brasil) U
Soybeam meal (USA) U
Soybean meal (Argentina) U
Sunflower meal (Italy) U
Sunflower meal (Russia) U
Palm oil (Indonesia) U
Soybean oil (Seed from Italy) U
Soybean oil (seed from Brazil) U
Soybean oil (seed from USA) U
Soybean oil (Seed from Argetina) U
Sunflower oil (seed Italy) U
Sunflower oil (seed Russia) U
Animal Fat (Italy) U
Sodium bicarbonate (Italy) U
sodium chloride (Italy) U
Calcium carbonate (Italy) U
Wheat bran (Italy) U
Maize gluten meal (Italy) U
Broken rice (Italy) U
Bakery byproducts (Italy) U
Hazelnut skin (Italy) U
Grape skins (fresh) U
Grape skins (dried in origin) U
Grape skins (dried in UNITO) U
Rapeseed meal (Italy) U
Rapeseed meal (Canada) U
Peas (Italy) U
Peas (France) U
Fava beans (Italy) U
Fava beans (France) U



D. Marine eutrophication, %
120,
100,
80,
60,
40,
20,
0,
Maize (Italy) U
Maize (France) U
Barley (France) U
Soybean meal (seed Italy) U
Soybean meal (seed Brazil) U
Soybean meal (seed USA) U
Soybean meal (seed Argentina) U
Soybean meal (Brasil) U
Soybeam meal (USA) U
Soybean meal (Argentina) U
Sunflower meal (Italy) U
Sunflower meal (Russia) U
Palm oil (Indonesia) U
Soybean oil (Seed from Italy) U
Soybean oil (seed from Brazil) U
Soybean oil (seed from USA) U
Soybean oil (Seed from Argetina) U
Sunflower oil (seed Italy) U
Sunflower oil (seed Russia) U
Animal Fat (Italy) U
Sodium bicarbonate (Italy) U
sodium chloride (Italy) U
Calcium carbonate (Italy) U
Wheat bran (Italy) U
Maize gluten meal (Italy) U
Broken rice (Italy) U
Bakery byproducts (Italy) U
Hazelnut skin (Italy) U
Grape skins (fresh) U
Grape skins (dried in origin) U
Grape skins (dried in UNITO) U
Rapeseed meal (Italy) U
Rapeseed meal (Canada) U
Peas (Italy) U
Peas (France) U
Fava beans (Italy) U
Fava beans (France) U



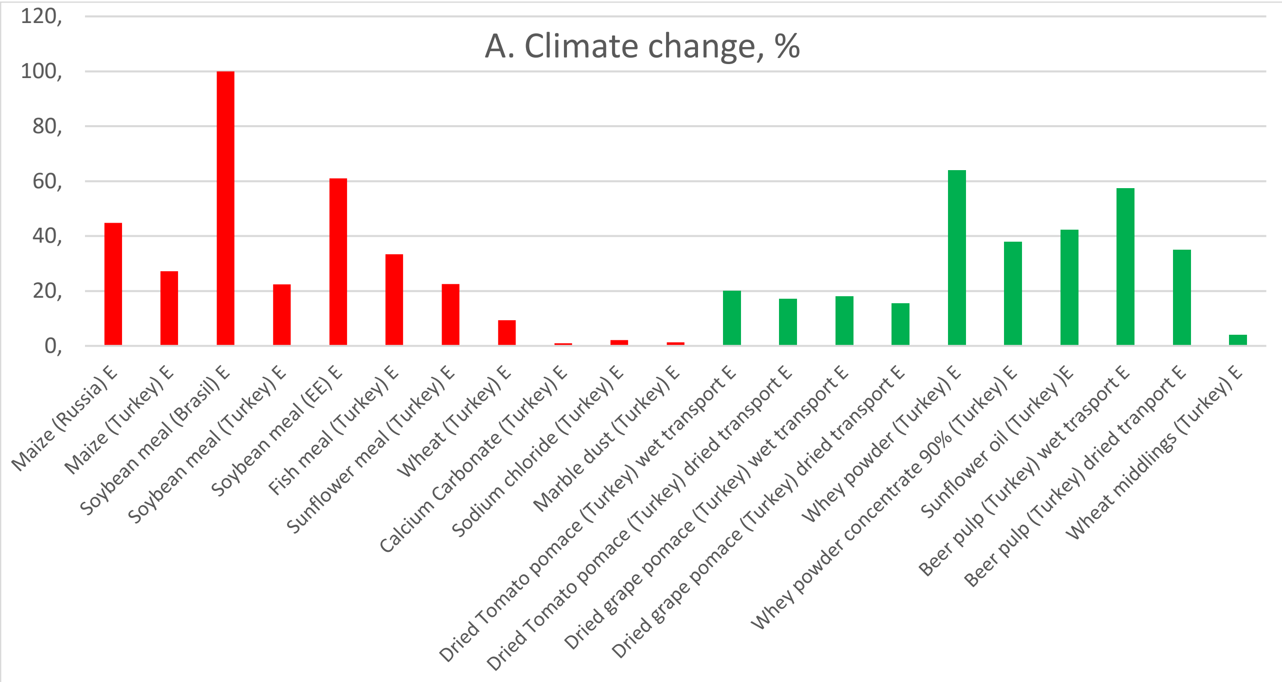
E. Human toxicity, cancer effects
120,
100,
80,
60,
40,
20,
0,
Maize (Italy) U
Maize (France) U
Barley (France) U
Soybean meal (seed Italy) U
Soybean meal (seed Brazil) U
Soybean meal (seed USA) U
Soybean meal (seed Argentina) U
Soybean meal (Brasil) U
Soybeam meal (USA) U
Soybean meal (Argentina) U
Sunflower meal (Italy) U
Sunflower meal (Russia) U
Palm oil (Indonesia) U
Soybean oil (Seed from Italy) U
Soybean oil (seed from Brazil) U
Soybean oil (seed from USA) U
Soybean oil (Seed from Argetina) U
Sunflower oil (seed Italy) U
Sunflower oil (seed Russia) U
Animal Fat (Italy) U
Sodium bicarbonate (Italy) U
sodium chloride (Italy) U
Calcium carbonate (Italy) U
Wheat bran (Italy) U
Maize gluten meal (Italy) U
Broken rice (Italy) U
Bakery byproducts (Italy) U
Hazelnut skin (Italy) U
Grape skins (fresh) U
Grape skins (dried in origin) U
Grape skins (dried in UNITO) U
Rapeseed meal (Italy) U
Rapeseed meal (Canada) U
Peas (Italy) U
Peas (France) U
Fava beans (Italy) U
Fava beans (France) U

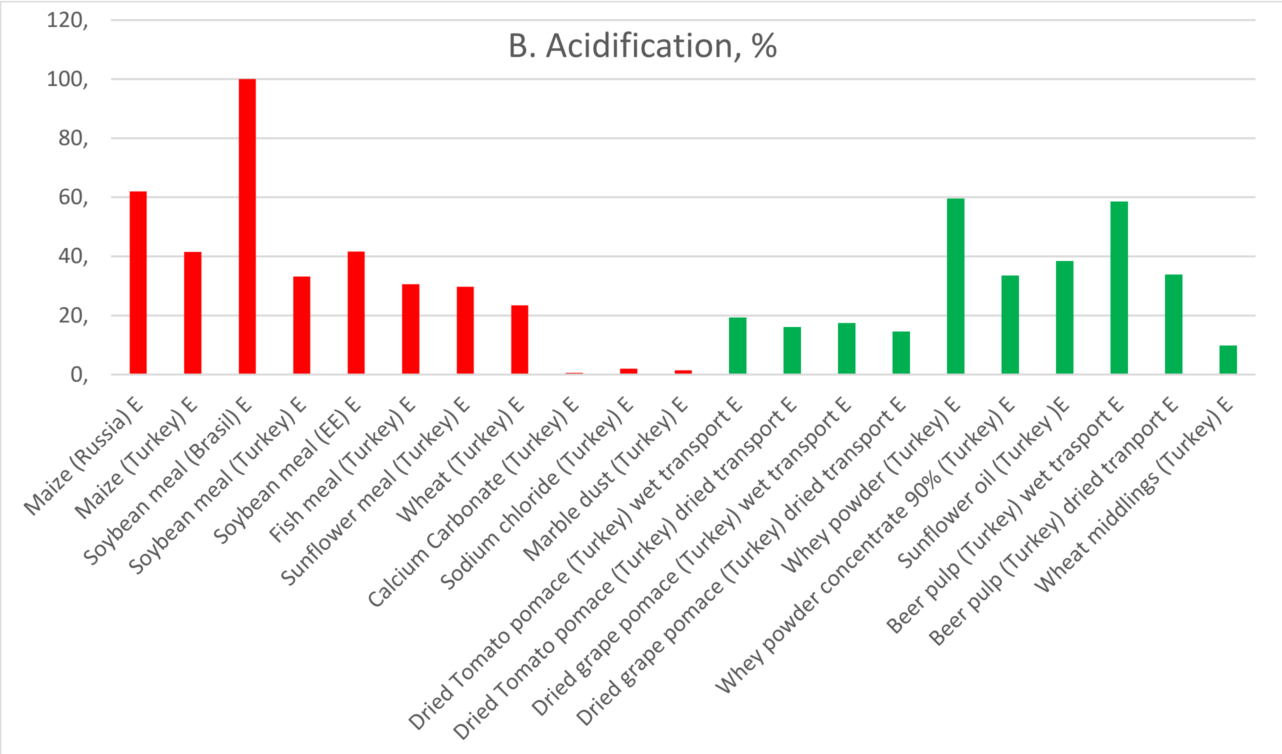


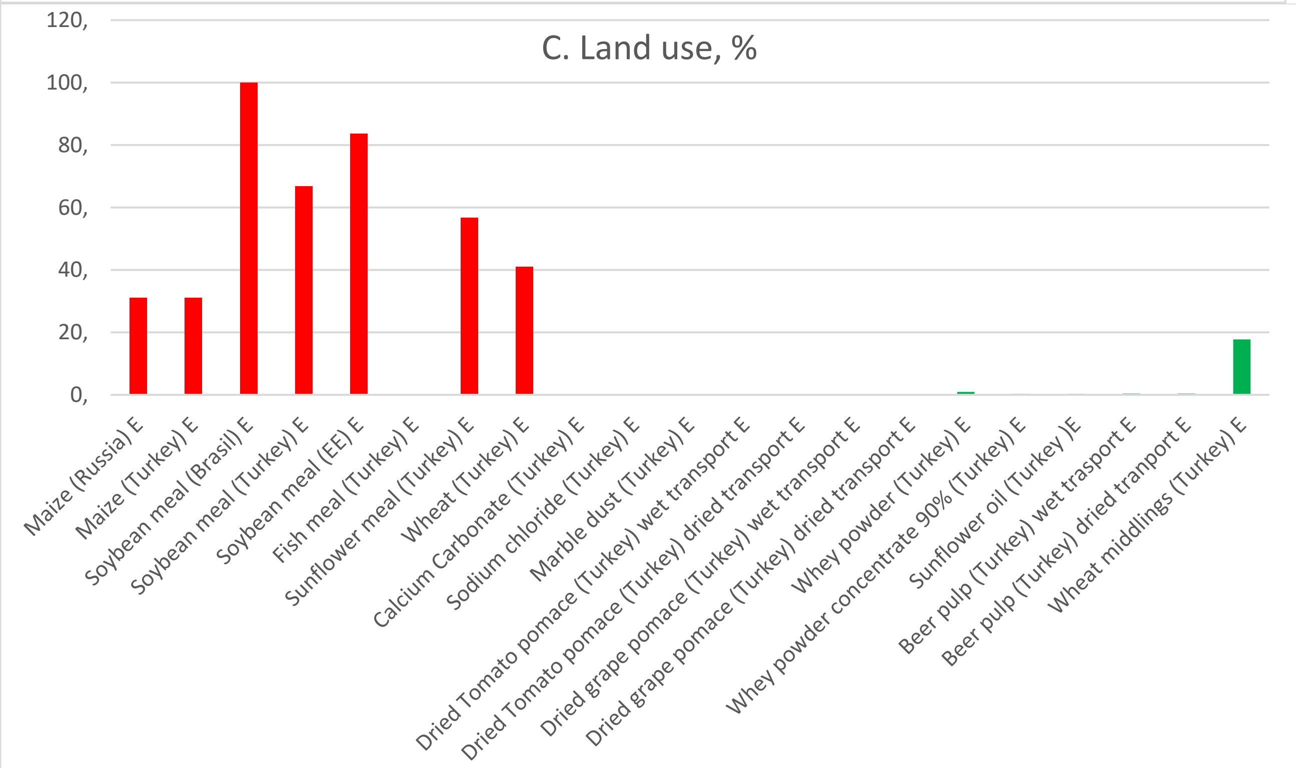
F. Human toxicity, non-cancer effects, %
120,
100,
80,
60,
40,
20,
0,
Maize (Italy) U
Maize (France) U
Barley (France) U
Soybean meal (seed Italy) U
Soybean meal (seed Brazil) U
Soybean meal (seed USA) U
Soybean meal (seed Argentina) U
Soybean meal (Brasil) U
Soybeam meal (USA) U
Soybean meal (Argentina) U
Sunflower meal (Italy) U
Sunflower meal (Russia) U
Palm oil (Indonesia) U
Soybean oil (Seed from Italy) U
Soybean oil (seed from Brazil) U
Soybean oil (seed from USA) U
Soybean oil (Seed from Argetina) U
Sunflower oil (seed Italy) U
Sunflower oil (seed Russia) U
Animal Fat (Italy) U
Sodium bicarbonate (Italy) U
sodium chloride (Italy) U
Calcium carbonate (Italy) U
Wheat bran (Italy) U
Maize gluten meal (Italy) U
Broken rice (Italy) U
Bakery byproducts (Italy) U
Hazelnut skin (Italy) U
Grape skins (fresh) U
Grape skins (dried in origin) U
Grape skins (dried in UNITO) U
Rapeseed meal (Italy) U
Rapeseed meal (Canada) U
Peas (Italy) U
Peas (France) U
Fava beans (Italy) U
Fava beans (France) U

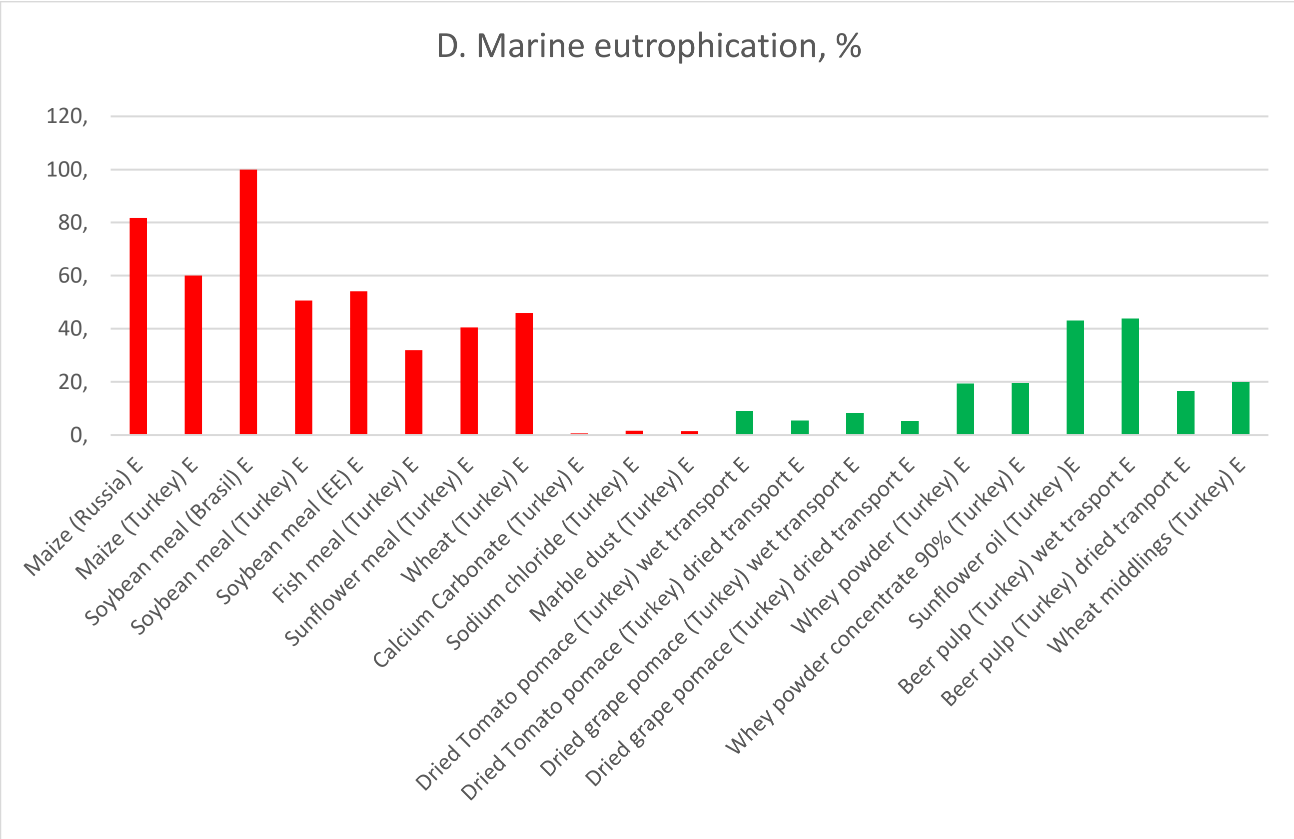
TURKISH PILOT

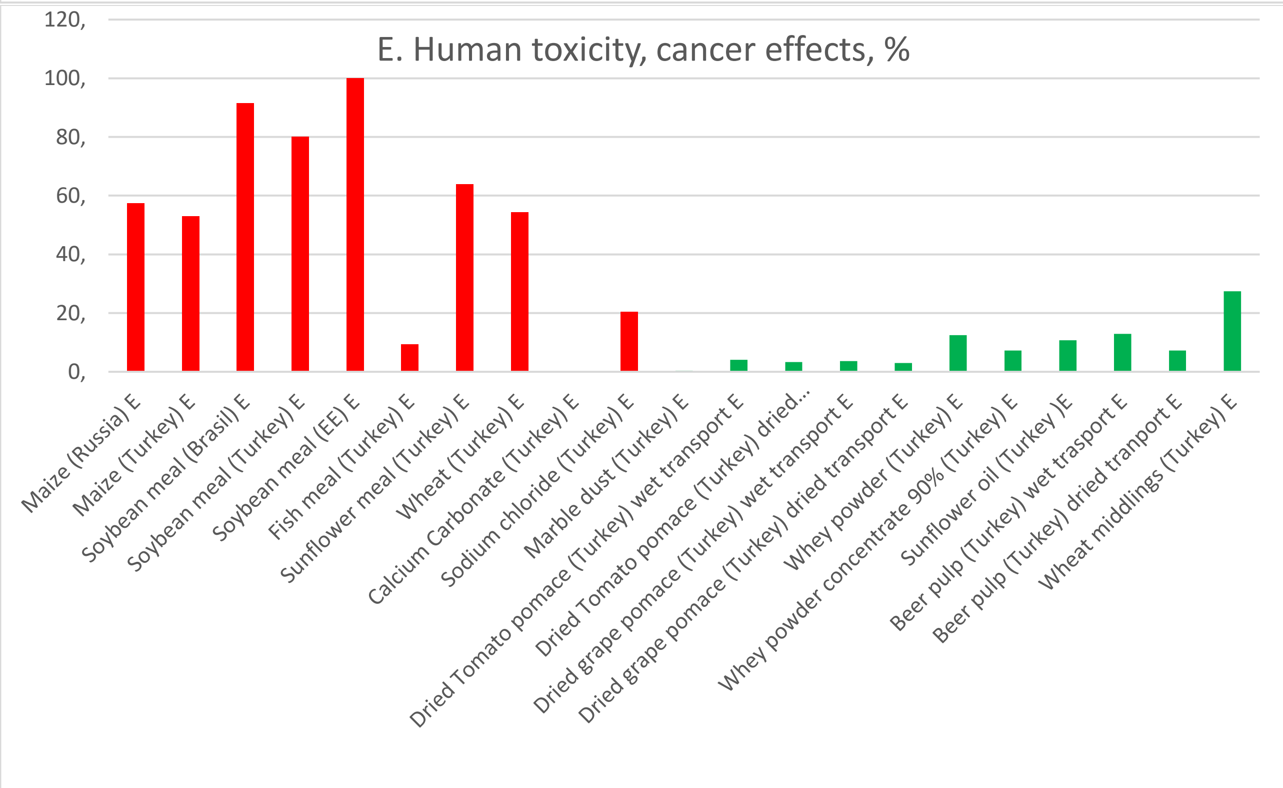
Figure 19. (Annex I). Environmental impact obtained with ILCD method on Climate change (A), Acidification (B), Land use (C), Marine eutrophication (D), Human toxicity, cancer effects € and non-cancer effects (F), from ingredients provided by Turkish pilot. Origin is indicated in parentheses. EE: Europe Eastern. The units are percentages with respect to the highest impact, which is considered 100%. Red: Usual ingredients. Green: alternative ingredients.

