# 4. Additional aspects: Biodiversity and water assessment of P2F prototypes

## 4.1. Biodiversity Assessment

Biodiversity and ecosystem services are increasingly being endangered. Moreover, maintaining biodiversity provides the basis for all agricultural services (EC 2010). Around 30% of the total human-induced global biodiversity loss among flora and fauna is related to livestock production (Westhoek 2011) and agriculture in general is the main driver of biodiversity loss in Europe and will be so for years to come. Therefore, biodiversity as an overarching area of environmental concern is assessed in addition to the LCIA categories. The biodiversity assessment carried out here will focus on the crop cultivation phase and is performed semi-qualitatively.

The present chapter contains a brief methodology description as well as the presentation of comparative biodiversity assessment results for the vegetable versus traditional food products.

**Methodology**

The basic principles for the methodological approach of the present biodiversity assessment are described in deliverable D.2.

P2F seeks to develop vegetable protein-rich products with a reduced pressure of agriculture on biodiversity. Therefore, five pressure categories have been identified in Deliverable 5.2: (1) N-/P-related pollution, (2) Pesticides and other pollution, (3) Water balance, (4) Soil degradation and (5) Landscape structure. The pressure categories were assigned to relevant and measurable influencing factors based on FAO (2016).

In the following, the approach and the applied metrics are specified in more detail. The operationalisation of the biodiversity assessment is carried out with individual metrics per influencing factors. These metrics have been defined in the present report. Table 4-1 gives an overview of pressure categories, influencing factors and includes a brief description of the metrics incl. data sources. Table 4-2 shows humus equivalents for selected arable crop types used as metric for the influencing factor “Increase of soil organic matter”.

In the first calculation step, results per metric are calculated for each crop and food product per reference value. The reference value is defined wither by the functional unit or the total area occupied for the production of the food products. The latter reference is used for influencing factors which address potential impacts on the specific soil quality.

In a second step, the results per influencing factor of the vegetable products are compared relatively with those of traditional protein-containing products and subsequently classified as more or less favourable. To define the significance of differences of results, an estimated significance threshold of 20 % is chosen as pragmatic approach. The threshold of 20 % is chosen with respect to the variability of generic cultivation data and especially regarding the new developed non-LCIA metrics. For common LCIA categories (e.g. Acidification, Eutrophication) an estimated significance threshold of 10 % is usually considered as common practice for LCA studies comparing different product systems. Nevertheless, all metrics in the biodiversity assessment are treated equally and all differences ≤ 20 % are considered as insignificant.

The single metrics are not aggregated to a single biodiversity score. Rather, they serve as indications for qualitative conclusions.



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**Table 4-1:** Factors and corresponding metrics targeting the improvement of benefits and mitigation of agricultural pressures on biodiversity based on Agri-Environment Schemes compiled by FAO (2016)

| Pressure category | Influencing factor | Metric | Description |
|---|---|---|---|
| **N-/P-related pollution** | A) Partial replacement of N-fertilizer input by including legumes in crop rotation | Area cultivated with legumes (m² *a/area used per fu)<br>Reference value: area used for production of food products | Proportion of agricultural area cultivated with legumes with nitrogen fixing properties for the production of the food products.<br>Data source: P2F cultivation models. |
| | B) Nutrient leaching to ground and surface water:<br>- Acidification<br>- Aquatic and terrestrial eutrophication | Acidification potential (g $SO_2$-e/fu)<br>Aquatic and terrestrial eutrophication potential (g $PO_4$-e/fu)<br>Reference value: crop input per fu | The LCIA results represent the N-/P-pollution due to N-/P input.<br>Data source: P2F LCIA assessment. |
| **Pesticides and other pollution** | C) Reduction of pesticide treatments | Use of pesticides (g/fu)<br>Reference value: crop amount for production of food products | Amount of pesticides applied on fields for the production of the food products.<br>Data source: P2F cultivation models. |
| | D) Reduction of stratospheric ozone depletion | Ozone depletion potential (g CFC-11-e/fu)<br>Reference value: crop input per fu | Data source: P2F LCIA assessment. |
| | E) Reduction of photochemical ozone formation | Photochemical ozone formation potential – Maximum incremental reactivity (MIR) (g $O_3$-e/fu)<br>Reference value: crop input per fu | Data source: P2F LCIA assessment. |
| **Water balance** | F) Reduction of water demand | Consumptive water use of crops (m³/fu)<br>Reference value: crop input per fu | Amount of consumptive water use of crops (blue and green water) needed for the production of the food products. Under the assumption that not only the blue, but also the green water does narrow the water availability for natural ecosystems (especially in dry regions) the total water demand of the crops is considered for the biodiversity assessment.<br>Data source: P2F cultivation models |
| **Soil degradation** | G) Reduced soil compaction due to mechanical field | diesel consumption of agricultural machines | Amount of diesel needed for fieldwork (e.g. harvest, fertiliser spreading) divided by the total area. The chosen metric should represent the frequency of |



