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Integrated Assessment and Policy Synopsis

Organisation name of lead for this deliverable:

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PP	Restricted to other program participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Remark on additional LCA Scenarios

The P2F prototypes developed during the project, especially the "VMA extrudate"[1] and "vegetable milk" prototypes, mostly contain protein isolates from lentils and lupins. Due to the fact that lentil has a relatively low crop yield (around 1 t/ha), LCA results of plant-based foods showed some flaws particularly regarding the indicators "Land Use" and "Aquatic Eutrophication". During the 4th annual meeting in Utrecht (NL) in June 2019, it was suggested by the consortium that the LCA might be extended in order to examine the potential of improved protein efficiencies along the whole process chain of P2F prototypes. This would be done by implementing scenario simulations according to the following points:

- higher protein crop yields
- a more efficient protein extraction
- improved use of sides-streams

Simulation 1: Higher yielding legume crop as protein source

- Assumption A: replace lentil production in the existing LCA models by faba beans with the latter having crop yields above 3 t/ha

Simulation 2: combination of simulation 1 with improved protein processing

- Assumption B: 75% of protein contained in lentil can be obtained as protein isolate[2]

Simulation 3: Combination of simulation 1 and 2 with high value use of sidestreams

- Assumption C: Economic value for legume flour assumed to be around 50% of that of legume protein isolate[3] causing a part of the environmental loads being assigned to by-products and therefore being shifted away from the protein isolate.

These scenario variations above were implemented into the LCA models of the VMA extrudate prototype and the vegetable milk prototype. The results are included in this deliverable in the following way:

1. Comparison of the lentil base case and the individual simulations for all LCA indicators. Results are shown graphically and short descriptions are provided in section B 5.3 of this deliverable.

2. The results of simulation 1 are applied in averaging LCA results of P2F prototypes across legume protein sources, i.e. lentil, lupine and faba bean. Those averages are then again applied in the diet scenarios at EU scale, presented further down in section A2 of this deliverable.

3. Also in section A2 the results of simulation 3 are applied in order to calculate additional EU scale scenarios with optimized protein efficiencies.

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[1] In the previous deliverables "VMA fiber". Renaming it was decided during WP leader meeting on October 2nd, 2019, as this is deemed being more adequate from a technical perspective and for the purpose of public communication of results

[2] Protein solubility (PS) is mainly depending on pH, but salt, temperature and raw material are also influencing it. The PS determines the max. protein amount that can be theoretically extracted in the protein extraction step. In addition, there will be losses in the protein precipitation and the separation processes. Within the project, the protein yields in the pilot plant were in the range from 60-62% (extraction at pH 7.5). Based on optimised conditions in the lab (86% extraction yield, 83% precipitation yield or 90% UF yield) the protein yield will range from 72-77%.

[3] This number is based on expert judgement of WP3-Partners

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A. Integrated Sustainability Assessment

1. Summary

The integrated sustainability assessment consists of an analysis of strengths, weaknesses of as well as opportunities and threads (SWOT) for innovative plant-based protein foods on the one hand and an assessment of the environmental effects of a protein diet shift on the other hand.

The SWOT analysis provides information on how environmental and socio-economic impacts are interrelated. It shows that innovative plant-based protein food ideally combines positive effects for environment, with increasing or at least stabilizing farmer income and improving health of consumers. There are a number of opportunities to achieve this, particularly the availability of higher yielding protein crops. However, attention should be also paid to possible threats. Any trade-offs need to be overcome to facilitate market success of these innovative products.

In the current situation supporting measures are yet indispensable. Options here would be for example, reduction of coupled payments for meat, or inversely, reduced taxes on vegetables for farmers. Other options include increased public programs providing access to information, training and innovation. On the long run, most optimal would be a true pricing framework within the EU in order to internalise external costs and potentially raise taxes on feed imports into the EU. Support could also be created through public campaigns endorsing plant based protein food from domestic sources.

The innovative P2F meat and cow milk replacers examined in the project show significant overall environmental advantages over the animal-based counterparts. Therefore, a change of protein diet at EU level shifting from animal based to a more plant-based protein consumption would help reduce large amounts of emissions. In addition, improvements are expected in areas that are of current concern regarding environmental or human health, and that are subject of political decision-making, such as greenhouse gases, fine particulate matter or nitrate in water bodies. At the same time, increasingly scarce resources like phosphate and blue water would be preserved at a larger extent.

However, such fundamental environmental improvements would require fundamental dietary shifts. These should not just encompass an exchange of animal-based foods by highly processed vegetable protein replacers, but would also require an inclusion of mildly processed legumes and pseudo-cereals.

This shift would require a major change of our agricultural landscape. Even with optimized protein efficiencies, arable land occupied by legumes and pseudo-cereals would be 10 to 20 times of the current area occupied by legumes in the EU. Therefore, this will only be possible if agricultural land is carefully managed, including new crop rotation strategies and producing crops most suitable to the individual locations.