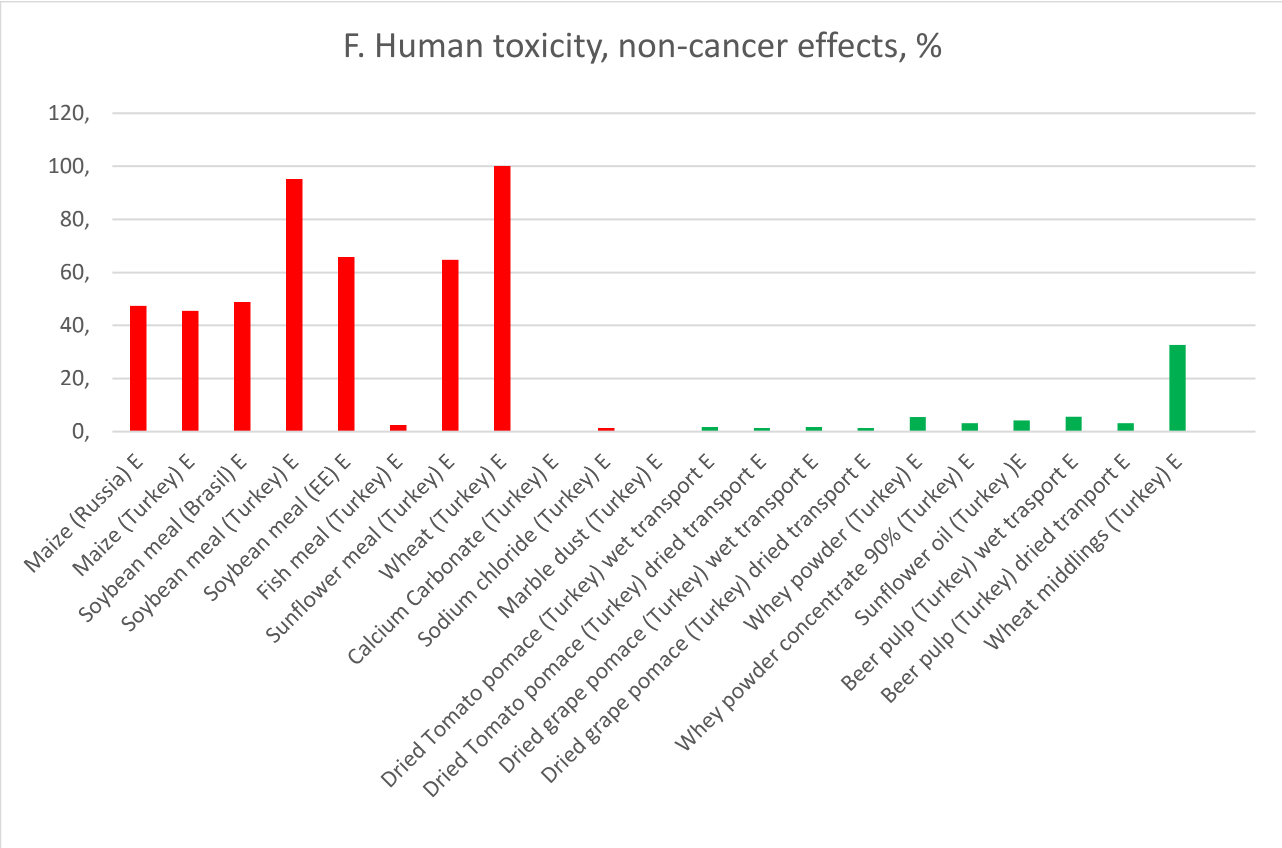



B. Acidification, %
120,
100,
80,
60,
40,
20,
0,
Maize (Russia) E
Maize (Turkey) E
Soybean meal (Brasil) E
Soybean meal (Turkey) E
Soybean meal (EE) E
Fish meal (Turkey) E
Sunflower meal (Turkey) E
Wheat (Turkey) E
Calcium Carbonate (Turkey) E
Sodium chloride (Turkey) E
Marble dust (Turkey) E
Dried Tomato pomace (Turkey) wet transport E
Dried Tomato pomace (Turkey) dried transport E
Dried grape pomace (Turkey) wet transport E
Dried grape pomace (Turkey) dried transport E
Whey powder (Turkey) E
Whey powder concentrate 90% (Turkey) E
Sunflower oil (Turkey)E
Beer pulp (Turkey) wet trasport E
Beer pulp (Turkey) dried tranport E
Wheat middlings (Turkey) E


C. Land use, %
120,
100,
80,
60,
40,
20,
0,
Maize (Russia) E
Maize (Turkey) E
Soybean meal (Brasil) E
Soybean meal (Turkey) E
Soybean meal (EE) E
Fish meal (Turkey) E
Sunflower meal (Turkey) E
Wheat (Turkey) E
Calcium Carbonate (Turkey) E
Sodium chloride (Turkey) E
Marble dust (Turkey) E
Dried Tomato pomace (Turkey) wet transport E
Dried Tomato pomace (Turkey) dried transport E
Dried grape pomace (Turkey) wet transport E
Dried grape pomace (Turkey) dried transport E
Whey powder (Turkey) E
Whey powder concentrate 90% (Turkey) E
Sunflower oil (Turkey)E
Beer pulp (Turkey) wet trasport E
Beer pulp (Turkey) dried tranport E
Wheat middlings (Turkey) E

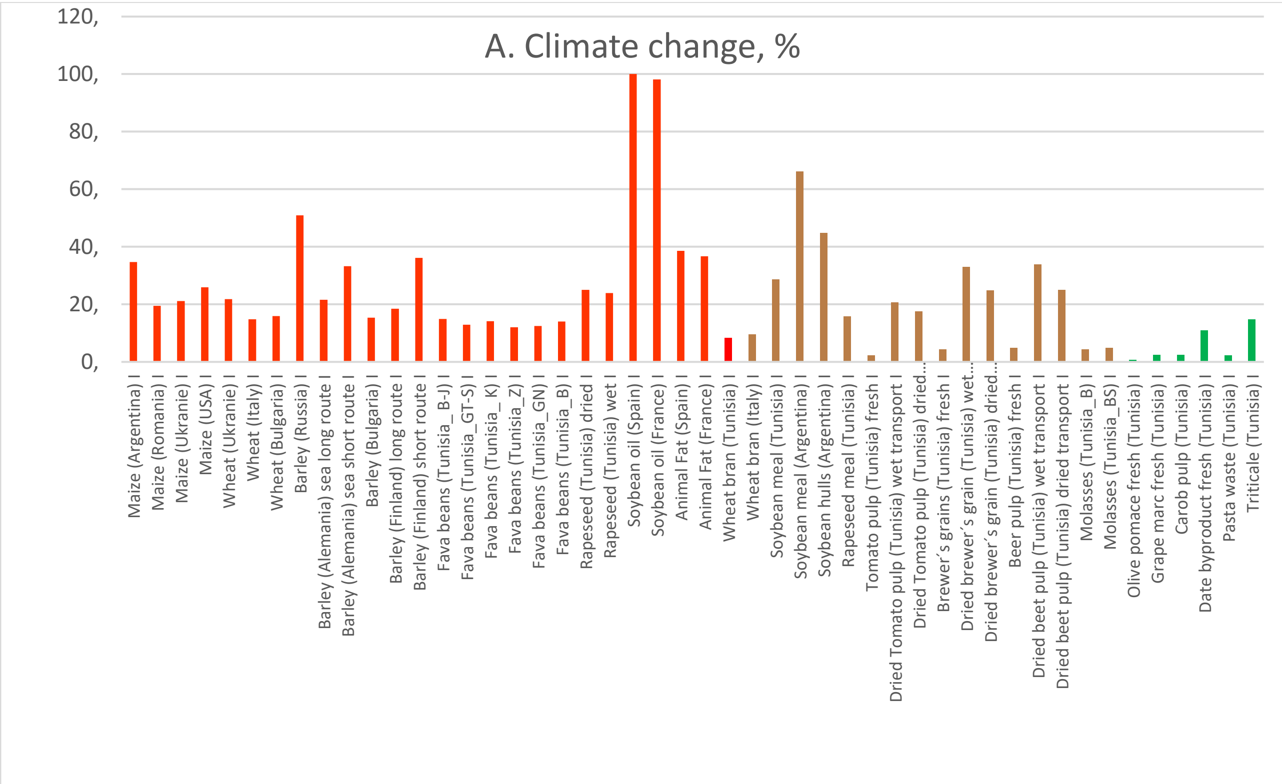

D. Marine eutrophication, %
120,
100,
80,
60,
40,
20,
0,
Maize (Russia) E
Maize (Turkey) E
Soybean meal (Brasil) E
Soybean meal (Turkey) E
Soybean meal (EE) E
Fish meal (Turkey) E
Sunflower meal (Turkey) E
Wheat (Turkey) E
Calcium Carbonate (Turkey) E
Sodium chloride (Turkey) E
Marble dust (Turkey) E
Dried Tomato pomace (Turkey) wet transport E
Dried Tomato pomace (Turkey) dried transport E
Dried grape pomace (Turkey) wet transport E
Dried grape pomace (Turkey) dried transport E
Whey powder (Turkey) E
Whey powder concentrate 90% (Turkey) E
Sunflower oil (Turkey)E
Beer pulp (Turkey) wet trasport E
Beer pulp (Turkey) dried tranport E
Wheat middlings (Turkey) E

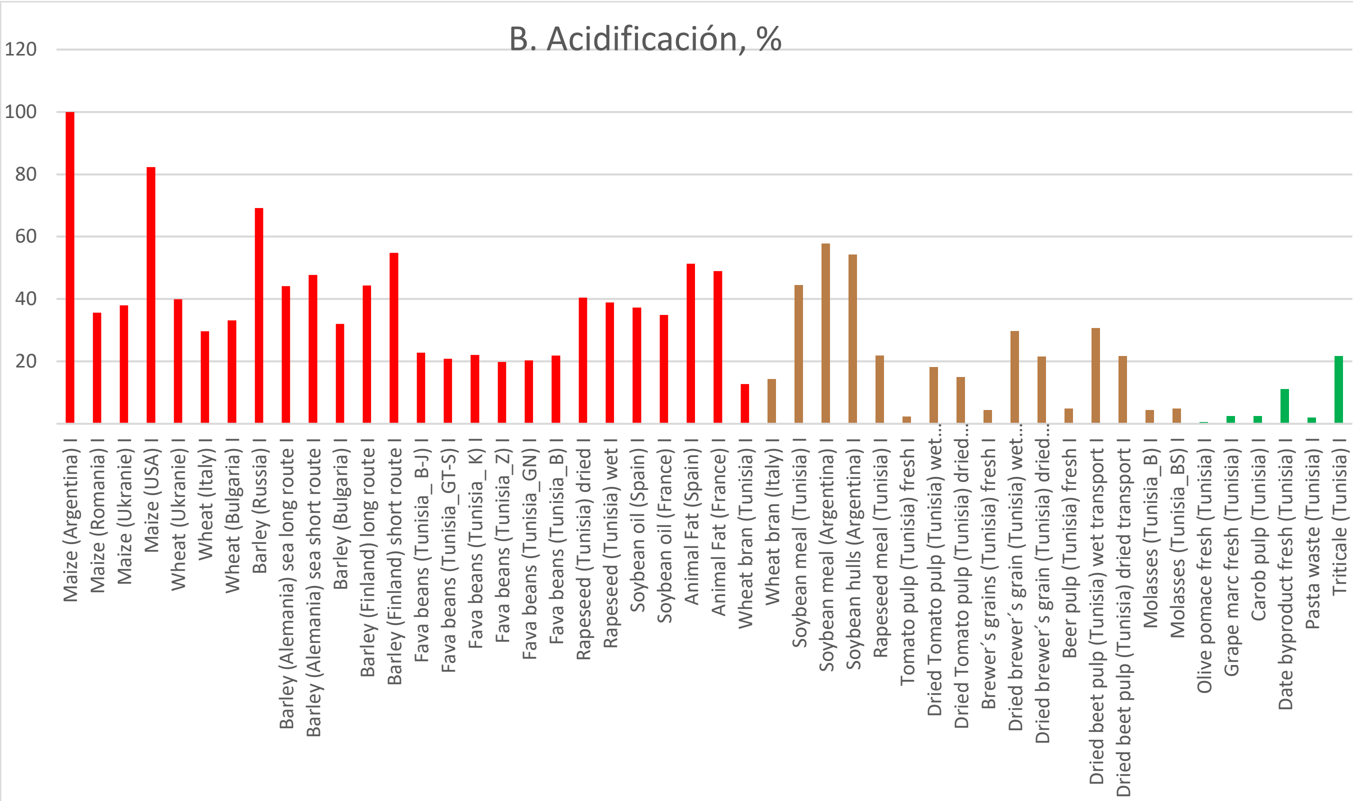

E. Human toxicity, cancer effects, %
120,
100,
80,
60,
40,
20,
0,
Maize (Russia) E
Maize (Turkey) E
Soybean meal (Brasil) E
Soybean meal (Turkey) E
Soybean meal (EE) E
Fish meal (Turkey) E
Sunflower meal (Turkey) E
Wheat (Turkey) E
Calcium Carbonate (Turkey) E
Sodium chloride (Turkey) E
Marble dust (Turkey) E
Dried Tomato pomace (Turkey) wet transport E
Dried Tomato pomace (Turkey) dried...
Dried grape pomace (Turkey) wet transport E
Dried grape pomace (Turkey) dried transport E
Whey powder (Turkey) E
Whey powder concentrate 90% (Turkey) E
Sunflower oil (Turkey)E
Beer pulp (Turkey) wet trasport E
Beer pulp (Turkey) dried tranport E
Wheat middlings (Turkey) E

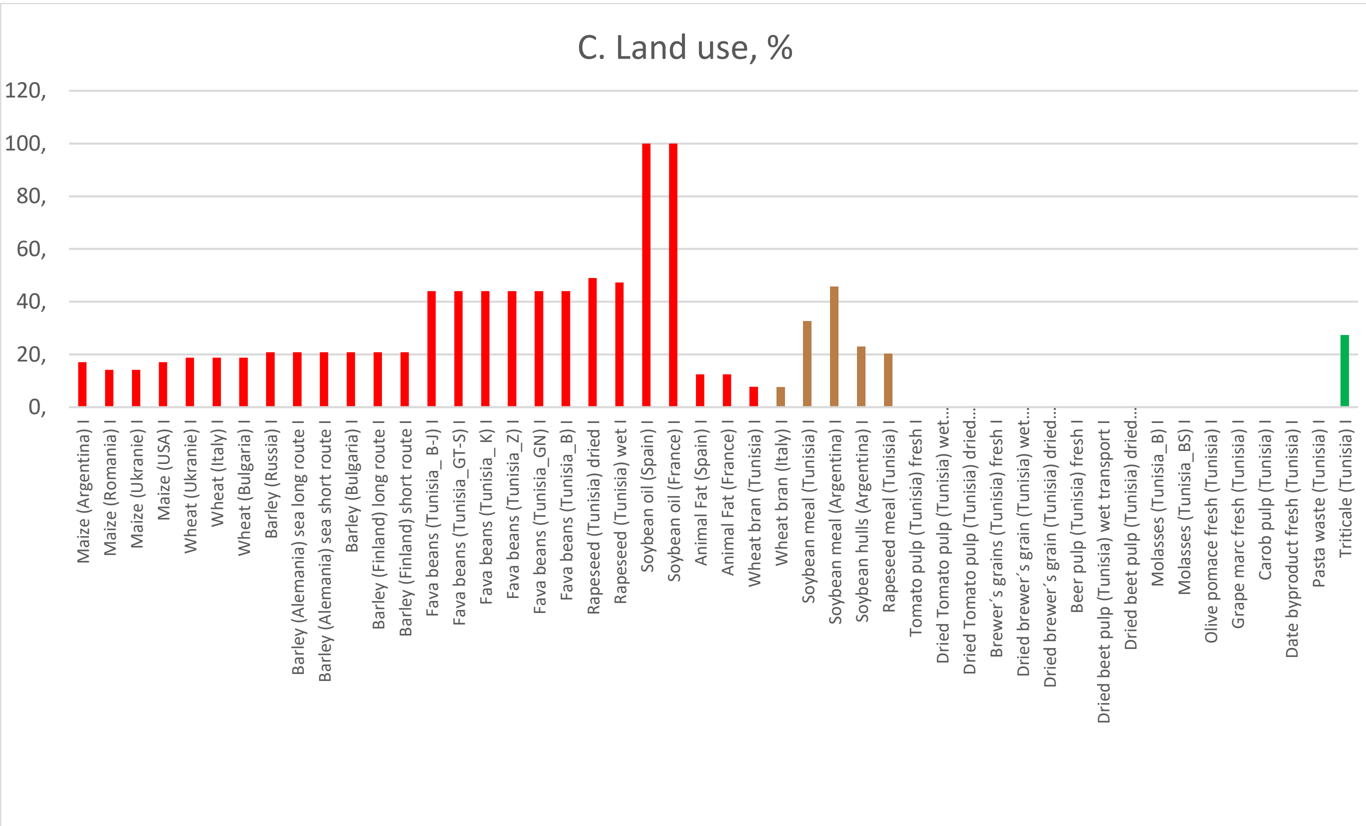

F. Human toxicity, non-cancer effects, %
120,
100,
80,
60,
40,
20,
0,
Maize (Russia) E
Maize (Turkey) E
Soybean meal (Brasil) E
Soybean meal (Turkey) E
Soybean meal (EE) E
Fish meal (Turkey) E
Sunflower meal (Turkey) E
Wheat (Turkey) E
Calcium Carbonate (Turkey) E
Sodium chloride (Turkey) E
Marble dust (Turkey) E
Dried Tomato pomace (Turkey) wet transport E
Dried Tomato pomace (Turkey) dried transport E
Dried grape pomace (Turkey) wet transport E
Dried grape pomace (Turkey) dried transport E
Whey powder (Turkey) E
Whey powder concentrate 90% (Turkey) E
Sunflower oil (Turkey)E
Beer pulp (Turkey) wet trasport E
Beer pulp (Turkey) dried tranport E
Wheat middlings (Turkey) E