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| Pressure category | Influencing factor | Metric | Description |
|---|---|---|---|
| | work | (l/area used per fu)<br>Reference value: area used for production of food products | field work and machine dimension: the more diesel is consumed, the heavier machines are used or the higher is the frequency of the field work and, therefore, the more soil compaction takes place. Due to the fact that a high frequent use of lighter field machines may not have the same impact on soil compaction than one ride of an agricultural field machine, the results of this metric have to be interpreted with caution.<br>Data source: P2F cultivation models |
| | H) Increase of soil organic matter | Humus equivalents (kg C/area used per fu)<br>Reference value: area used for production of food products | Amount of humus equivalents (expressed in terms of carbon) reproduced or depleted by crops needed for the production of the food products divided by the total crop area.<br>The humus equivalents represent the increase or decrease of soil organic matter and highlight humus-depleting crops.<br>Data source: humus equivalents (see table 4-2) based on KTBL (2009) and P2F cultivation models |
| **Landscape structure** | I) Diversifying crop rotations | Area cultivated with minor crops where the share of cropped area declined throughout Europe ($m^2$ *a/area used per fu)<br>Reference value: area used for production of food products | All crops needed for the production of the food products are categorised into three classes (A, B and C) based on crop decline and their current share of the cropped area. The crop decline or increase is determined by evaluation of crop area time series with figures from 1961 to 2016 published by FAOSTAT. According to tendencies in the time series the crops are classified into A) crop area has declined, B) crop area has remained unchanged and C) crop area has increased. In combination with the current crop share based on EuroStat crop production of the years 2014-2016, the crops are classified into following classes:<br>A = decrease in cropped area and < 5 % of European cultivation area<br>B = decrease in cropped area and > 5 % of European cultivation area or cropped area remained unchanged and 5-20 % of European cultivation area<br>C = increase in cropped area and > 5 % of European cultivation area<br>The agricultural area needed for the production of the food products is then multiplied by 1 for class A and 0.5 for class B. To get area-related results, the area cultivated with minor crops is divided by the total area occupied per functional unit.<br>Data source: FAOSTAT and Eurostat and P2F cultivation models |



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| Pressure category | Influencing factor | Metric | Description |
|---|---|---|---|
| | | | |
| Note: All influencing factors except of I) Diversifying crop rotations do cover all crops independent of their region of origin. The metric for diversifying crop rotations primarily aims to enhance the European crop diversity as the P2F crops will be cultivated in Europe. | | | |

**Table 4-2:** Humus equivalents for selected arable crop types based on KTBL (2009)

| Arable crop types | humus equivalents (kg C/ha*a) (KTBL 2009) | | |
|---|---|---|---|
| | min | max | average |
| Feed (legumes, pasture, pasture mix)/legumes gr.4 | 600 | 800 | 700 |
| Fallow (greening) | 80 | 700 | 390 |
| Nurse crop (e.g. buckwheat) | 200 | 300 | 250 |
| Grain legumes | 160 | 240 | 200 |
| Winter catch crops | 120 | 160 | 140 |
| Stubble crops | 80 | 120 | 100 |
| Cereals/oilseeds/legumes gr.3 | -400 | -280 | -340 |
| Maize (silo, grain)/vegetable gr.2 | -800 | -560 | -680 |
| Potatoes/vegetables gr.1 | -1000 | -760 | -700 |
| Sugar/fodder beets | -1300 | -760 | -1030 |

## Comparative results: innovative/modern vs. traditional food products

Figures 4-1 to 4-4 show the comparative results of the vegetable food products for the biodiversity metrics to those of the traditional food products in the same product lines:

- VMA-fiber prototype versus chicken meat (low and high impact variant)
- VMA-spread prototype versus pork based Leberwurst (Liver Pâté) (low and high impact variant)
- Vegetable milk (innovative and modern) versus cow milk (low and high impact variant)
- Vegetable burger (innovative and modern) versus beef burger

### Product line VMA-fiber

In general, the **lentil** based P2F prototypes perform more favourable than the traditional **low impact** chicken meat product regarding most of the influencing factors. Merely, the results of the LCIA category aquatic eutrophication and the influencing factor water demand do not show significant differences. Compared to the **high impact** chicken meat, the lentil based VMA-fiber prototypes show more favourable results in all influencing factor categories.



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The **lupin** based P2F prototypes also perform more favourable than the traditional **low-impact** chicken meat regarding most of the influencing factors, but do not show significant differences for the influencing factors F) water demand and G) soil compaction. Compared to the **high impact** chicken meat, the **lupin** based VMA-fiber prototypes show more favourable results in almost all influencing factor categories, except for soil compaction where no significant differences occur.

Product line VMA-spread

The VMA-spread type **curry** performs more favourable than the traditional **high impact** pork based leberwurst regarding most of the influencing factors except for F) reduction of water demand where no significant differences occur. The VMA-spread types **leberwurst** and **tomato** also perform more favourable than the traditional **high impact** pork based leberwurst regarding most of the influencing factors, but show no differences in the categories soil compaction and aquatic eutrophication. Due to lower land occupation but higher water demand of fruits used in the VMA-spread type **curry**, this type shows more favourable results for reduced soil compaction, but higher results regarding the category water demand compared to the other two VMA-spread types.

However, the VMA-spread products show higher results than the **low-impact** pork based leberwurst for the influencing factos F) reduction of water demand and in case of the types **leberwurst** and **tomato** in the LCIA category aquatic eutrophication. The VMA-spread products show lower results or no significant differences than the traditional product regarding all other influencing factors.