2. Introduction and Objectives

The intention of part A is to boil down the quite comprehensive findings obtained in the course of the LCA and the sLCA work into rather condensed overarching information and conclusions by means of a SWOT analysis (see chapter 3 of part A). Secondly, it derives a rough estimate on the potential environmental benefits of plant-based proteins, assuming they will achieve a higher share

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within future food consumption patterns. This is done through what we call "protein diet scenarios" (see chapter 4 of part A).

3. SWOT Analysis

The SWOT analysis provides information on how environmental (positive and negative) and socio-economic impacts (positive and negative) are interrelated. The objective here is to identify trade-offs and correlations between socio-economic and environmental impacts of the protein product systems. For that purpose SWOT analysis is carried out.

3.1. Activities for solving this task

A SWOT analysis is a tool to identify and assess the Strengths (S), Weaknesses (W), Opportunities (O) and Threats (T) of the surveyed project, product or company. Activities for solving this task involved the development of a so-called SWOT matrix and the selection of indicators. The general structure of the SWOT matrix as applied in P2F is shown in **Table 1**.

	Favourable	Unfavourable
Internal Factors	Strengths	Weaknesses
External Factors	Opportunities	Threats

Table 1: Structure of SWOT matrix in P2F

Internal factors address strengths and weaknesses, which can directly be attributed to the product systems as examined in the LCA and sLCA that were carried-out by ifeu and UPM. Changes here can be triggered by modifications within the product systems themselves. For example: Higher protein yield through improved protein extraction processes.

External factors address opportunities and threats, which do not depend on internal factors of the product systems but rather on given political, technological, economic, social and environmental framework and related developments. Changes here cannot be triggered by modifications within the product systems themselves. For example: Improved profitability by specifically targeted CAP programs and payments.

The LCA and sLCA studies, which were presented in earlier deliverables D5.1 to D.5.3, are detailed studies of individual P2F-prototypes and variants of those, which were benchmarked against respective traditional products on a case by case basis. The SWOT analysis now aims at a highly concentrated view of the abovementioned results, while putting them into a broader perspective. In order to keep this task feasible and meaningful, a set of indicators that were more limited but politically relevant at EU-level, were chosen and are described below.

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Environmental categories and indicators:

1. Carbon Footprint (CO_2-equivalents)
2. Nitrogen Footprint
   - Aquatic Eutrophication (PO4-equivalents)
   - Fine Particulate Matter (NH_3 emissions as a source of secondary particles)
3. Raw Material Efficiency
   - Phosphate Rock Demand
   - Process Yields
4. Occupation of Agricultural Land
5. Deforestation (based on carbon footprint including Land Use Change)
6. Biodiversity

Socio-economic categories and indicators:

1. Health; nutritional value in terms of content of
   - proteins
   - saturated fat
   - extrudate
   - cholesterol
   - vitamins
2. Rural development / Agriculture conditions:
   - Profitability (Net margin)
   - Yield variability
   - Production price variability
   - CAP direct support (variant: CAP/total direct payments/total value of a specific crop?)
3. Job creation / Gender situation:
   - Labor related: Risk of average wage being lower than non-poverty line
   - Gender related: gender inequality
4. Consumer acceptance
   - Protein affordability

3.2. Results

3.2.1. SWOT plots of plant-based P2F alternatives to animal-based food

The plots of the environmental and socio-economic SWOT are shown in **table 2** and **table 3** respectively.

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Strengths	Weaknesses
Strengths Carbon Footprint • significantly less total GHG-emissions Nitrogen Footprint • substantial reduction of nutrient leaching to water bodies (no N-fertiliser for legumes required) • substantial reduction of N-emissions (especially NH_3 to air (no animal husbandry, no manure management)) Raw Material Efficiency • less phosphate demand as legumes can mobilize phosphor from soils Deforestation (of primary forests) • reduced risk of deforestation as no import of soybeans + palm fruits for feed required Biodiversity • increased agrobiodiversity, gain of soil humus stocks due to cultivation of legumes, less pressure on biodiversity in overseas soybean producer countries	**Weaknesses** Occupation of agricultural land • relatively large agricultural areas required due to still low yields of legumes grown in Europe (as compared to commodity crops like wheat and maize) Raw Material Efficiency • protein extraction from legumes can be associated with a high share of side streams ('by-products' such as hulls, shells, starch) • high energy intensity of processing protein isolates
Opportunities (and supporting measures) • find high value applications of side streams • open markets for new by-products • contribution to clean water policies (nitrate directive compliance in the CAP) • contribution to clean air policies (NEC directive) • taxes on soy-feed imports • enabling of consumption patterns with less meat	**Threats** • low value use of side streams (e.g. if no uses for human food production are found) • land competition with commodity crops (which have higher yields, less yield variability and established markets)

Table 2: Environmental SWOT of vegetable P2F alternatives to animal-based food

Strengths	Weaknesses
Strengths Health • healthier (less cholesterol and saturated fat) • less costs for health Rural development/ agriculture conditions	**Weaknesses** Health • lack of Vitamin B12 (potential lack of iron, if not supplemented)