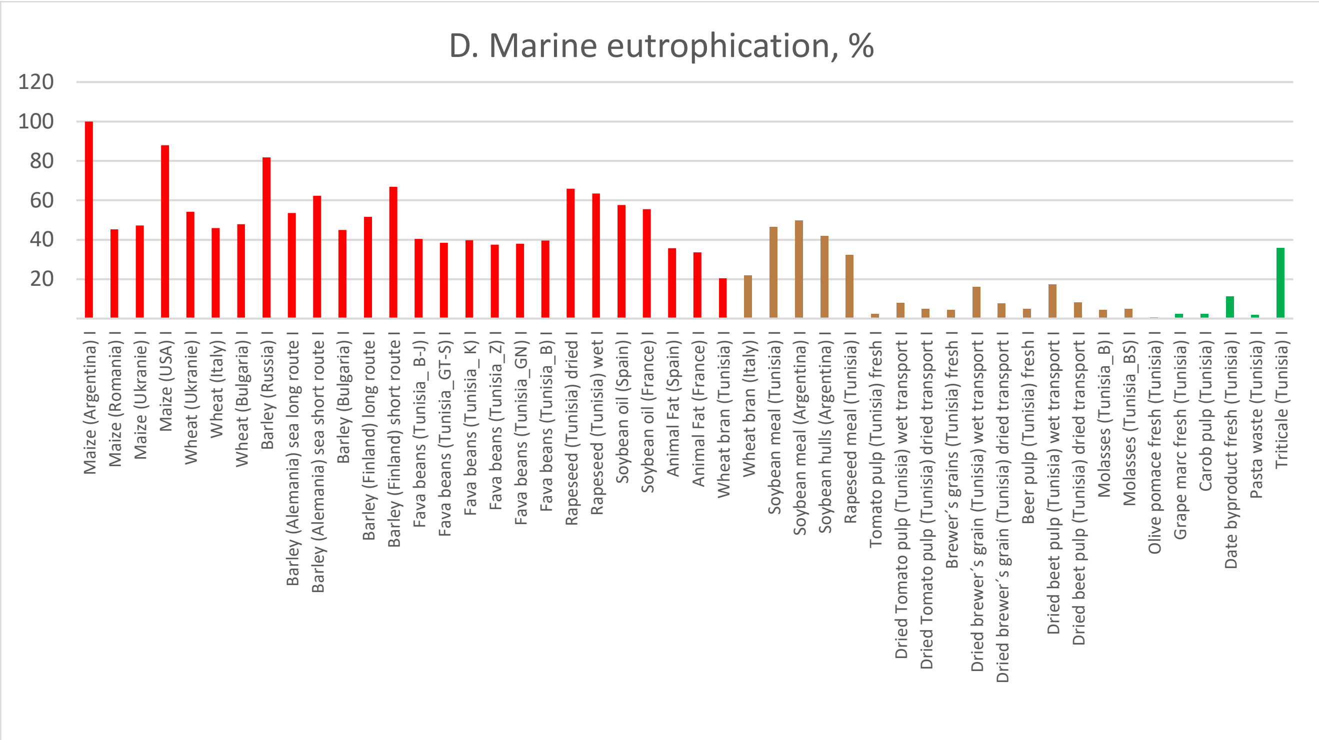
TUNISIAN PILOT

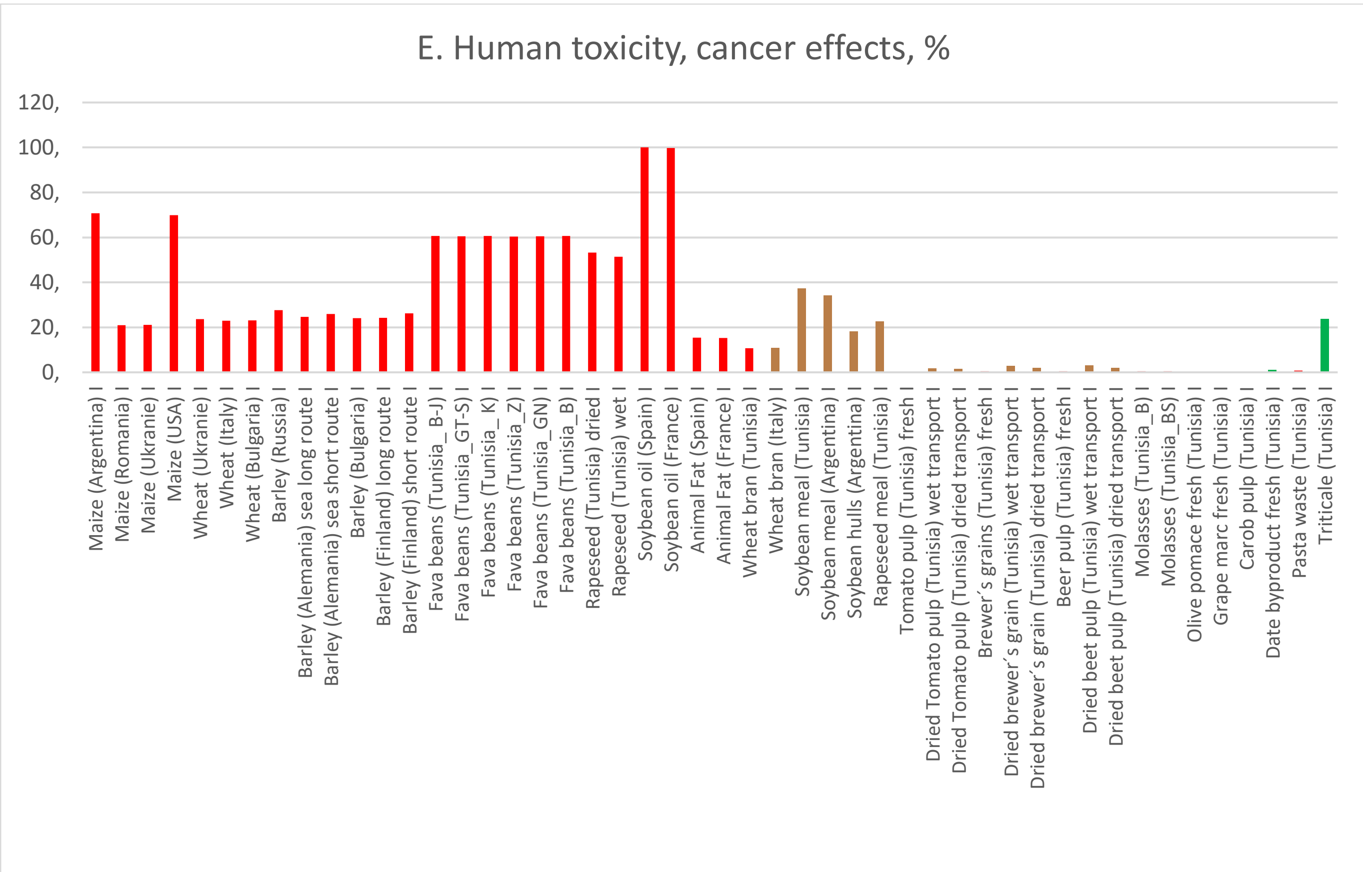
Figure 20. (Annex I). Environmental impact obtained with ILCD method on Climate change (A), Acidification (B), Land use (C), Marine eutrophication (D), Human toxicity, cancer effects (E) and non-cancer effects (F), from ingredients provided by Tunisian pilot. Origin is indicated in parentheses: EE: Eastern Europe; Tunisia_B-J: from Bèja-Jendouba; Tunisia_GT-S:from Gran Tunis and Siliana; Tunisia_K: from Kef; Tunisia_Z: from Zaghouan; Tunisia_GN: from Governorate Nabeul; Tunisia_B: from Bèja; Tunisia_BS: from Ben Bèchir-Bou Salem. The units are percentages with respect to the highest impact, which is considered 100%. Red: Usual ingredients. Brown: usual/alternative subproducts. Green: Other alternative ingredients.

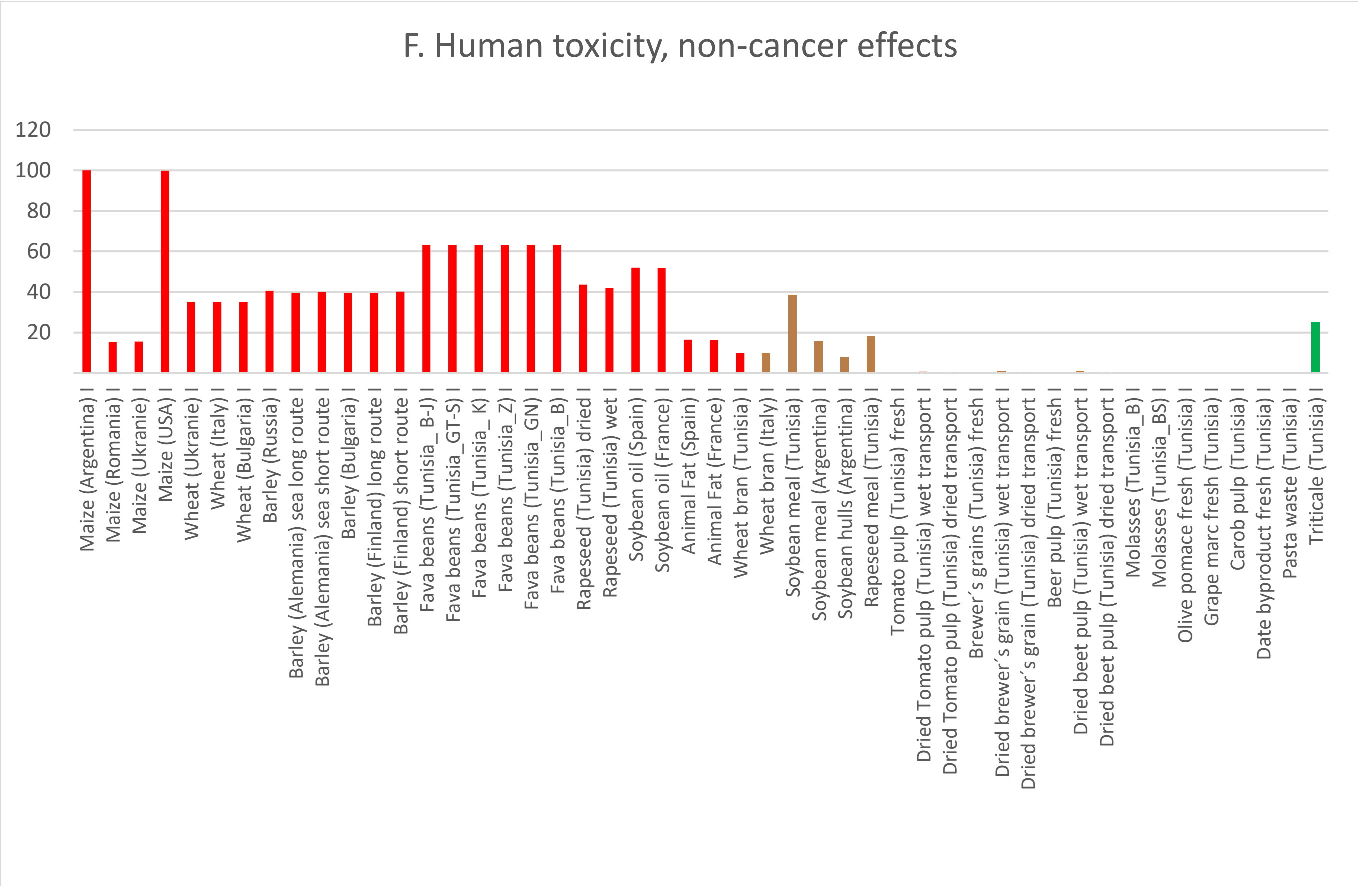



B. Acidificación, %
120
100
80
60
40
20
Maize (Argentina)
Maize (Romania)
Maize (Ukranie)
Maize (USA)
Wheat (Ukranie)
Wheat (Italy)
Wheat (Bulgaria)
Barley (Russia)
Barley (Alemania) sea long route
Barley (Alemania) sea short route
Barley (Bulgaria)
Barley (Finland) long route
Barley (Finland) short route
Fava beans (Tunisia_B-J)
Fava beans (Tunisia_GT-S)
Fava beans (Tunisia_K)
Fava beans (Tunisia_Z)
Fava beans (Tunisia_GN)
Fava beans (Tunisia_B)
Rapeseed (Tunisia) dried
Rapeseed (Tunisia) wet
Soybean oil (Spain)
Soybean oil (France)
Animal Fat (Spain)
Animal Fat (France)
Wheat bran (Tunisia)
Wheat bran (Italy)
Soybean meal (Tunisia)
Soybean meal (Argentina)
Soybean hulls (Argentina)
Rapeseed meal (Tunisia)
Tomato pulp (Tunisia) fresh
Dried Tomato pulp (Tunisia) wet...
Dried Tomato pulp (Tunisia) dried...
Brewer´s grains (Tunisia) fresh
Dried brewer´s grain (Tunisia) wet...
Dried brewer´s grain (Tunisia) dried...
Beer pulp (Tunisia) fresh
Dried beet pulp (Tunisia) wet transport
Dried beet pulp (Tunisia) dried transport
Molasses (Tunisia_B)
Molasses (Tunisia_BS)
Olive pomace fresh (Tunisia)
Grape marc fresh (Tunisia)
Carob pulp (Tunisia)
Date byproduct fresh (Tunisia)
Pasta waste (Tunisia)
Triticale (Tunisia)


C. Land use, %
120,
100,
80,
60,
40,
20,
0,
Maize (Argentina)
Maize (Romania)
Maize (Ukranie)
Maize (USA)
Wheat (Ukranie)
Wheat (Italy)
Wheat (Bulgaria)
Barley (Russia)
Barley (Alemania) sea long route
Barley (Alemania) sea short route
Barley (Bulgaria)
Barley (Finland) long route
Barley (Finland) short route
Fava beans (Tunisia_B-J)
Fava beans (Tunisia_GT-S)
Fava beans (Tunisia_K)
Fava beans (Tunisia_Z)
Fava beans (Tunisia_GN)
Fava beans (Tunisia_B)
Rapeseed (Tunisia) dried
Rapeseed (Tunisia) wet
Soybean oil (Spain)
Soybean oil (France)
Animal Fat (Spain)
Animal Fat (France)
Wheat bran (Tunisia)
Wheat bran (Italy)
Soybean meal (Tunisia)
Soybean meal (Argentina)
Soybean hulls (Argentina)
Rapeseed meal (Tunisia)
Tomato pulp (Tunisia) fresh
Dried Tomato pulp (Tunisia) wet...
Dried Tomato pulp (Tunisia) dried...
Brewer´s grains (Tunisia) fresh
Dried brewer´s grain (Tunisia) wet...
Dried brewer´s grain (Tunisia) dried...
Beer pulp (Tunisia) fresh
Dried beet pulp (Tunisia) wet transport
Dried beet pulp (Tunisia) dried...
Molasses (Tunisia_B)
Molasses (Tunisia_BS)
Olive pomace fresh (Tunisia)
Grape marc fresh (Tunisia)
Carob pulp (Tunisia)
Date byproduct fresh (Tunisia)
Pasta waste (Tunisia)
Triticale (Tunisia)

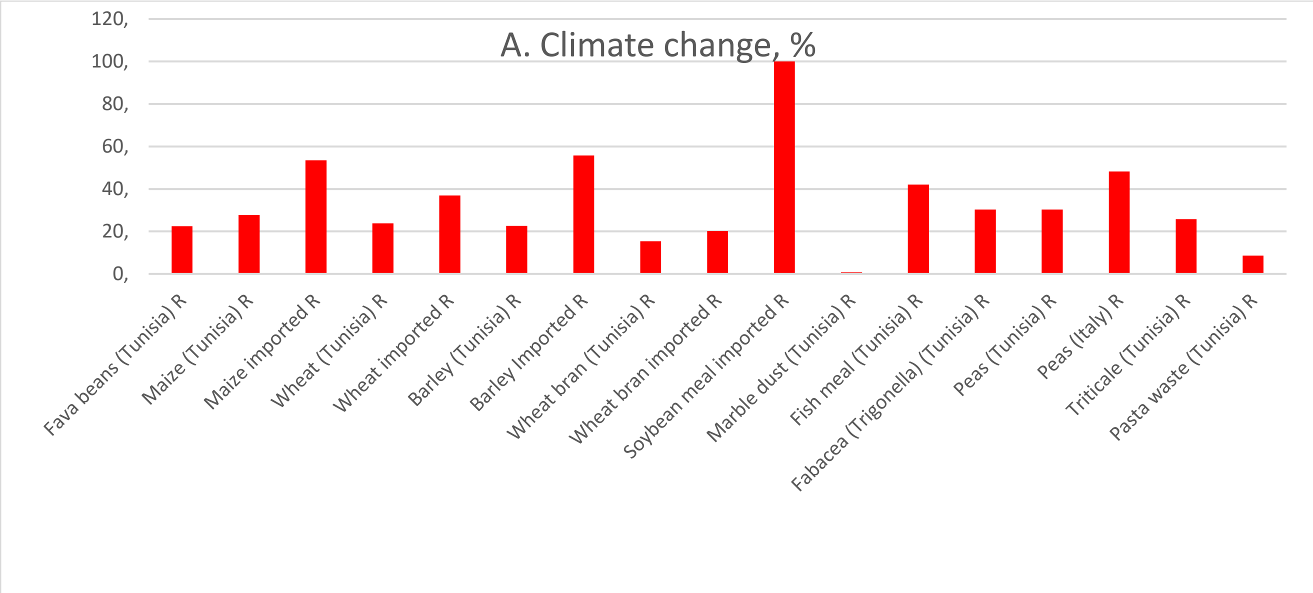

D. Marine eutrophication, %
120
100
80
60
40
20
Maize (Argentina)
Maize (Romania)
Maize (Ukranie)
Maize (USA)
Wheat (Ukranie)
Wheat (Italy)
Wheat (Bulgaria)
Barley (Russia)
Barley (Alemania) sea long route
Barley (Alemania) sea short route
Barley (Bulgaria)
Barley (Finland) long route
Barley (Finland) short route
Fava beans (Tunisia_B-J)
Fava beans (Tunisia_GT-S)
Fava beans (Tunisia_K)
Fava beans (Tunisia_Z)
Fava beans (Tunisia_GN)
Fava beans (Tunisia_B)
Rapeseed (Tunisia) dried
Rapeseed (Tunisia) wet
Soybean oil (Spain)
Soybean oil (France)
Animal Fat (Spain)
Animal Fat (France)
Wheat bran (Tunisia)
Wheat bran (Italy)
Soybean meal (Tunisia)
Soybean meal (Argentina)
Soybean hulls (Argentina)
Rapeseed meal (Tunisia)
Tomato pulp (Tunisia) fresh
Dried Tomato pulp (Tunisia) wet transport
Dried Tomato pulp (Tunisia) dried transport
Brewer´s grains (Tunisia) fresh
Dried brewer´s grain (Tunisia) wet transport
Dried brewer´s grain (Tunisia) dried transport
Beer pulp (Tunisia) fresh
Dried beet pulp (Tunisia) wet transport
Dried beet pulp (Tunisia) dried transport
Molasses (Tunisia_B)
Molasses (Tunisia_BS)
Olive pomace fresh (Tunisia)
Grape marc fresh (Tunisia)
Carob pulp (Tunisia)
Date byproduct fresh (Tunisia)
Pasta waste (Tunisia)
Triticale (Tunisia)