Product line vegetable milk

The **vegetable P2F prototype** performs more favourable than the **traditional low- and high-impact cow milk** regarding all influencing factors except, in case of low-impact cow milk, for F) Reduction of water demand and aquatic eutrophication.

The **modern food product (soy milk)** also performs more favourable than the high and low impact cow milk regarding most of the influencing factors, but shows no significant differences for A) the inclusion of legumes in crop rotation. The inclusion of legumes in crop rotation (influencing factor A) show no different results for the modern and traditional food products, as soy beans used for both systems are not considered as legumes with nitrogen fixing properties. This is because soy beans do not constantly fix nitrogen beyond their needs and, contrary to the P2F legumes, the cultivation of soy beans may not lead to an increase of nitrogen in the soil pool.

Product line burger

The **vegetable burger based on European soy** performs more favourable than the **beef burger** regarding the influencing factors B) to G) and I). Neither of the two products consists of legumes with nitrogen fixing properties. Therefore, the inclusion of legumes in crop rotation shows no different results. Regarding the influencing factor H) Increase of soil organic matter the vegetable burger shows less favourable results compared to the beef burger. This is a result of large area requirements for grass silage in the fodder of the cattle. Grassland farming areas show an increase in humus equivalents. Therefore, systems based on grass input may show more favourable results in this category.

The comparison of the **beef burger** with the **vegetable P2F burgers** based on lentil and lupin shows a similar picture except for the influencing factor A) inclusion of legumes in crop rotation where the P2F legumes show more favourable results. Due to a relatively high oat seed input for the production of the innovative burgers, a potential decrease of humus equivalents would occur



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for these products despite the potential humus formation from legumes. Along with potential humus formation from grass silage in the fodder of the cattle for the beef burger, the vegetable burger shows less favourable results compared to the beef burger for H) Increase of soil organic matter.

Summary

Based on the chosen metrics, the biodiversity assessment indicates that the new developed vegetarian protein-rich products would potentially reduce the pressure of agriculture on biodiversity.

Overall, the vegetable products show more favourable results for most of the influencing factors or do not show significant differences compared to the **high-impact** traditional products. Especially, the vegetable innovative milk and the lentil based VMA-fiber food product show lower results compared to the high impact traditional product in all pressure categories.

Furthermore, **vegetable milk** and **lentil and lupin based VMA-fiber** food products also perform more favourable or do not show significant differences compared to the **low-impact** traditional products.

However, compared to the **low-impact** traditional product, the **VMA-spread** products show higher results for one or two influencing factors. **Vegetable burger products** also show higher results in one category (H) Increase of soil organic matter) compared to the traditional beef burger. Nevertheless, these vegetable food products perform better in most of the categories. The factor G) soil compaction is measured by the amount of diesel needed for fieldwork. Most of the arable crops like cereals and protein or oil crops have roughly the same diesel demand per hectare. For example, one kilogram wheat, maize or lupin need about 84 l diesel per hectare. It should be noted that the size and weight of the agricultural machines would be smaller, but the frequency of field work would be higher for low yield crops like legumes or pseudocereals compared to cereals or oils seeds. Thus, even with the same diesel demand per hectare, the potential soil compaction associated with the low yield crops may be smaller compared to traditional cereal or oil seed crops. Consequently, the diesel demand serves only as a first hint on soil compaction.



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| Pressure category | Influencing factor | | VMA-fiber vs. low impact chicken meat | | | | VMA-fiber vs. high impact chicken meat | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | P2F prototypes are more (green) or less (red) favourable than the traditional products | | | | | | | |
| | | | AF LuPI | BWF LuPI | AF LePI | BWF LePI | AF LuPI | BWF LuPI | AF LePI | BWF LePI |
| N-/P-related pollution | A) Inclusion of legumes in crop rotation | | | | | | | | | |
| | B) N-/P-leaching to ground and surface water | Acidification | | | | | | | | |
| | | Aquatic Eutrophication | | | | | | | | |
| | | Terrestrial Eutrophication | | | | | | | | |
| Pesticides and other pollution | C) Reduction of pesticide treatments | | | | | | | | | |
| | D) Reduction of stratospheric ozone depletion | | | | | | | | | |
| | E) Reduction of photochemical ozone formation | | | | | | | | | |
| Water balance | F) Reduction of water demand | | | | | | | | | |
| Soil degradation | G) Reduced soil compaction | | | | | | | | | |
| | H) Increase of soil organic matter | | | | | | | | | |
| Landscape structure | I) Diversifying crop rotations | | | | | | | | | |

1. differences ≤ 20% are considered as insignificant and therefore are marked grey

2. light red/green is used for the comparison with low impact traditional food products and dark red/green for the comparison with high impact traditional food products

**Figure 4-1:** Comparison of results regarding influencing factors addressing pressure on biodiversity: VMA-fiber food products versus low-impact and high-impact traditional food products



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| Pressure category | Influencing factor | | VMA-spread vs. low impact Leberwurst (Liver Pâté) | | | VMA-spread vs. high impact Leberwurst (Liver Pâté) | | |
|---|---|---|---|---|---|---|---|---|
| | | | P2F prototypes are more (green) or less (red) favourable than the traditional products | | | | | |
| | | | Type Leber-wurst | Type Tomato | Type Curry | Type Leber-wurst | Type Tomato | Type Curry |
| N-/P-related pollution | A) Inclusion of legumes in crop rotation | | | | | | | |
| | B) N-/P-leaching to ground and surface water | Acidification | | | | | | |
| | | Aquatic Eutrophication | | | | | | |
| | | Terrestrial Eutrophication | | | | | | |
| Pesticides and other pollution | C) Reduction of pesticide treatments | | | | | | | |
| | D) Reduction of stratospheric ozone depletion | | | | | | | |
| | E) Reduction of photochemical ozone formation | | | | | | | |
| Water balance | F) Reduction of water demand | | | | | | | |
| Soil degradation | G) Reduced soil compaction | | | | | | | |
| | H) Increase of soil organic matter | | | | | | | |
| Landscape structure | I) Diversifying crop rotations | | | | | | | |

1. differences ≤ 20% are considered as insignificant and therefore are marked grey

2. light red/green is used for the comparison with low impact traditional food products and dark red/green for the comparison with high impact traditional food products

**Figure 4-2:** Comparison of results regarding influencing factors addressing pressure on biodiversity: VMA-spread food products versus low-impact and high-impact traditional food products

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| Pressure category | Influencing factor | | Vegetable milk vs. low impact cow milk | | Vegetable milk vs. high impact cow milk | |
|---|---|---|---|---|---|---|
| | | | P2F prototypes are more (green) or less (red) favourable than the traditional products | | | |
| | | | Vegetable innovative milk | Modern soy milk | Vegetable innovative milk | modern soy milk |
| N-/P-related pollution | A) Inclusion of legumes in crop rotation | | | | | |
| | B) N-/P-leaching to ground and surface water | Acidification | | | | |
| | | Aquatic Eutrophication | | | | |
| | | Terrestrial Eutrophication | | | | |
| Pesticides and other pollution | C) Reduction of pesticide treatments | | | | | |
| | D) Reduction of stratospheric ozone depletion | | | | | |
| | E) Reduction of photochemical ozone formation | | | | | |
| Water balance | F) Reduction of water demand | | | | | |
| Soil degradation | G) Reduced soil compaction | | | | | |
| | H) Increase of soil organic matter | | | | | |
| Landscape structure | I) Diversifying crop rotations | | | | | |

1. differences ≤ 20% are considered as insignificant and therefore are marked grey

2. light red/green is used for the comparison with low impact traditional food products and dark red/green for the comparison with high impact traditional food products

**Figure 4-3:** Comparison of results regarding influencing factors addressing pressure on biodiversity: vegetable innovative and modern milk versus low-impact and high-impact traditional food products

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| Pressure category | Influencing factor | | Vegetable burger vs. beef burger | | |
|---|---|---|---|---|---|
| | | | P2F prototypes are more (green) or less (red) favourable than the traditional products | | |
| | | | Soy burger | Vegetable lupin burger | Vegetable lentil burger |
| N-/P-related pollution | A) Inclusion of legumes in crop rotation | | | | |
| | B) N-/P-leaching to ground and surface water | Acidification | | | |
| | | Aquatic Eutrophication | | | |
| | | Terrestrial Eutrophication | | | |
| Pesticides and other pollution | C) Reduction of pesticide treatments | | | | |
| | D) Reduction of stratospheric ozone depletion | | | | |
| | E) Reduction of photochemical ozone formation | | | | |
| Water balance | F) Reduction of water demand | | | | |
| Soil degradation | G) Reduced soil compaction | | | | |
| | H) Increase of soil organic matter | | | | |
| Landscape structure | I) Diversifying crop rotations | | | | |

1. differences ≤ 20% are considered as insignificant and therefore are marked grey

2. light red/green is used for the comparison with low impact traditional food products and dark red/green for the comparison with high impact traditional food products

**Figure 4-4:** Comparison of results regarding influencing factors addressing pressure on biodiversity: vegetable burger (soy, lentil and lupin based burger) versus beef burger

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## 4.2. Water scarcity Assessment

In the previous sections, water use along the life cycle of the food products has been presented at the inventory level:

- blue process water as sectoral results
- green water as part of the biodiversity assessment

As P2F crops and feed crops are assumed to be non-irrigated in the base LCA model, irrigation water does not show up in the blue water results.

This assumption is checked in the following exemplary water scarcity assessment where a certain share of irrigation water is assumed for all crops. The assessment is conducted exemplarily for the following products of the product line VMA-fiber:

- VMA-fiber food product based on lentil and buckwheat (BWF LePi)
- VMA-fiber food product based on lupin and buckwheat (BWF LuPi)

The present chapter contains a brief methodology description including underlying assumptions as well as the results of the exemplary water scarcity assessment. The results rather aim to show bandwidths when assessing water scarcity at regional level and to provide information on hotspots regarding conservation and management of water resources in Europe than serving as basis for comparative conclusions.