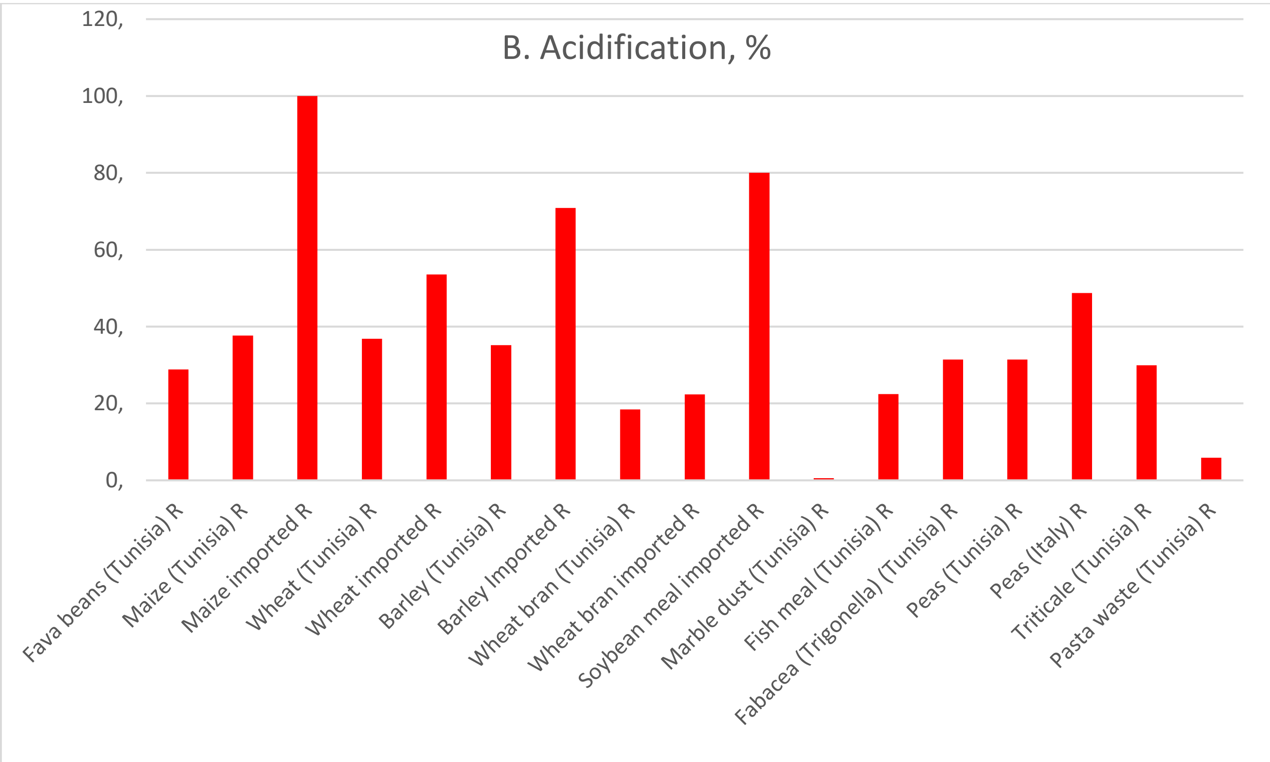

E. Human toxicity, cancer effects, %
120,
100,
80,
60,
40,
20,
0,
Maize (Argentina)
Maize (Romania)
Maize (Ukranie)
Maize (USA)
Wheat (Ukranie)
Wheat (Italy)
Wheat (Bulgaria)
Barley (Russia)
Barley (Alemania) sea long route
Barley (Alemania) sea short route
Barley (Bulgaria)
Barley (Finland) long route
Barley (Finland) short route
Fava beans (Tunisia_B-J)
Fava beans (Tunisia_GT-S)
Fava beans (Tunisia_K)
Fava beans (Tunisia_Z)
Fava beans (Tunisia_GN)
Fava beans (Tunisia_B)
Rapeseed (Tunisia) dried
Rapeseed (Tunisia) wet
Soybean oil (Spain)
Soybean oil (France)
Animal Fat (Spain)
Animal Fat (France)
Wheat bran (Tunisia)
Wheat bran (Italy)
Soybean meal (Tunisia)
Soybean meal (Argentina)
Soybean hulls (Argentina)
Rapeseed meal (Tunisia)
Tomato pulp (Tunisia) fresh
Dried Tomato pulp (Tunisia) wet transport
Dried Tomato pulp (Tunisia) dried transport
Brewer´s grains (Tunisia) fresh
Dried brewer´s grain (Tunisia) wet transport
Dried brewer´s grain (Tunisia) dried transport
Beer pulp (Tunisia) fresh
Dried beet pulp (Tunisia) wet transport
Dried beet pulp (Tunisia) dried transport
Molasses (Tunisia_B)
Molasses (Tunisia_BS)
Olive pomace fresh (Tunisia)
Grape marc fresh (Tunisia)
Carob pulp (Tunisia)
Date byproduct fresh (Tunisia)
Pasta waste (Tunisia)
Triticale (Tunisia)

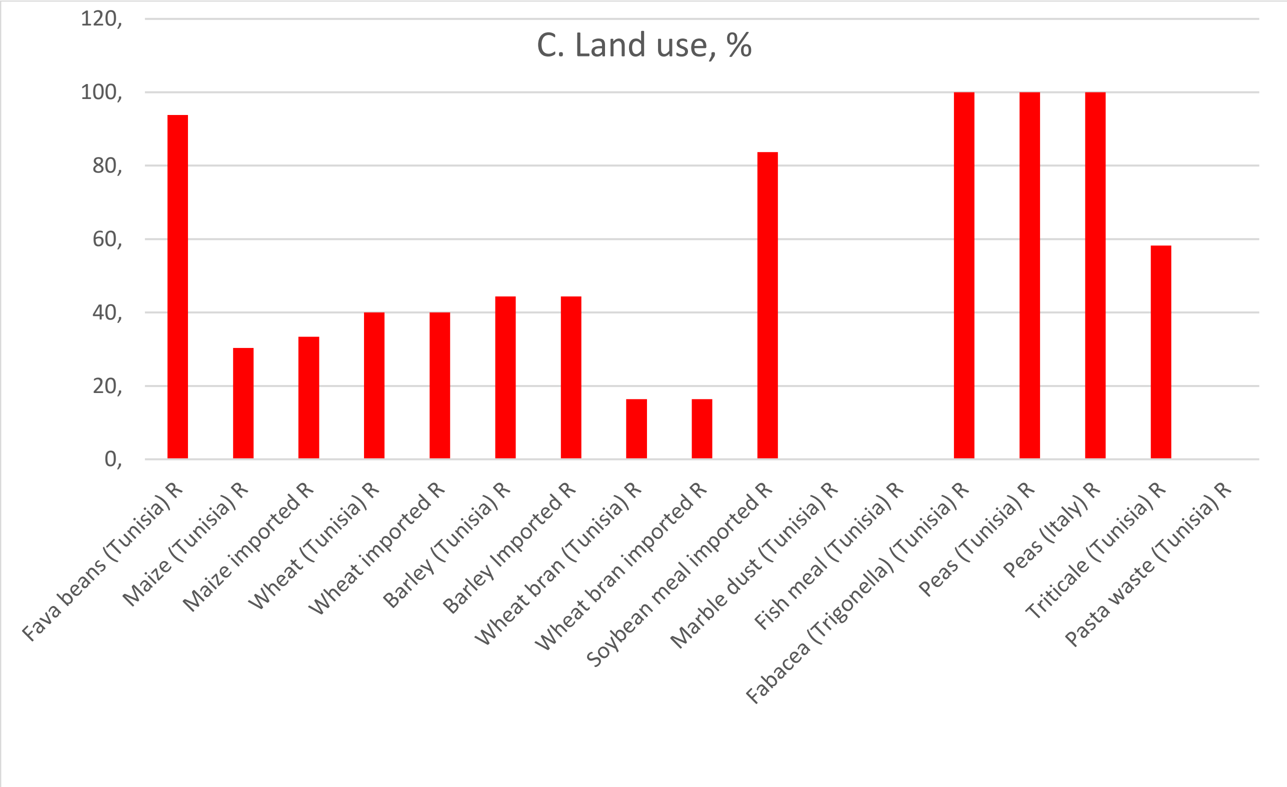

F. Human toxicity, non-cancer effects
120
100
80
60
40
20
Maize (Argentina) I
Maize (Romania) I
Maize (Ukranie) I
Maize (USA) I
Wheat (Ukranie) I
Wheat (Italy) I
Wheat (Bulgaria) I
Barley (Russia) I
Barley (Alemania) sea long route
Barley (Alemania) sea short route
Barley (Bulgaria) I
Barley (Finland) long route I
Barley (Finland) short route I
Fava beans (Tunisia_ B-J) I
Fava beans (Tunisia_GT-S) I
Fava beans (Tunisia_ K) I
Fava beans (Tunisia_Z) I
Fava beans (Tunisia_GN) I
Fava beans (Tunisia_B) I
Rapeseed (Tunisia) dried
Rapeseed (Tunisia) wet
Soybean oil (Spain) I
Soybean oil (France) I
Animal Fat (Spain) I
Animal Fat (France) I
Wheat bran (Tunisia) I
Wheat bran (Italy) I
Soybean meal (Tunisia) I
Soybean meal (Argentina) I
Soybean hulls (Argentina) I
Rapeseed meal (Tunisia) I
Tomato pulp (Tunisia) fresh
Dried Tomato pulp (Tunisia) wet transport I
Dried Tomato pulp (Tunisia) dried transport I
Brewer´s grains (Tunisia) fresh I
Dried brewer´s grain (Tunisia) wet transport I
Dried brewer´s grain (Tunisia) dried transport I
Beer pulp (Tunisia) fresh
Dried beet pulp (Tunisia) wet transport I
Dried beet pulp (Tunisia) dried transport I
Molasses (Tunisia_B) I
Molasses (Tunisia_BS) I
Olive pomace fresh (Tunisia) I
Grape marc fresh (Tunisia) I
Carob pulp (Tunisia) I
Date byproduct fresh (Tunisia) I
Pasta waste (Tunisia) I
Triticale (Tunisia) I

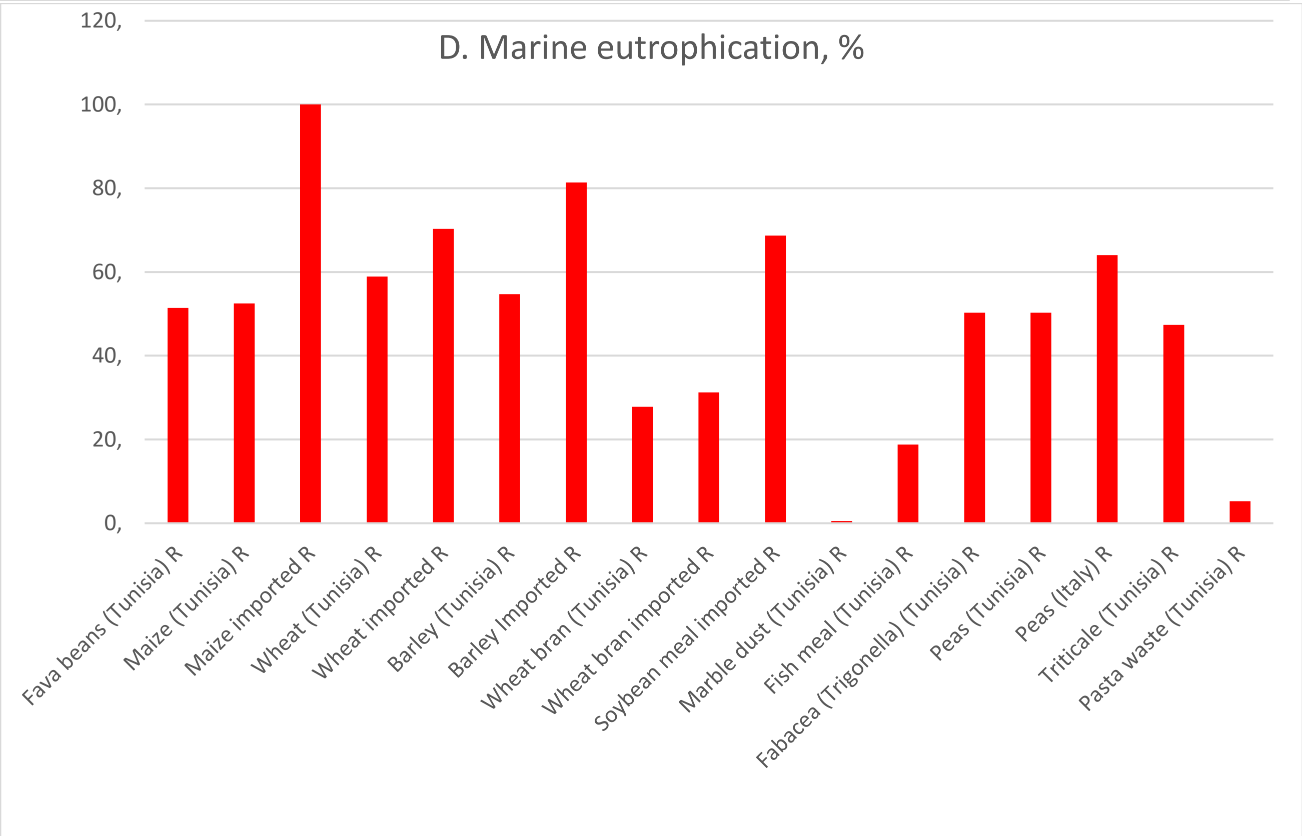
TUNISIA PILOT (RAYHANA)

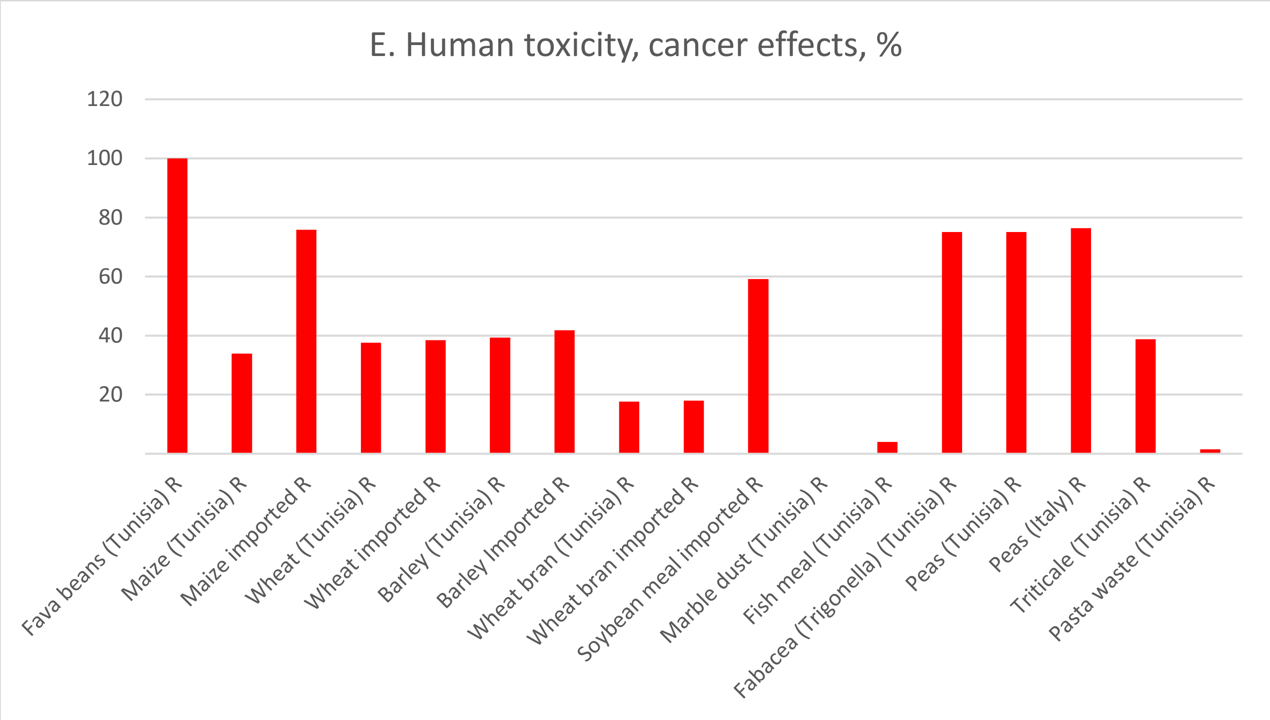
Figure 21. (Annex I). Environmental impact obtained with ILCD method on Climate change (A), Acidification (B), Land use (C), Marine eutrophication (D), Human toxicity, cancer effects € and non-cancer effects (F), from ingredients provided by Tunisian pilot (Rayhana). Origin is indicated in parentheses: The units are percentages with respect to the highest impact, which is considered 100%. Red: Usual ingredients. Green: alternative ingredients.

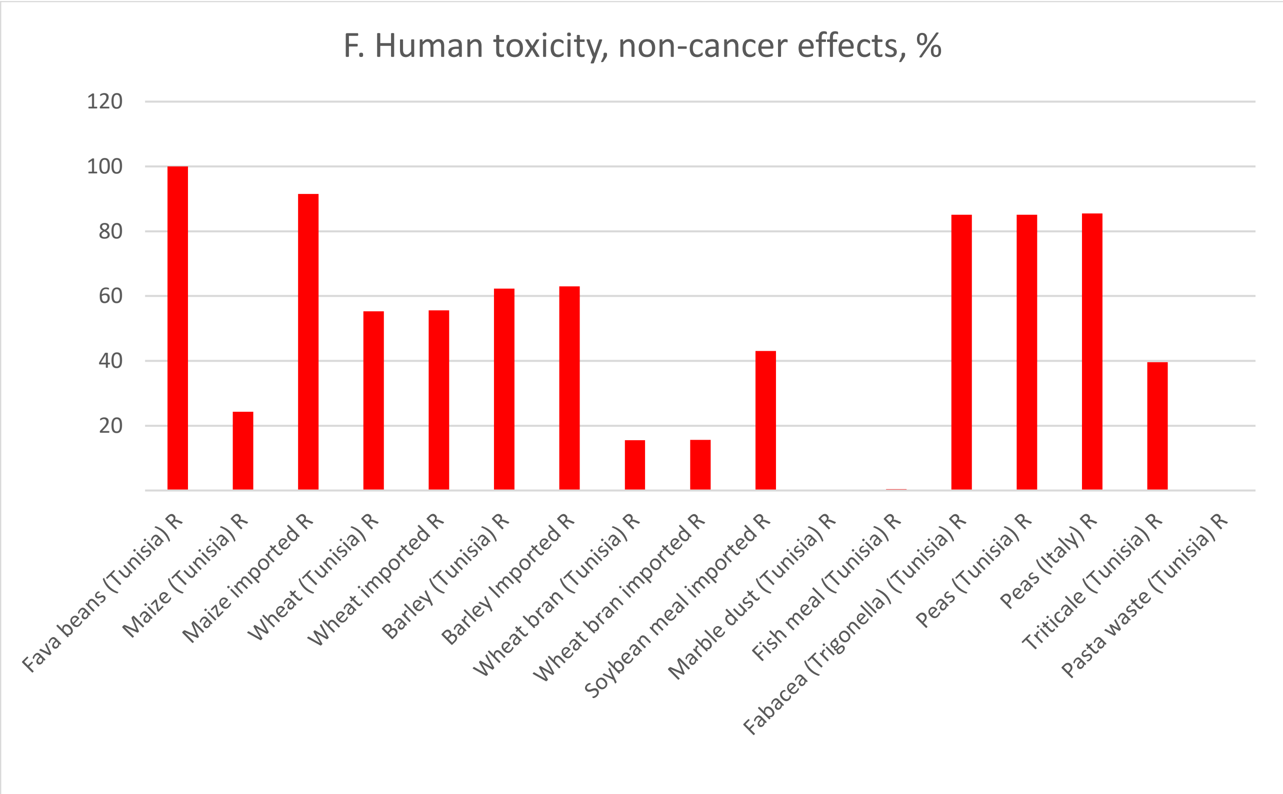





C. Land use, %
120,
100,
80,
60,
40,
20,
0,
Fava beans (Tunisia) R
Maize (Tunisia) R
Maize imported R
Wheat (Tunisia) R
Wheat imported R
Barley (Tunisia) R
Barley Imported R
Wheat bran (Tunisia) R
Wheat bran imported R
Soybean meal imported R
Marble dust (Tunisia) R
Fish meal (Tunisia) R
Fabacea (Trigonella) (Tunisia) R
Peas (Tunisia) R
Peas (Italy) R
Triticale (Tunisia) R
Pasta waste (Tunisia) R


D. Marine eutrophication, %
120,
100,
80,
60,
40,
20,
0,
Fava beans (Tunisia) R
Maize (Tunisia) R
Maize imported R
Wheat (Tunisia) R
Wheat imported R
Barley (Tunisia) R
Barley Imported R
Wheat bran (Tunisia) R
Wheat bran imported R
Soybean meal imported R
Marble dust (Tunisia) R
Fish meal (Tunisia) R
Fabacea (Trigonella) (Tunisia) R
Peas (Tunisia) R
Peas (Italy) R
Triticale (Tunisia) R
Pasta waste (Tunisia) R


E. Human toxicity, cancer effects, %
120
100
80
60
40
20
Fava beans (Tunisia) R
Maize (Tunisia) R
Maize imported R
Wheat (Tunisia) R
Wheat imported R
Barley (Tunisia) R
Barley Imported R
Wheat bran (Tunisia) R
Wheat bran imported R
Soybean meal imported R
Marble dust (Tunisia) R
Fish meal (Tunisia) R
Fabacea (Trigonella) (Tunisia) R
Peas (Tunisia) R
Peas (Italy) R
Triticale (Tunisia) R
Pasta waste (Tunisia) R


F. Human toxicity, non-cancer effects, %
120
100
80
60
40
20
Fava beans (Tunisia) R
Maize (Tunisia) R
Maize imported R
Wheat (Tunisia) R
Wheat imported R
Barley (Tunisia) R
Barley Imported R
Wheat bran (Tunisia) R
Wheat bran imported R
Soybean meal imported R
Marble dust (Tunisia) R
Fish meal (Tunisia) R
Fabacea (Trigonella) (Tunisia) R
Peas (Tunisia) R
Peas (Italy) R
Triticale (Tunisia) R
Pasta waste (Tunisia) R

9 Annex II. Environmental Impact with ReCipe 2016 Endpoint (H) method on human health, ecosystem, and resources of the ingredients of the five pilot.