**Methodology**

In order to provide an operational ISO compliant method, the working group "Water Use in LCA (WULCA)" of the UNEP –SETAC Life Cycle Initiative published in 2017 a consensus-based water scarcity midpoint method for the use in LCA: the AWARE (available water remaining) approach. It is based on the inverse of available water minus the demand of humans and aquatic ecosystems (available minus demand - AMD) per area in a given watershed and timeframe relative to the world average (Boulay et al. 2017). The resulting AWARE characterisation factors ($CF_{AWARE}$) represent - similar to the Global Warming Potential (GWP) - a relative value expressed in terms of $m^3$ world-equivalents per $m^3$ consumed water. They range between 0.1 and 100 and are calculated at sub-watershed level and monthly time-steps. To meet current inventory data, aggregated characterisation factors per year and country for agricultural and non-agricultural water use have been provided by Boulay et al. (2017). The approach represents the state of art concerning the current knowledge about assessing potential impacts from water use in LCA.

At disaggregated level, the AWARE approach requires following inventory data per process: specific geographic location (sub-watershed), month, differentiation between agricultural and non-agricultural use and quantity of water consumed. Consumed water is defined in ISO 14046 and Boulay et al. (2017) as the part of the water use that is not released into the same watershed due to evaporation, evapotranspiration, product incorporation and discharge into another watershed.

In the following, the implementation of the AWARE approach for the present exemplary water scarcity assessment with respect to the inventory data of the P2F food models is described.

Most of the inventories applied in the P2F food models still do not include explicit the water released from the technosphere into watersheds. Therefore, only the volume of water inputs (process water (blue water) incl. water for irrigation) along the life cycle of the food products is



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considered for the present water scarcity assessment. This is deemed adequate for this purpose, as irrigation water input - accountable for the largest water volume - may be assumed as consumption (it is removed but not returned to the watersheds). As data on exact location of the cultivation areas within a country is not known, three different scenarios are calculated which should illustrate the bandwidths of the water scarcity assessment:

- Scenario A ("MIN CFs"): minimum CFs out of the main cultivation areas and related country irrigation water consumption
- Scenario B ("MAX CFs"): maximum CFs out of the main cultivation areas and related country irrigation water consumption
- Scenario C ("country CFs"): average of country CFs and country irrigation water consumption of the three main cultivation countries

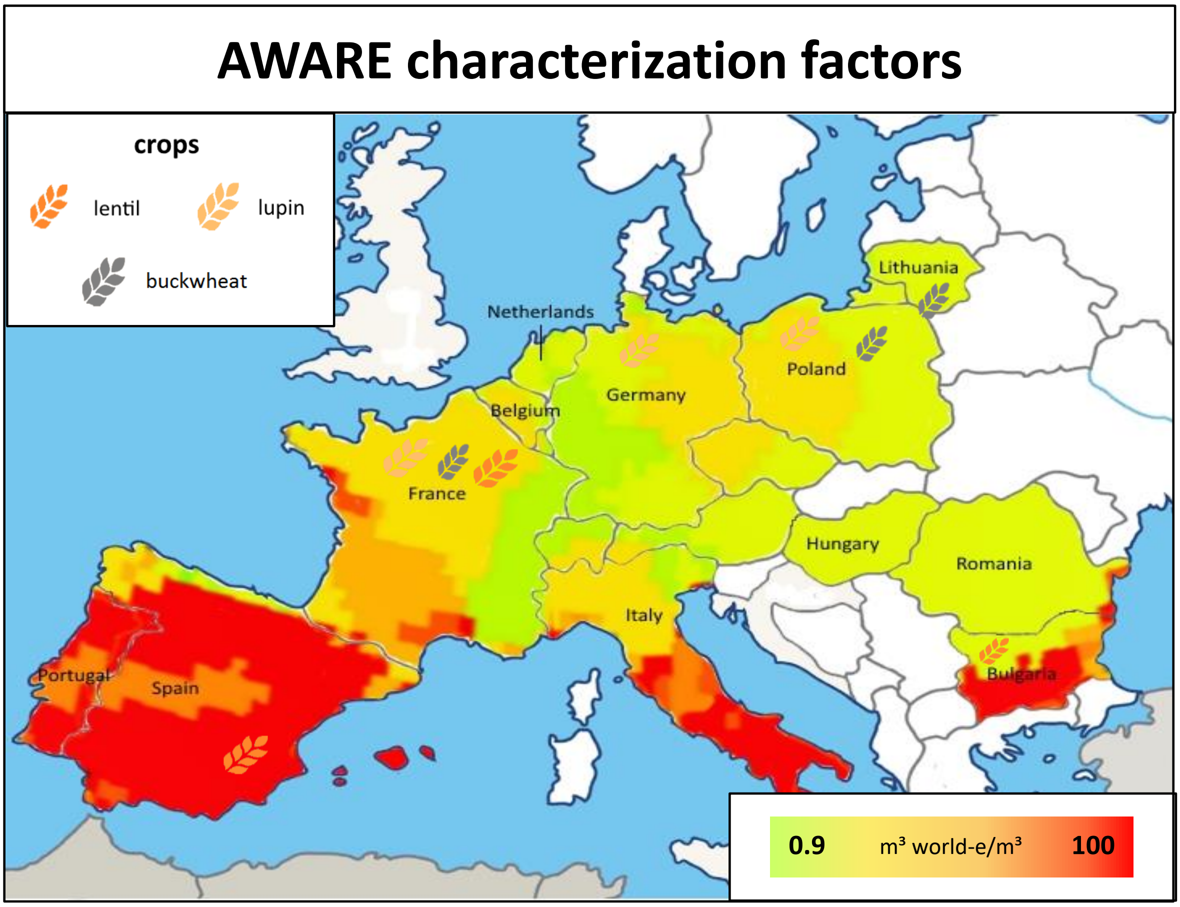


**Figure 4-5:** AWARE characterization factors (from green (0.9 $m^3$ world-equivalents/$m^3$) to red (100 $m^3$ world-equivalents/$m^3$) and main cultivation countries of lentil, lupin and buckwheat (source: own illustration)