SPAIN PILOT

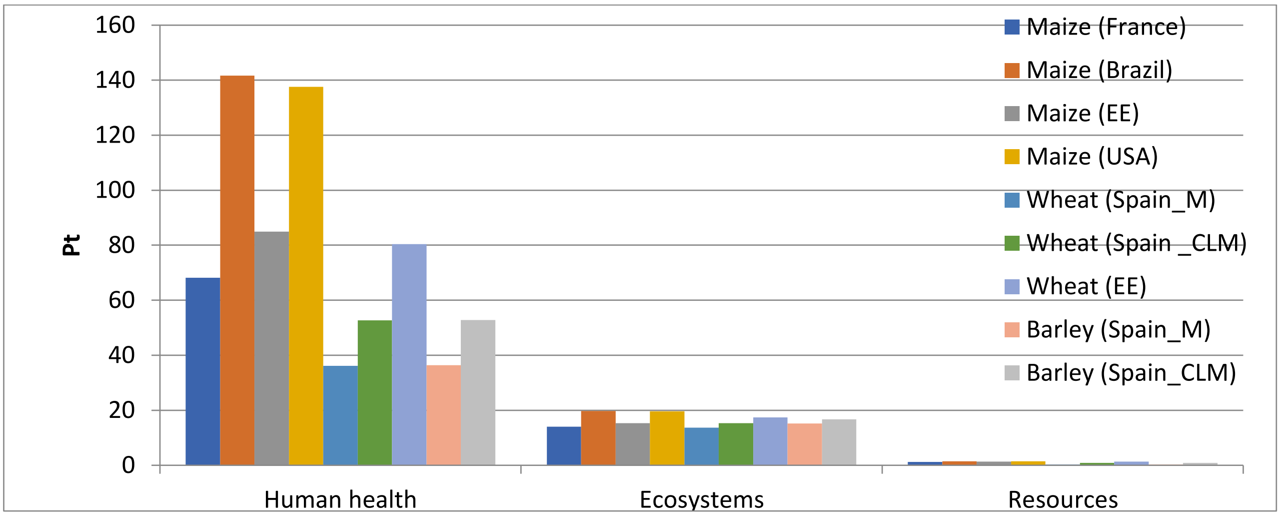


Figure 22. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of cereal grains provided by Spanish pilot. Origin is indicated in parentheses: EE: Eastern Europe, Spain_M: from Murcia, Spain_CLM: from Castilla La Mancha.

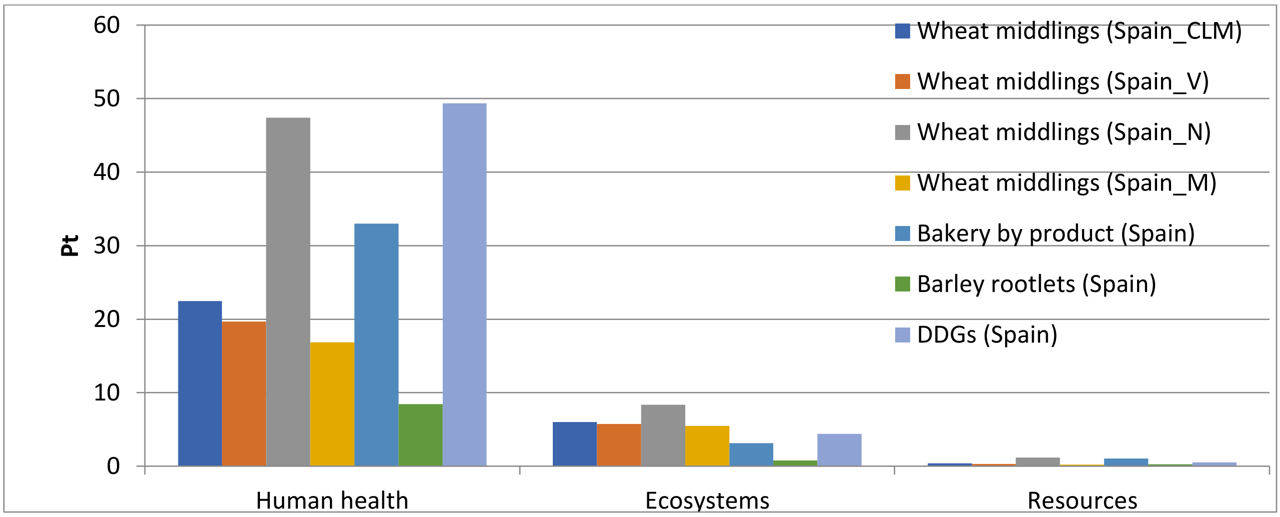


Figure 23. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of by-products cereals provided by Spanish pilot. Origin is indicated in parentheses, Spain_CLM: from Castilla La Mancha. Spain _V: from Valencia, Spain _N: from Navarra, Spain_M: from Murcia.

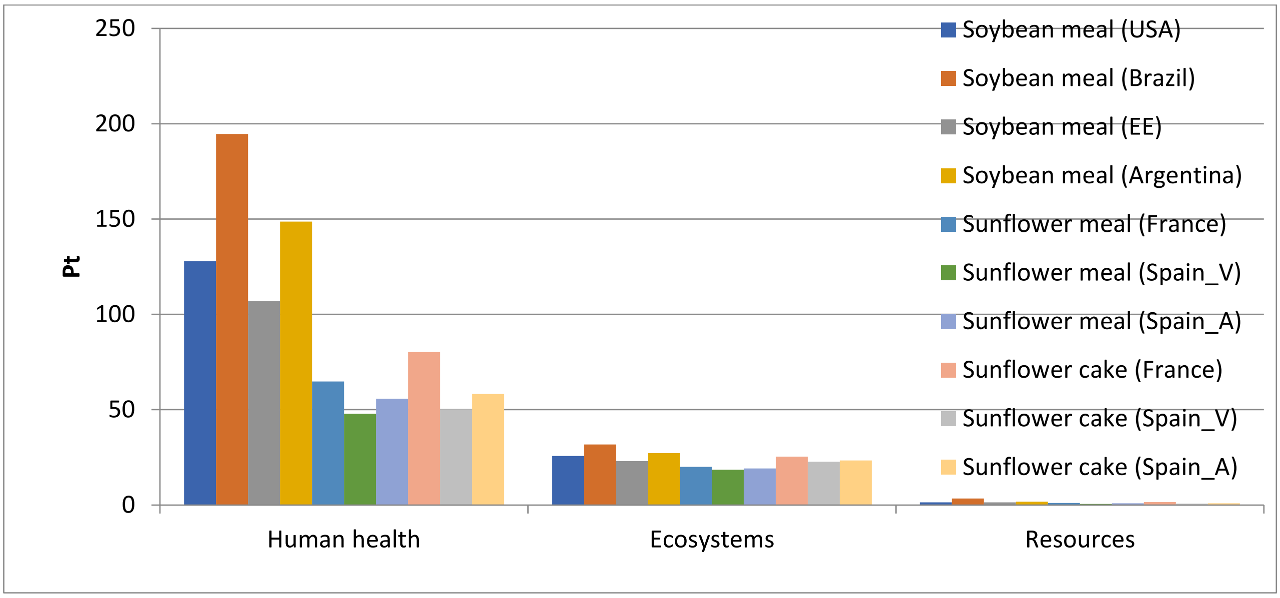


Figure 24. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of protein sources provided by Spanish pilot. Origin is indicated in parentheses: EE: Eastern Europe, Spain_V: from Valencia, Spain_A: from Andalucía.

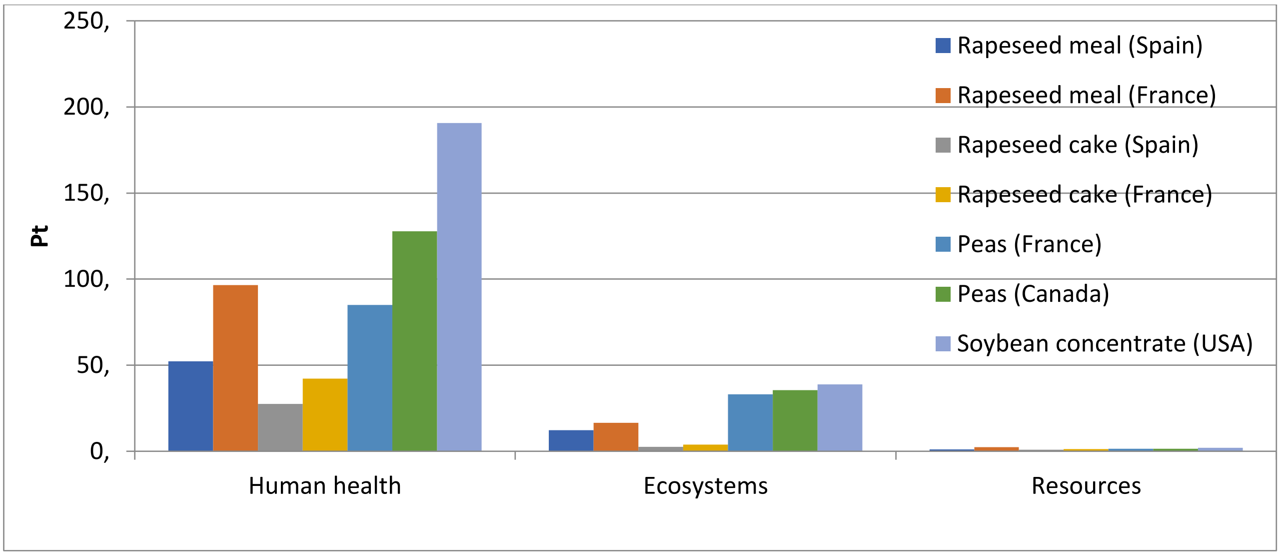


Figure 25. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of other protein sources in Spanish pilot. Origin is indicated in parentheses.

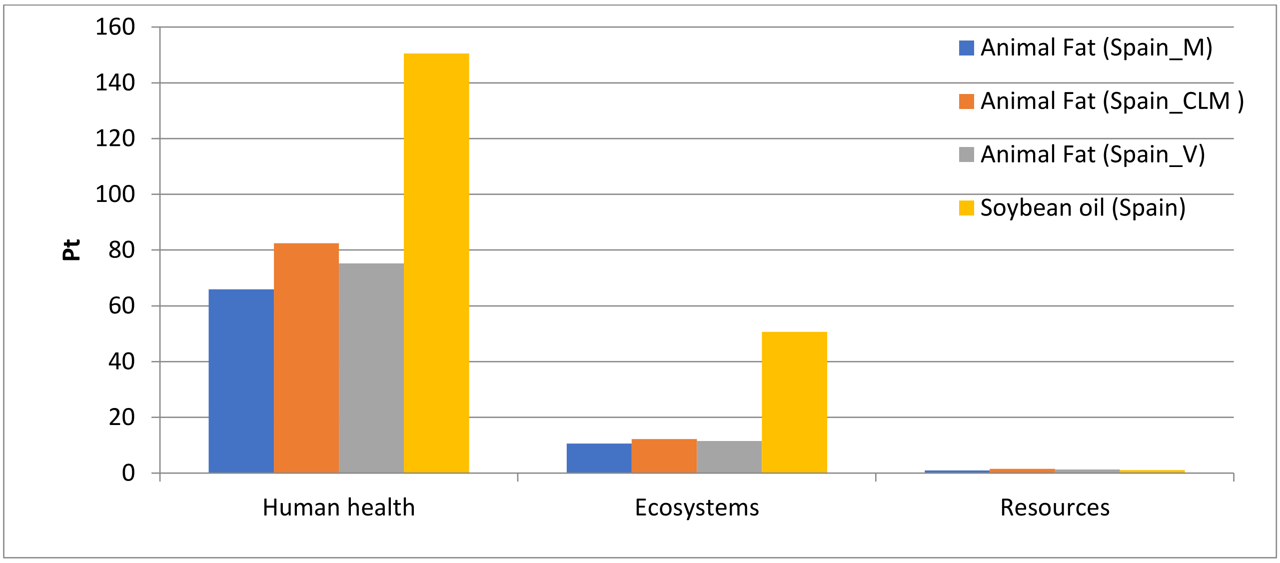


Figure 26. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of fat sources provided by Spanish pilot. Origin is indicated in parentheses: Spain_M: from Murcia, Spain_CLM: from Castilla La Mancha, Spain_V: Valencia.

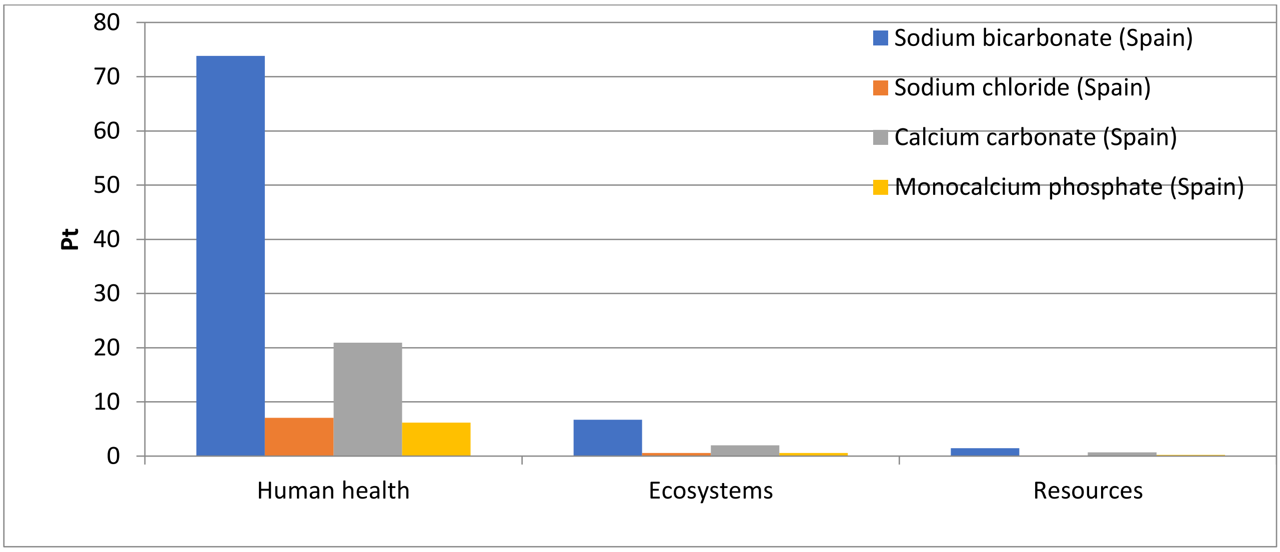


Figure 27. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of mineral sources used in diets provided by Spanish pilot. Origin is indicated in parentheses.

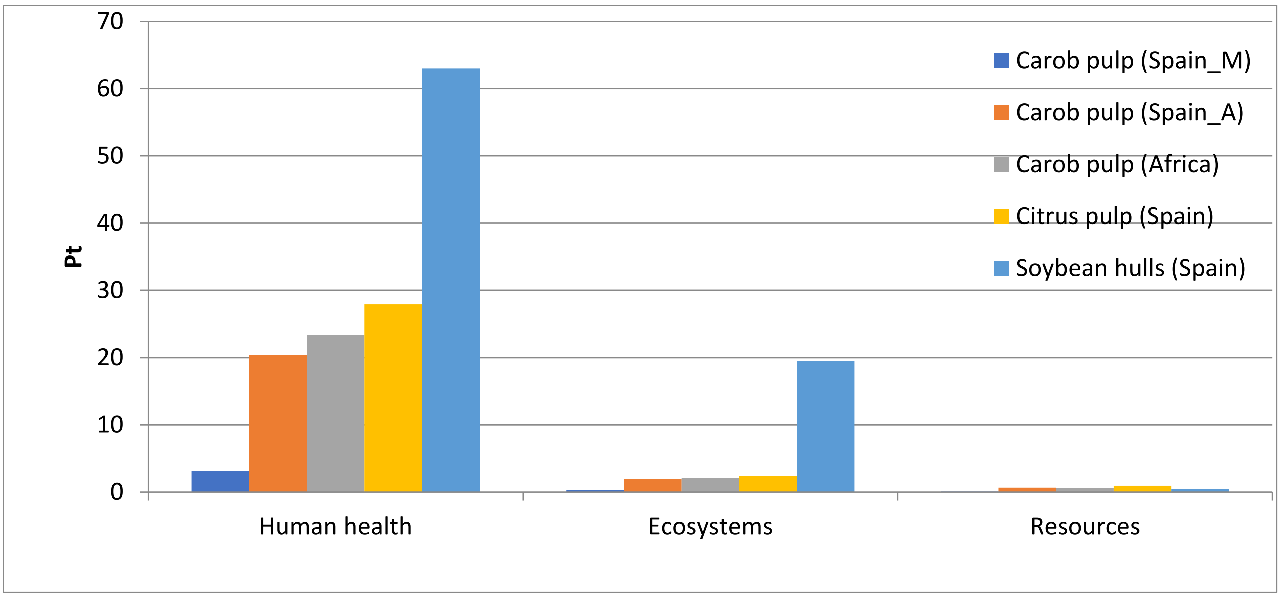


Figure 28. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of alternative ingredients fiber source provided by Spanish pilot. Origin is indicated in parentheses: Spain_M: from Murcia, Spain_A: from Andalucía.