Figure 4-5 shows the main cultivation areas within the three main cultivation countries of buckwheat, lentil and lupin and illustrates its water scarcity, expressed in AWARE characterization factors.

Table 4-1 summarizes the exact AWARE agricultural characterization factors of the water sheds with the highest and lowest water scarcity potential in the crop cultivation areas. This table also includes the country and European average CFs and the expected blue water consumption per country and crop. The CFs and expected blue water consumption of the three scenarios (A-C) are selected or calculated based on these figures and are documented in table 4-2.



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**Table 4-3:** Cultivation countries, expected blue water consumption (irrigation water) and the respective minimum, maximum and country average agricultural characterisation factors (CF agri.) for the examined crops (light and dark coloured CFs highlight European MIN and MAX CFs for the three crops which are taken into account in scenario A and B (see table 3-2))

| Crop | | Buckwheat | Lentil | Lupin |
|---|---|---|---|---|
| Country 1 | **country** | **Poland** | **Spain** | **Poland** |
| | $BW_{expected}$ (m³/ha) | 593.0 | 3591.4 | 662.1 |
| | CF(agri.) min (m3 world-e/m3) | 1.96 | 10.65 | 1.96 |
| | CF(agri.) max (m3 world-e/m3) | 2.24 | 96.67 | 2.24 |
| | CF(agri.) country (m3 world-e/m3) | 2.05 | 79.13 | 2.05 |
| Country 2 | **country** | **Lithuania** | **France** | **Germany** |
| | $BW_{expected}$ (m³/ha) | 592.68 | 2868.0(1) | 875.1 |
| | CF(agri.) min (m3 world-e/m3) | 2.00 | 3.14 | 0.93 |
| | CF(agri.) max (m3 world-e/m3) | 2.00 | 34.95 | 2.47 |
| | CF(agri.) country (m3 world-e/m3) | 1.49 | 8.29 | 1.61 |
| Country 3 | **country** | **France** | **Bulgaria** | **France** |
| | $BW_{expected}$ (m³/ha) | 998.8 | 1862.3 | 1054.0(1) |
| | CF(agri.) min (m3 world-e/m3) | 0.93 | 1.29 | 3.38 |
| | CF(agri.) max (m3 world-e/m3) | 3.19 | 62.28 | 34.95 |
| | CF(agri.) country (m3 world-e/m3) | 8.29 | 24.41 | 8.29 |
| | **European CFs (non-agri) for all non-agricultural processes** | | | |
| | CF(non-agri.) min (m3 world-e/m3) | 0.16 | | |
| | CF(non-agri.) max (m3 world-e/m3) | 80.64 | | |
| | CF(non-agri.) country (m3 world-e/m3) | 30.01 | | |

*(1) BW(expected) for lentil and lupin cultivated in France is not reported in In Pfister et al. (2011), therefore an average of Romania and Slovakia is used instead*

Following bullet points summarize the most important information about the AWARE approach application:

## A. Inventory data:

- Types and forms of used water resources: process water (blue water) incl. water for irrigation
- Quantities of used water: volume of water inputs along the life cycle of the food products

*Irrigation water for crops:*

The amount of irrigation water (m³/ha) is based on the "expected blue water consumption" (BWexpected) from Pfister et al. (2011). The BWexpected is calculated by the total blue water evapotranspiration of the crops and average country irrigation areas. This expected



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amount of irrigation water is published for more than 150 crops and their cultivation countries respectively (Pfister et al. 2011). The BWexpected for the main cultivation areas of the crops are shown in table table 4-1. The present water scarcity assessment is subject to the following assumptions per scenario (A to C) regarding the expected blue water consumption:

*Scenario A ("MIN CFs"):* BWexpected of the country with the minimum CF (table 4-2)

*Scenario B ("MAX CFs"):* BWexpected of the country with the maximum CF ( table 4-2)

*Scenario C ("country CFs"):* unweighted average BWexpected of the three main cultivation countries (table 4-2)

*Crop processing, cultivation pre-chains (e.g. fertilizer production) and processing to final product:*

The amount of water input ($m^3$) is taken from the P2F LCA models.