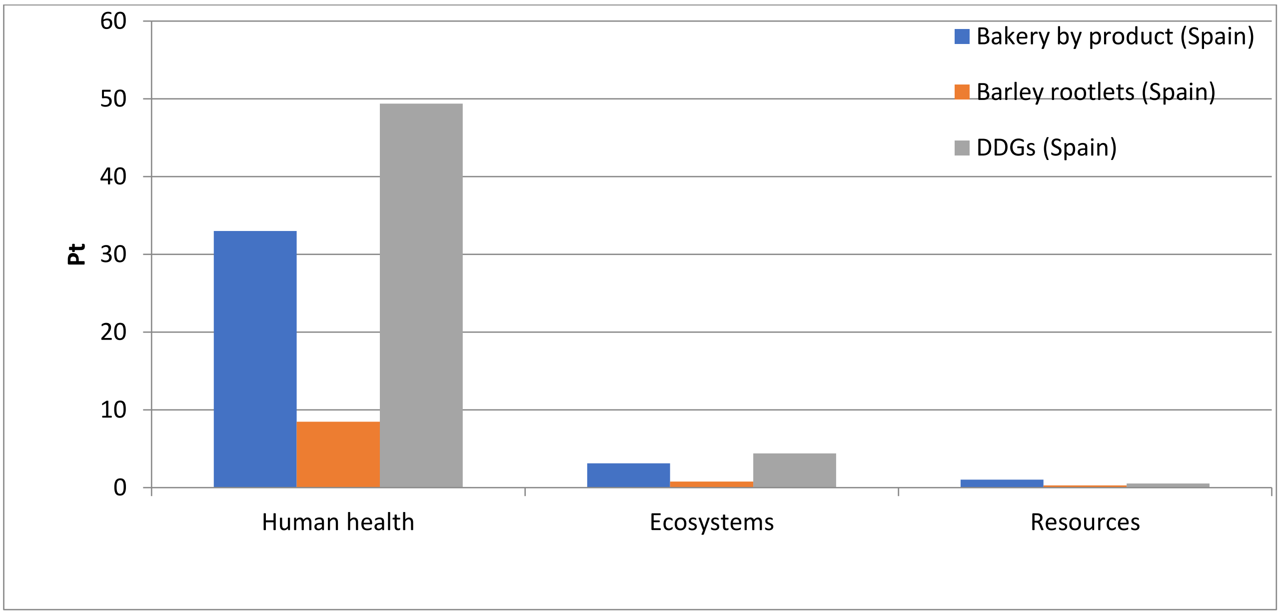


Figure 29. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of cereal by-products ucts provided by Spanish pilot. Origin is indicated in parentheses.

ITALY PILOT (UNITO UNIVERSITY)

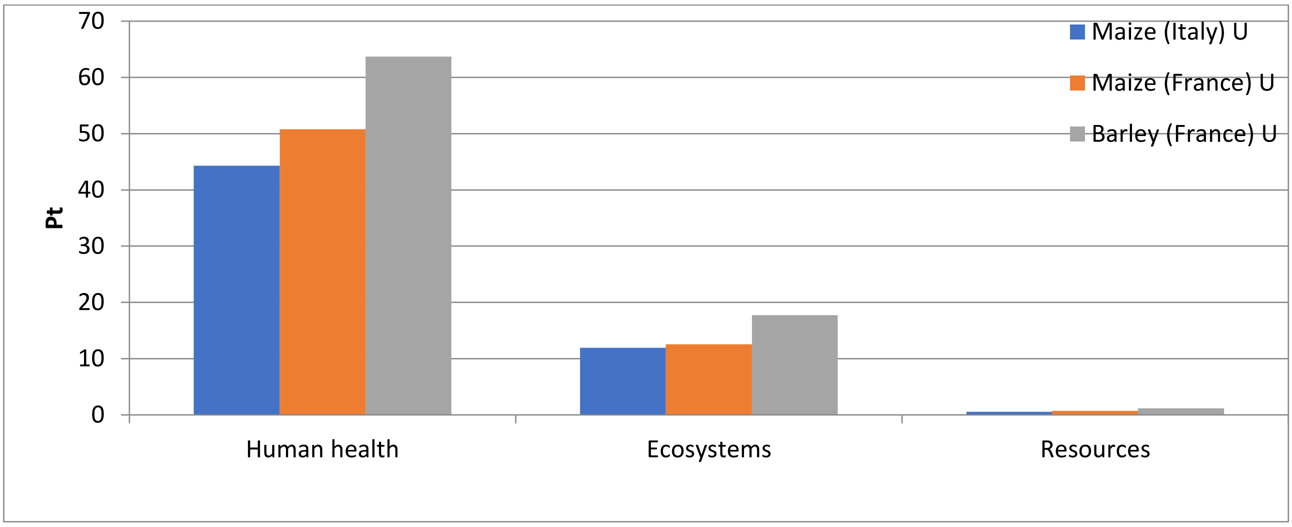


Figure 30. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of cereals provided by Italian pilot. Origin is indicated in parentheses.

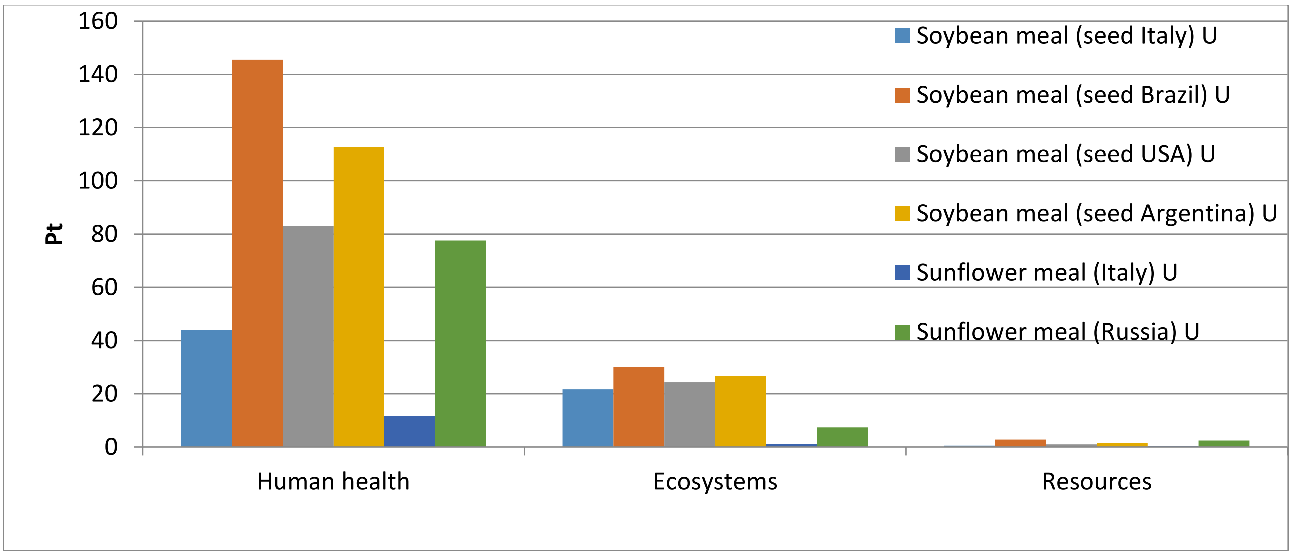


Figure 31. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of protein sources provided by Italian pilot. Origin is indicated in parentheses.

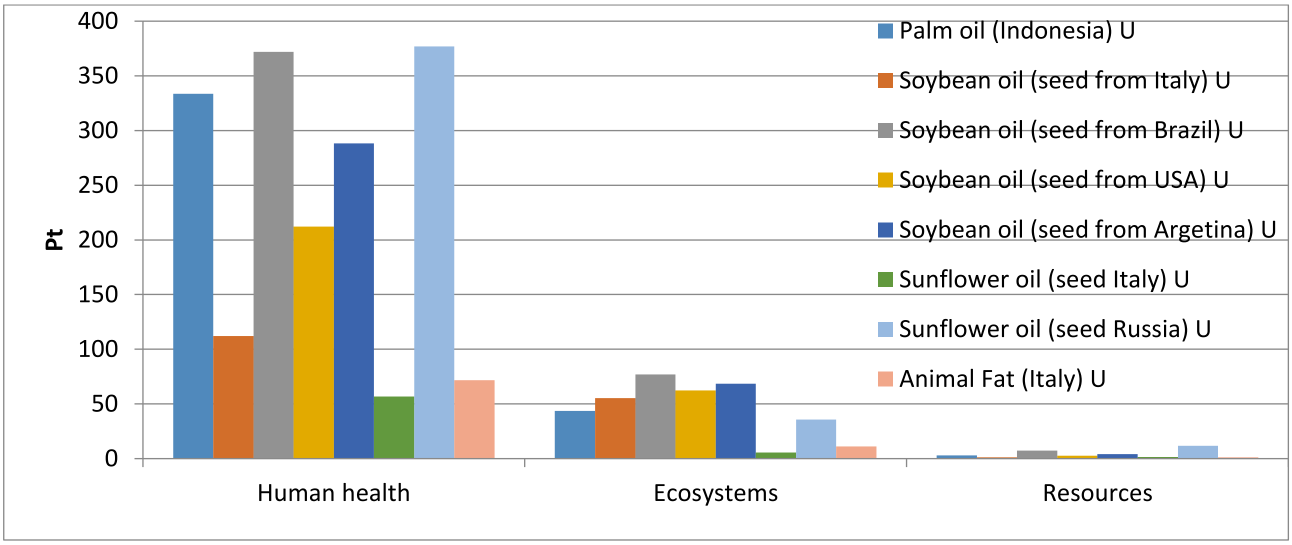


Figure 32. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of fat sources provided by Italian pilot. Origin is indicated in parentheses.

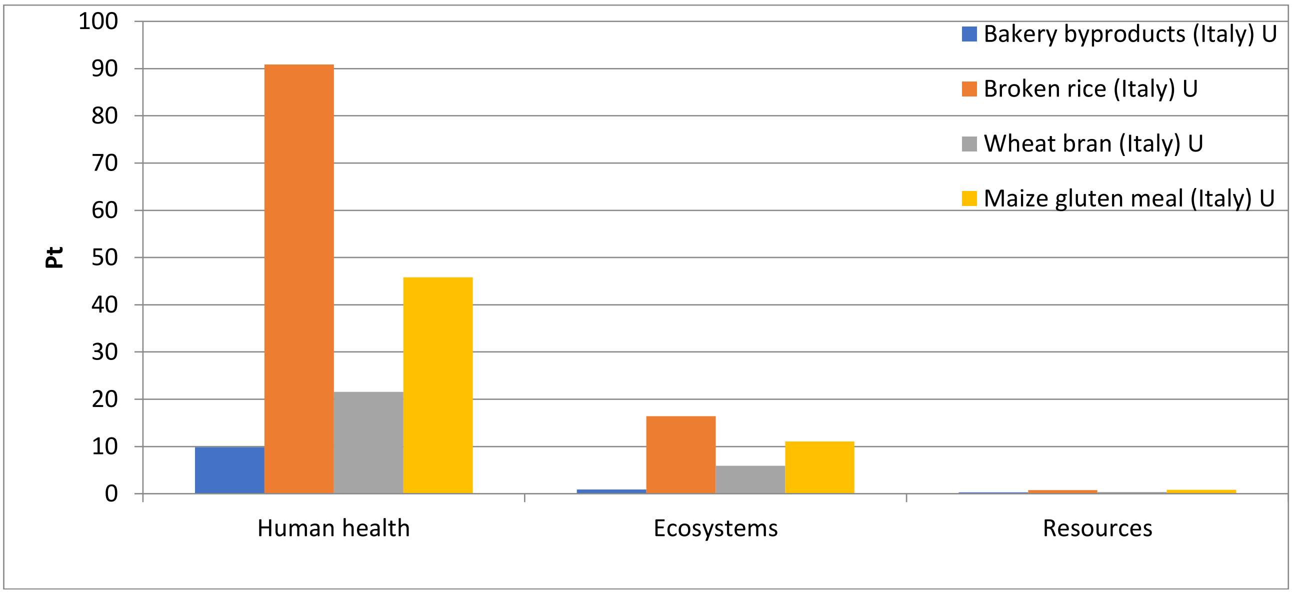


Figure 33. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of cereal by products provided by Italian pilot. Origin is indicated in parentheses.

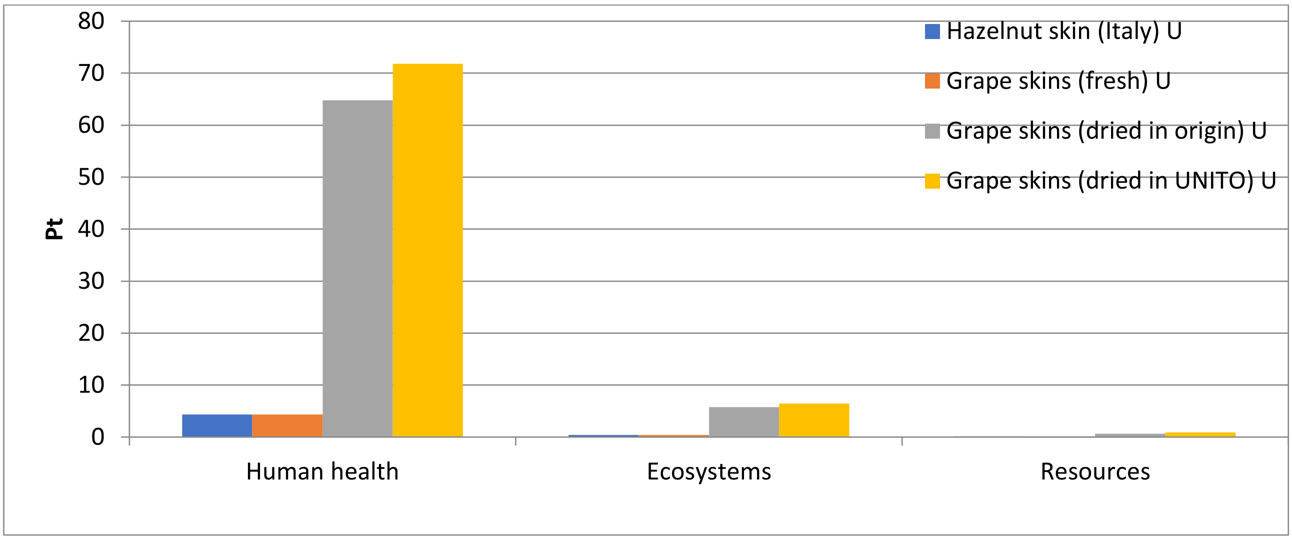


Figure 34. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of some alternative by products provided by Italian pilot. Origin is indicated in parentheses.

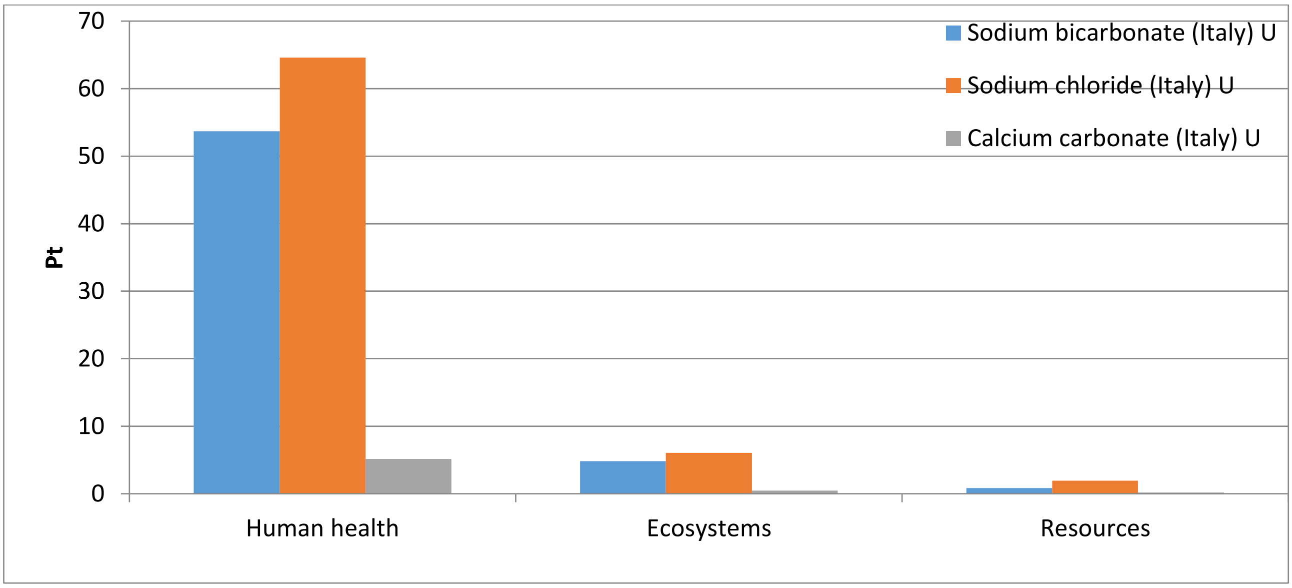


Figure 35. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of some minerals used for diets provided by Italian pilot. Origin is indicated in parentheses.

TURKEY PILOT (EGE UNIVERSITY)

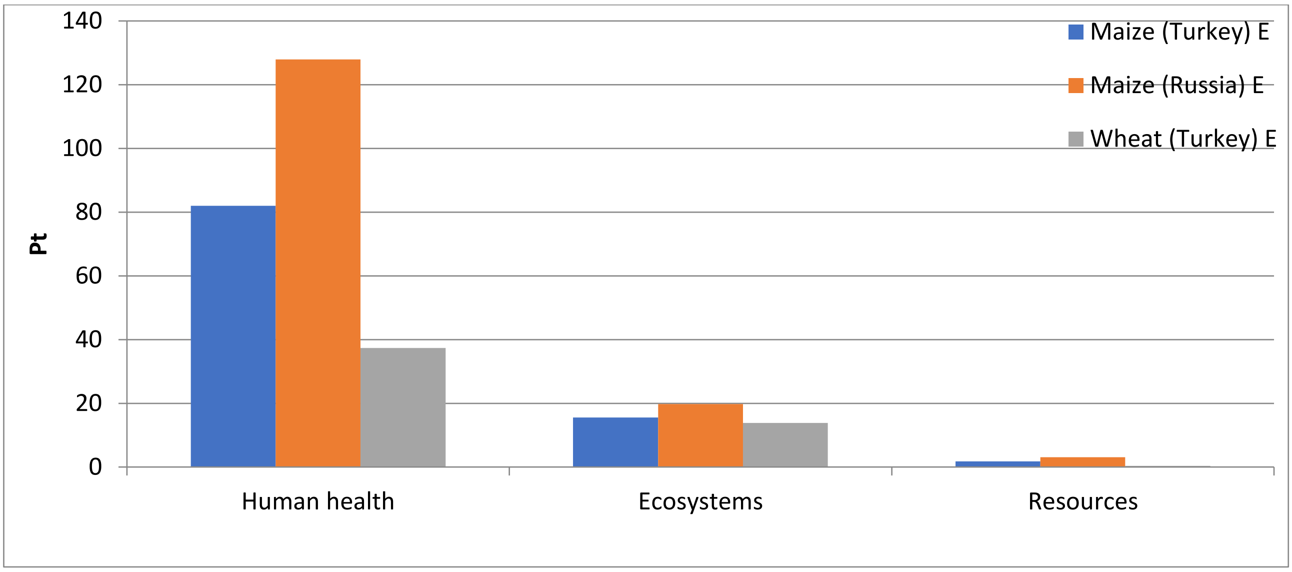


Figure 36. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of cereals provided by Turkish pilot. Origin is indicated in parentheses.