**B. Characterization factors[8]:**

- Time of used water: annual aggregated CFs
- Type of characterization factor used: agricultural CFs for irrigation water and non-agricultural CFs for all other processes
- Geographical location of water use:

*Scenario A ("MIN CFs"):* minimum CF out of the main cultivation areas for irrigation water (CF agri.) and crop processing and smallest European CF for all other processes (table 4-2)

*Scenario B ("MAX CFs"):* maximum CF out of the main cultivation areas for irrigation water (CF agri.) and crop processing and highest European CF (non-agri.) for all other processes (table 4-2)

*Scenario C ("country CFs"):* average out of the main cultivation country CFs for irrigation water (CF agri.) and crop processing and European average CF (non-agri.) for all other processes (table 4-2)

[8] CFs (AWARE) (annual and monthly) are made available via a Google EarthTM-Layers Tool (http://www.wulca-waterlca.org/aware.html) and as Excel download for 11.050 water sheds and per country for agricultural and non-agricultural water use.



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**Table 4-4:** Expected blue water consumption (irrigation water) and agricultural characterisation factors (CF agri.)) of the crops as input data for the three scenarios A - C

| Crop | Buckwheat | Lentil | Lupin |
|---|---|---|---|
| **Scenario A: "MIN CFs"** | | | |
| CF(agri.) min (m3 world-e/m3) | 0.93 | 1.29 | 0.93 |
| $BW_{expected}$ ($m^3$/ha) (country) | 998.8 *(France)* | 1862.3 *(Bulgaria)* | 875.1 *(Germany)* |
| **Scenario B: "MAX CFs"** | | | |
| CF(agri.) max (m3 world-e/m3) | 3.19 | 96.67 | 34.95 |
| $BW_{expected}$ ($m^3$/ha) (country) | 998.8 *(France)* | 1862.3 *(Spain)* | 1054.0 *(France)* |
| **Scenario C: "country CFs"** *(unweighted average of the 3 countries)* | | | |
| CF(agri.) country average (m3 world-e/m3) | 3.94 | 37.94 | 3.98 |
| $BW_{expected}$ ($m^3$/ha) | 728 | 2868 | 1054 |
| **European average CF (non-agri) for all non-agricultural processes (m3 world-e/m3)** | | | |
| Scenario A: "MIN CFs | 0.16 | | |
| Scenario B: "MAX CFs" | 80.64 | | |
| Scenario C: "country CFs" | 30.01 | | |

**Results**

Figure 4-6 shows the water scarcity footprint results for scenario A) to C) regarding the two exemplarily examined food products: lentil and buckwheat (BWF LePi) based and lupin and buckwheat (BWF LuPi) based VMA-fiber food product.



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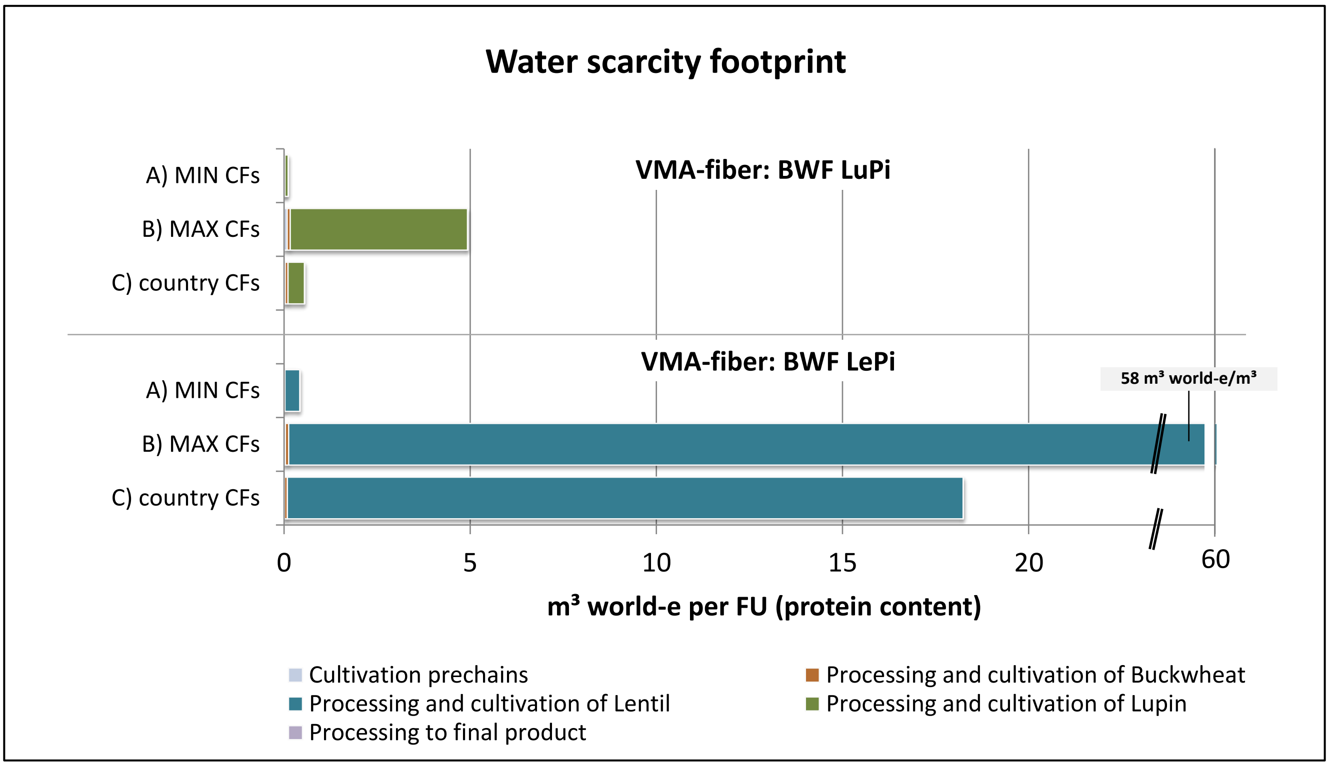