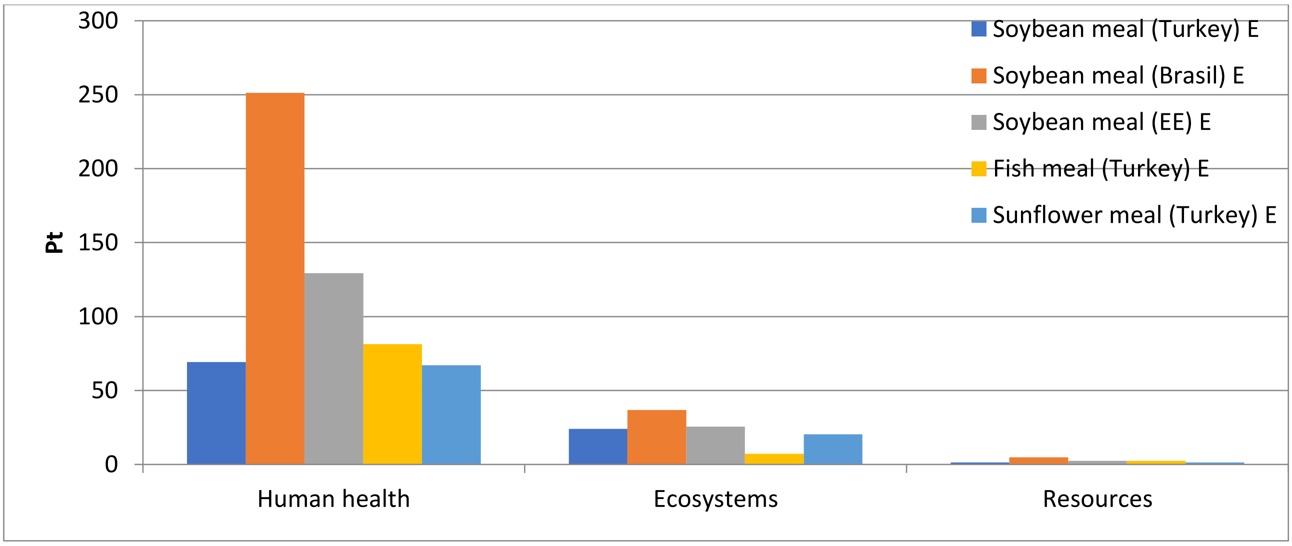


Figure 37. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of protein sources provided by Turkish pilot. Origin is indicated in parentheses. EE: from Eastern Europe.

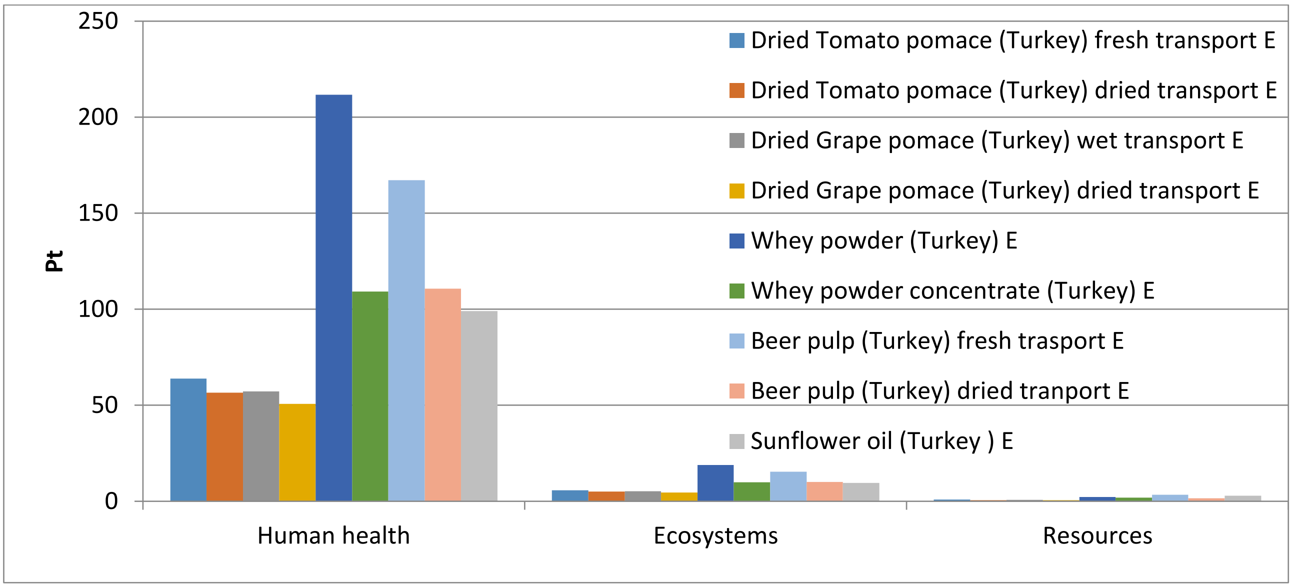


Figure 38. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of by-products ucts provided by Turkish pilot. Origin is indicated in parentheses.

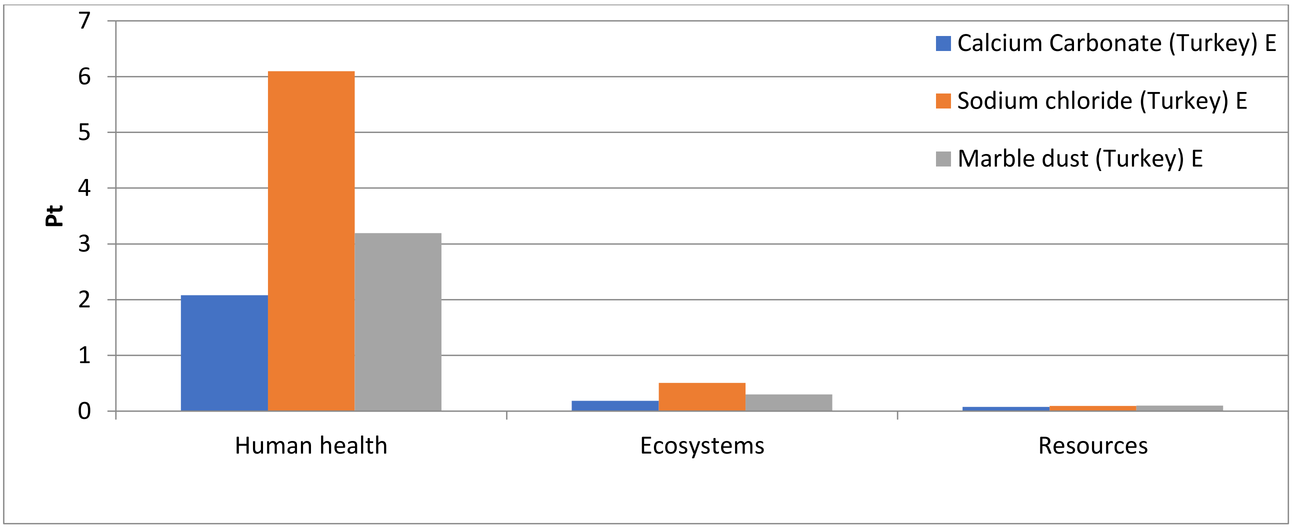


Figure 39. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of mineral sources provided by Turkish pilot. Origin is indicated in parentheses.

TUNISIA PILOT (ISA CM UNIVERSITY)

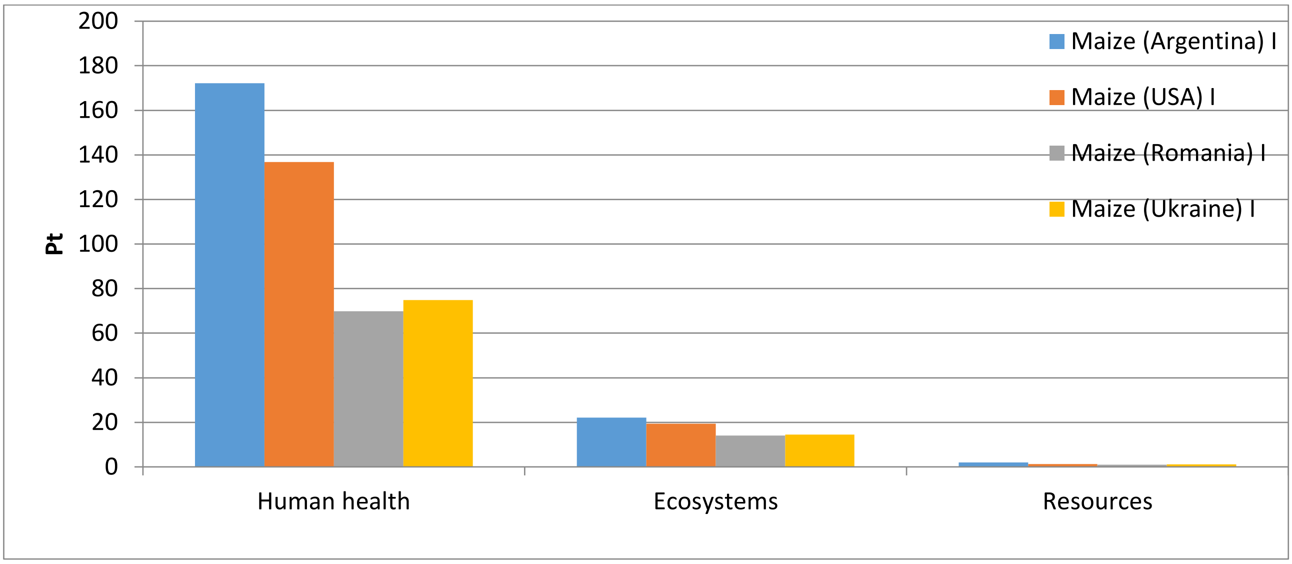


Figure 40. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of Maize grain provided by Tunisian pilot (ISA CM University). Origin is indicated in parentheses.

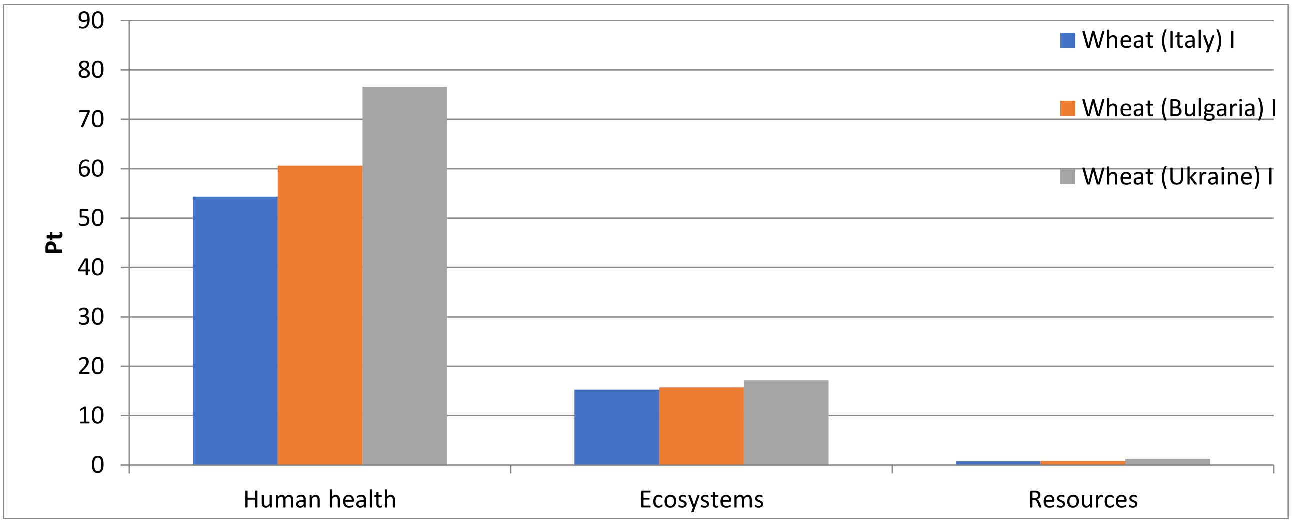


Figure 41. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of Wheat grain provided by Tunisian pilot (ISA CM University). Origin is indicated in parentheses.

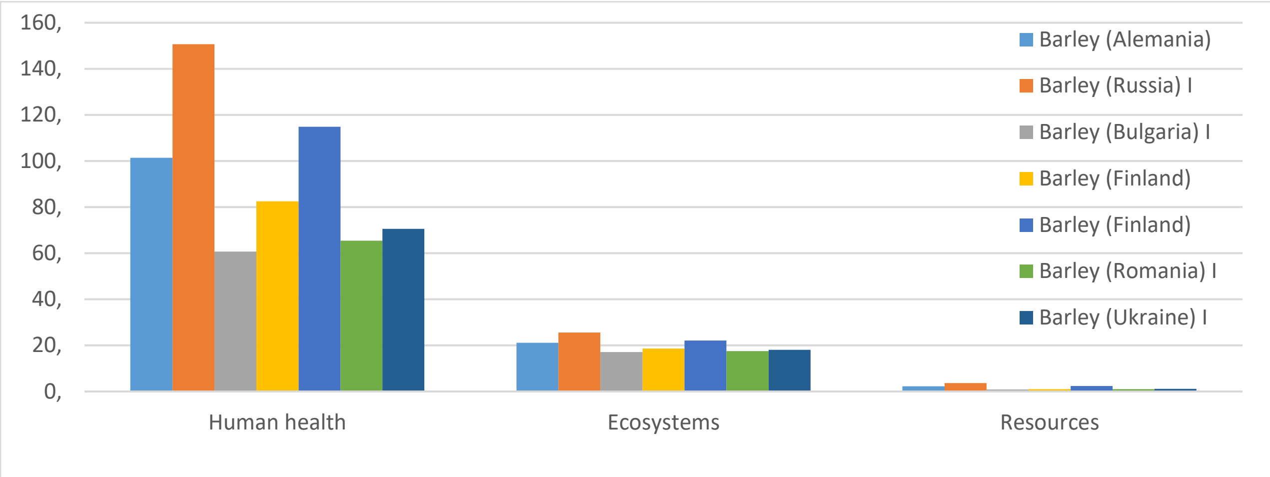


Figure 42. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of Barley grain provided by Tunisian pilot (ISA CM University). Origin is indicated in parentheses.

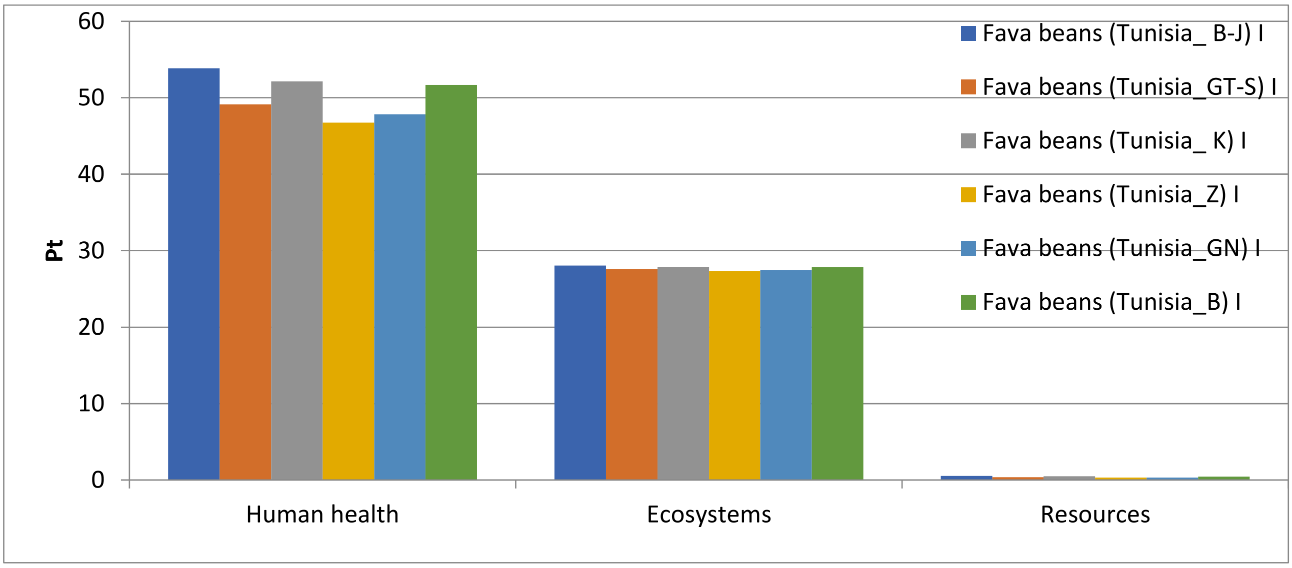


Figure 43. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of Fava beans provided by Tunisian pilot (ISA CM University). Origin is indicated in parentheses. B_J: from Beja-Jendouba, GT_S: from Gran Tunisia-Siliana, K: from Kef, Z: from Zaghouan, GN: from Governorate Nabeoul, B: from Bizerte.

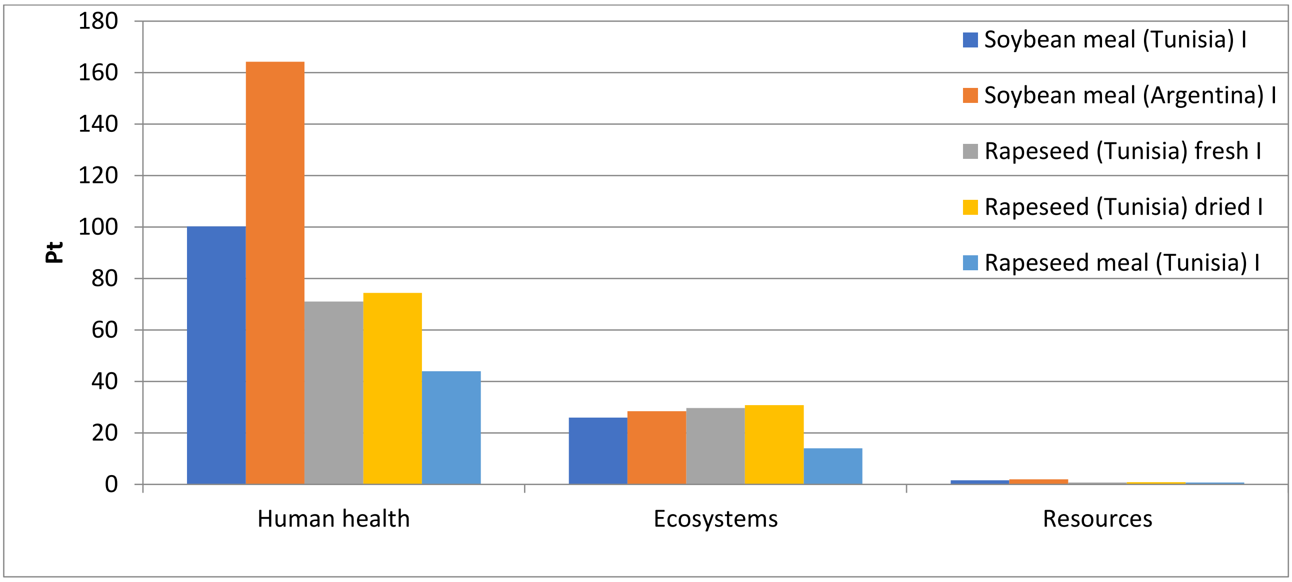


Figure 44. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of protein sources provided by Tunisian pilot (ISA CM University). Origin is indicated in parentheses.