**Figure 4-6:** Sectoral water scarcity footprint results of Lentil and buckwheat (BWF LePi) based and Lupin and buckwheat (BWF LuPi) based VMA-fiber food product for following characterization factor scenarios: A) minimum CFs(AWARE), B) maximum CFs(AWARE) and C) country CFs(AWARE)

First of all, the sectoral bars and underlying numbers show that irrigation water dominates the water scarcity footprint results across all scenarios and examined food products. Therefore, the following discussion focuses on irrigation water use for crop cultivation.

The minimum and maximum CF scenarios show the whole bandwidth of the potential water scarcity for potential cultivation in more humid or arid regions. A high variability in results occurs for crops which are partly grown in arid regions of southern countries. It is clearly visible that the water scarcity differs due to regional climate differences in north and south Europe (Figure 4-5). However, the results are driven not only by the water scarcity characterisation factors, but also by the amount of irrigation water. A high scarcity of water in a region is often accompanied by low precipitation as well as high evaporation and therefore high irrigation rates. Additionally, the crop yields have an effect on the area which has to be irrigated and therefore the amount of irrigation water. For example, a larger area has to be irrigated for the production of lentils than for lupines due to a three times lower yield of lentils than lupins. Especially, the lentil results highlight the water scarcity issue of growing plants in arid countries. Whereas the cultivation in humid regions (e.g. in Germany, Poland or Bulgaria) shows the lower range of water scarcity results. The graphs of scenario A (MIN CFs) show that bothproducts could be cultivated with relative low impacts on water scarcity. In scenario D (European average country CFs) the average amount of irrigation water per hectar is assumed multiplied by the country characterisation factors. The results of scenario C (average country CFs) are in the middle of the minimum and maximum results.

The results show a high variability in water scarcity footprints depending on the cultivation watershed. Especially crops which are partly grown in arid regions of southern countries show a



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high variability in results. For example, the potential impact on water scarcity of lentil cultivation may differ by the factor 140.

The results based on average country CF may be useful for giving a first orientation, but display neither the potential nor the risks associated with water scarcity for cultivation of specific crops. The assessment demonstrates very clearly that it is important to look at the regional water availability and whether crop cultivation in an area would deprive another freshwater user (human or ecosystem) or future generations in an irreversible way.

Following questions have been raised related to management of crop cultivation and water scarcity:

- What is the driver (crop specific, economic) to cultivate the crops in the respective countries and cultivation regions?
- How does the yield perform by cropping in more humid or arid regions?
- How could the protein-rich crops be introduced in more humid areas?
-

It would be necessary to answer these questions for the discussion of strategies on European self-sufficiency in proteins and water scarcity aspects.



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# 5. Conclusive summary

## 5.1. P2F product lines examined

In the report presented here, the environmental impact profiles of the following four innovative protein-rich food prototypes (P2F prototypes) were assessed and compared against conventional animal-based and where appropriate also against soy-based (modern) reference food alternatives:

1. Fiber-like vegetable meat alternative („VMA-fiber")
   Conventional alternative: chicken breast meat
2. Spread-like vegetable meat alternative ("VMA-spread")
   Conventional alternative: pork-based Leberwurst (liver paté)
3. Vegetable burger alternative („Vegetable burger")
   Conventional alternative: beef burger
   Modern alternative: soy burger
4. Lentil protein based milk alternative („Vegetable milk")
   Conventional alternative: cow milk
   Modern alternative: soy milk

The first prototype was examined with two different protein sources combined with two different sources of flour

- 1.A.1 Lupin-based VMA-fiber with Amaranth flour ("VMA-fiber AF LuPI")
- 1.A.2. Lupin-based VMA-fiber with Buckwheat flour ("VMA-fiber BWF LuPI")
- 1.B.1 Lentil-based VMA-fiber with Amaranth flour ("VMA-fiber AF LePI")
- 1.B.2. Lentil-based VMA-fiber with Buckwheat flour ("VMA-fiber AF LuPI")

The second prototype was examined with three different taste variants each with specific combination of ingredients:

- 2.A. "VMA-spread type leberwurst"
- 2.B. "VMA-spread type tomato"
- 2.C. "VMA-spread type curry"

The third prototype was examined with two different protein sources:

- 3.A. "Lupin Burger"
- 3.B. "Lentil Burger"

## 5.2. Important assumptions

To put the LCA results in the right perspective a couple of points should be taken into consideration.

- The P2F crop processing and food preparation data from P2F partners were at pilot or laboratory scale. For the purpose of the LCA selected parameters such as overall "protein yield per protein content of crops" and "energy efficiency" were adjusted so as to simulate operation at small/medium industrial scale. Overall this "up-scaling" was done in a conservative way to avoid an overestimation of the process performance.



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