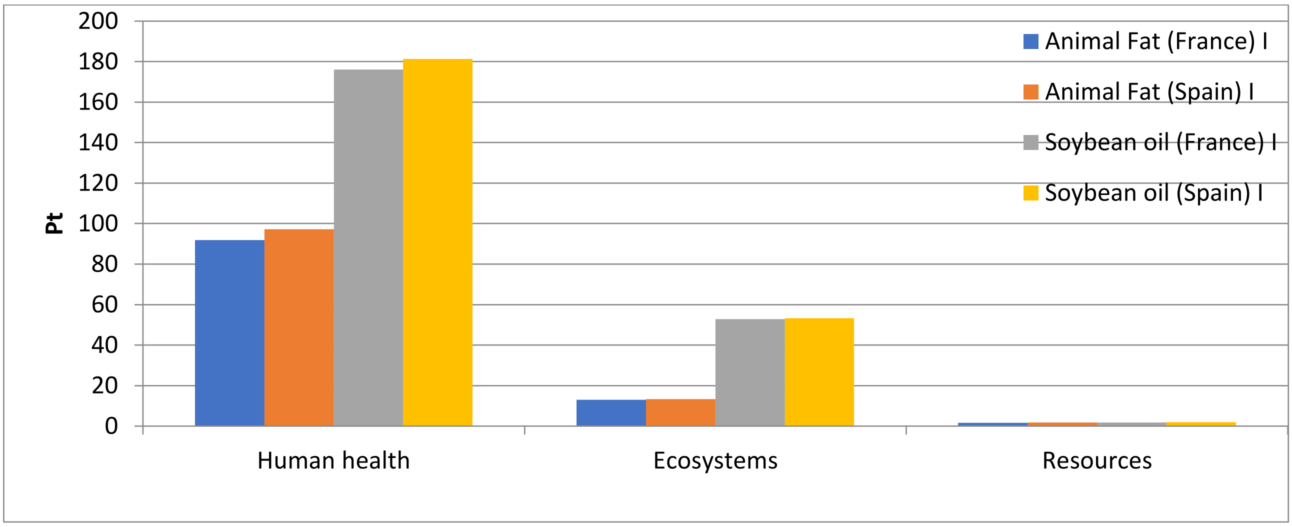


Figure 45. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of fat sources provided by Tunisian pilot (ISA CM University). Origin is indicated in parentheses.

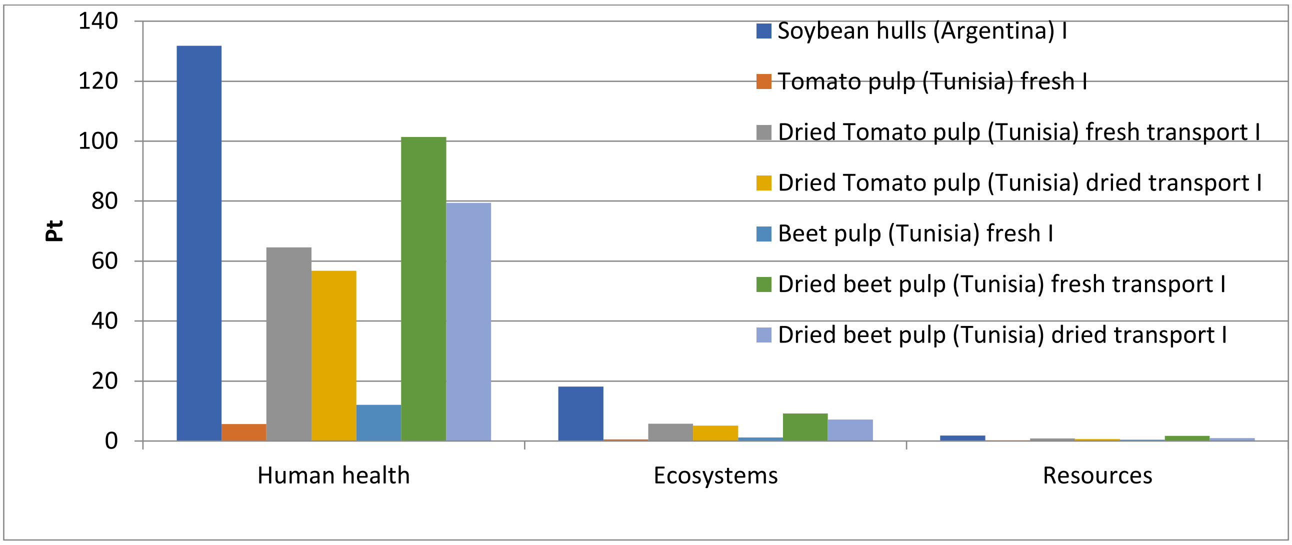


Figure 46. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of sub-products provided by Tunisian pilot (ISA CM University). Origin is indicated in parentheses.

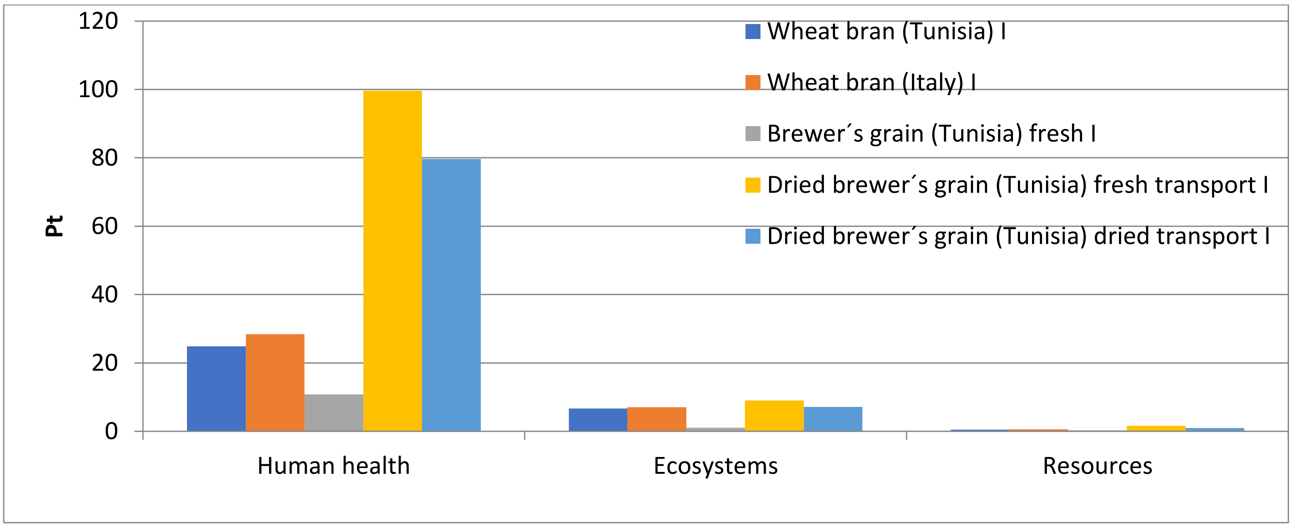


Figure 47. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of cereal by-products provided by Tunisian pilot (ISA CM University). Origin is indicated in parentheses.

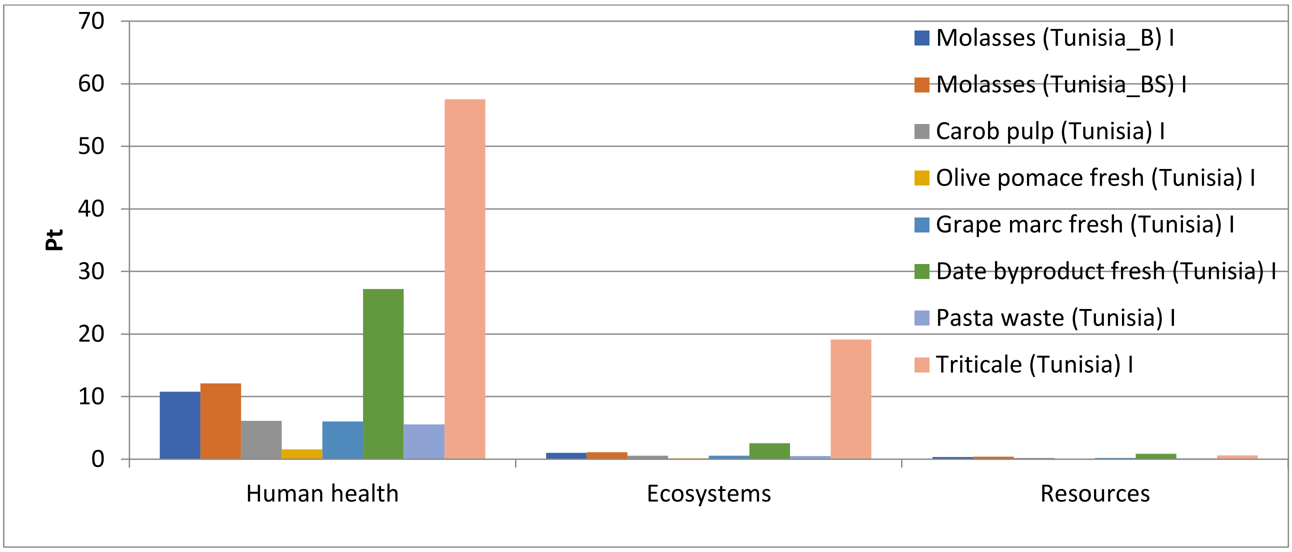


Figure 48. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of alternative ingredients provided by Tunisian pilot (ISA CM University). Origin is indicated in parentheses. B: from Béja, BS: from Bou Salem.

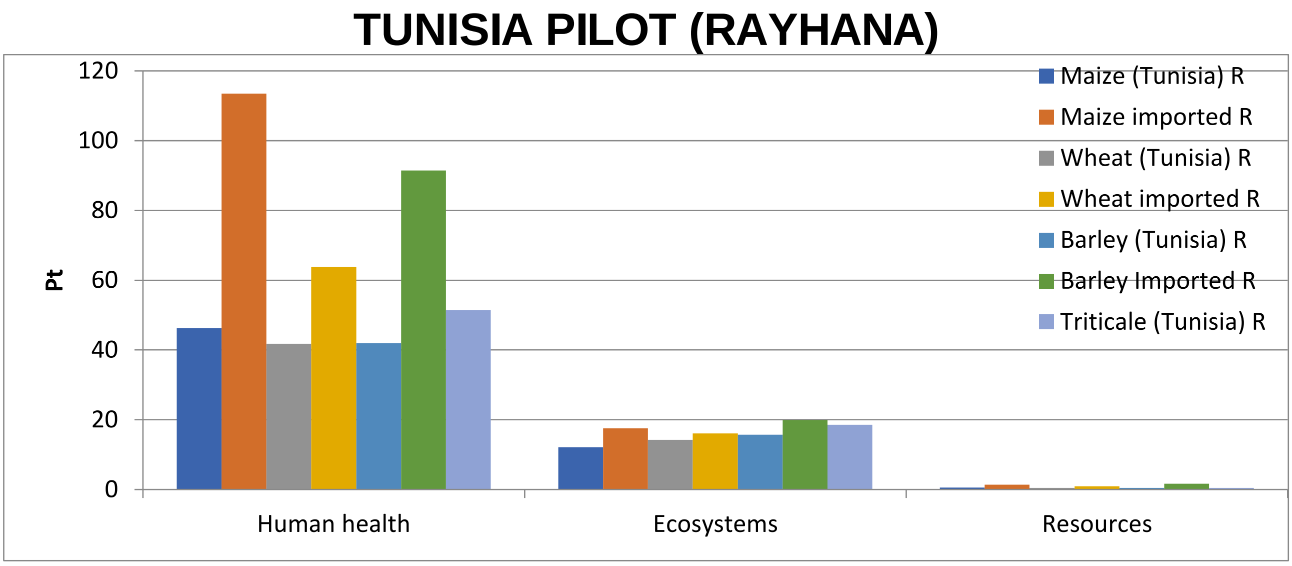


Figure 49. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of cereals provided by Tunisian pilot (Rayhana). Origin is indicated in parentheses.

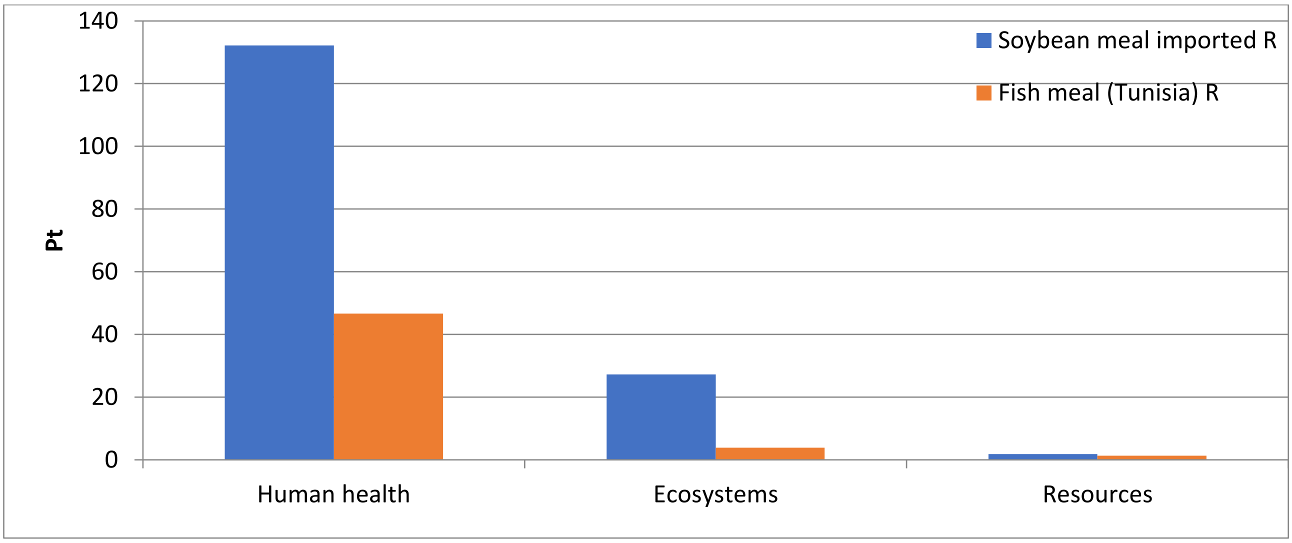


Figure 50. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of protein sources provided by Tunisian pilot (Rayhana). Origin is indicated in parentheses.

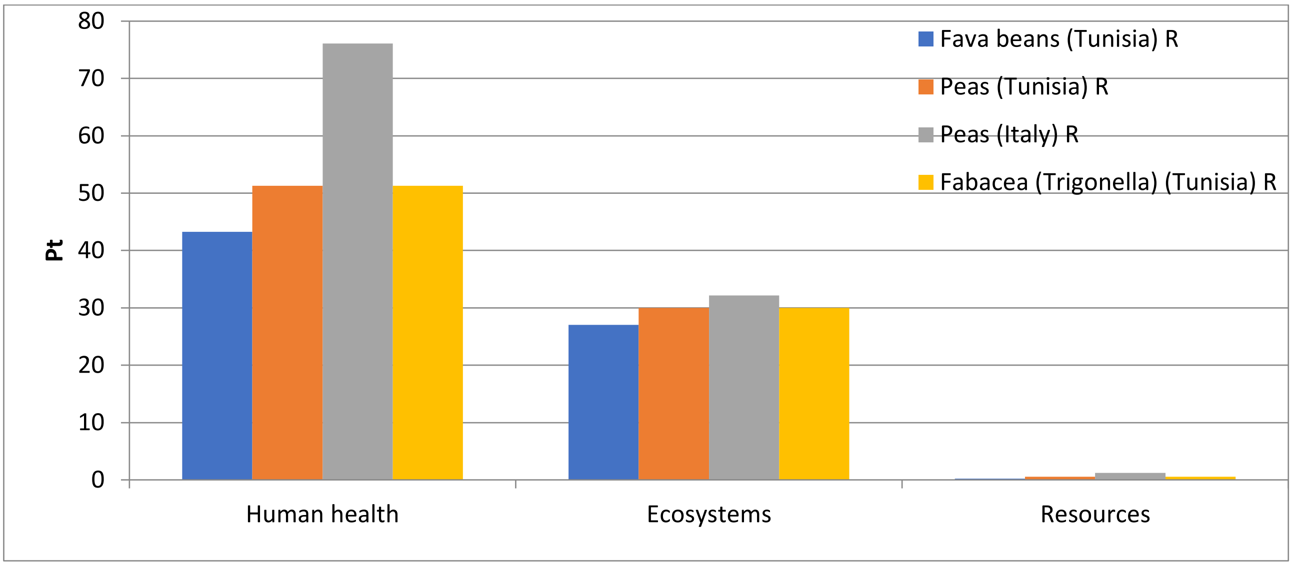


Figure 51. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of other protein sources provided by Tunisian pilot (Rayhana). Origin is indicated in parentheses.

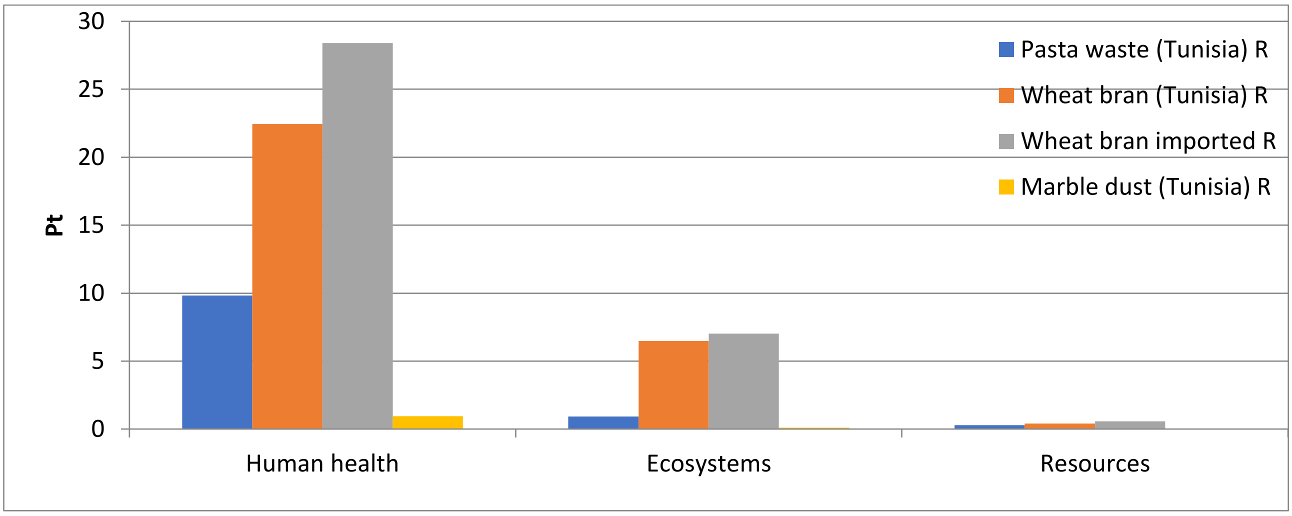


Figure 52. (Annex II). Impact with RECIPE method on human health, ecosystem, and resources of other ingredients provided by Tunisian pilot (Rayhana). Origin is indicated in parentheses.