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• CAP green payment (legumes) contribute to achieve CAP cross-compliance • less costs for inputs such as mineral fertiliser needed • investment smaller than for animal production • possibility of storing the crop (dried grains) until the right time for sale <u>Job creation / Gender situation</u> • no differences <u>Consumer Acceptance</u> • trend towards more healthy life styles	• vegetable alternatives tend to be more processed and with higher levels of additives <u>Rural development/ agriculture conditions</u> • profitability for farmers is lower • high dependency on climate conditions (rain fed crops), smaller areas of cultivation, breeds are not as far developed as traditional crops • higher yield variability • dependency on market price fluctuations (caused by e.g. climate change, small stocks) • overall, markets are still niche at the moment <u>Job creation / Gender situation</u> • no differences <u>Consumer Acceptance</u> • prices for vegetable P2F type products tend to be higher (than meat and cow milk)
Opportunities (and supporting measures) • boost for innovations regarding new recipes, energy- and water-efficient crop processing and high value use of side streams • vehicle for dissemination of information on nutritional value of food to a broader public • greening of CAP • increased payments to farmers • higher skills required (processing) which could lead to higher wages • More types of jobs, jobs are more flexible • Expected increase of market share; e.g. more vegetable protein containing burgers recently been offered by large retailers *Supporting measures:* • reduced taxes on vegetables for farmers, • reduction of coupled payments for meat • increasing information, training and innovation • provide incentives for local protein crop processing industries • regulation of the stock market for "futures investments"	**Threats** • missing/false information • enduring culturally acquired preferences for meat • trade agreements (WTO: reduced taxes for import of soy (legumes) to EU, export subsidies for meat, CAP direct support) • lack of locally based processing (protein crop) industries and sites respectively • uncertain effects of climate change on growing conditions for legumes

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• international observatory of prices, global food crisis of 2008 (knowledge, lesson learned)	

Table 3: Socio-economic SWOT of vegetable P2F alternatives to animal-based food

3.2.2. Correlations and trade-offs

Strengths and weaknesses

A favourable environmental footprint is a clear strength of plant-based protein food produced in the P2F prototype stile. In total, it causes significantly less carbon emissions and demand of non-renewable resources. In addition, using domestic legumes and pseudo-cereals help reduce pressure on natural areas of high value – especially overseas – and foster biodiversity on arable land, both in the EU and globally. This correlates with positive contributions to farmers through CAP green payments as well as with beneficial health aspects for consumers such as lower cholesterol and saturated fat contents. Overall, this results in less external environmental and health costs for society. Under the current CAP regulation it opens ways to the greening of EU agriculture and facilitates achievement of CAP requirements for cross-compliance.

On the other hand, some domestic legumes such as lentils, due to relatively low yields per hectare, tend to have a relatively high land footprint per unit of protein. This again correlates with criteria economically adverse for farmers, such a high yield variations and fluctuations regarding market prices of legume crops. Overall, this may result in a smaller profitability for farmers. Furthermore, protein extraction and concentration is a vital element in creating high-value protein food, but this corresponds with a relatively large amount of by-products and energy demand. Combined with the previously mentioned negative effects for farmers this may eventually lead to higher protein food prices for the consumer (though being healthier).

Opportunities and threads

Opportunities consist of expanding research in breeding of domestic legumes for higher agricultural yields and for improved protein crop processing techniques. Innovative companies developing profitable food applications for use of by-products will have competitive advantages on the food market. This will most probably go along with requests for skilled workers/employees and could lead to higher wages.

On the other hand, a number of serious barriers need yet to be overcome. Trade agreements such as reduced taxes for imported soy or the recent EU-Mercosur agreement are likely to increase the abundance of cheap meat on EU markets. This strongly counteracts activities striving for high quality protein products made from domestic crops. This might further lead to perpetuation of the still prevailing meat-oriented food patterns in the EU, which could result in slowly growing protein crop focused SMEs.

Outlook

The previous discussion shows that innovative plant-based protein food ideally combines positive effects for environment, with increasing or at least stabilizing farmer income and improving health of consumers. There are a number of opportunities to achieve this, particularly the availability of

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higher yielding protein crops. However, attention should be also paid to possible threats. Any trade-offs need to be overcome to facilitate market success of these innovative products.

In the current situation supporting measures are yet indispensable. Options here would be for example, reduction of coupled payments for meat, or inversely, reduced taxes on vegetables for farmers. Other options include increased public programs providing access to information, training and innovation. On the long run, most optimal would be a true pricing framework within the EU in order to internalise external costs and potentially raise taxes on feed imports into the EU. Support could also be created through public campaigns endorsing plant based protein food from domestic sources.

4. Diet change scenarios at EU scale

4.1. Activities for solving this task

The diet change scenarios examine the environmental benefits associated with the substitution of meat and cow milk in the average EU consumer diet by more legume-based diets at an EU level. Activities for solving this task included the definition of food intake patterns and the calculation of protein supply under assumed replacement of animal-based protein intake.

The baseline is the overall food intake in the EU, which was calculated based on FAO data (FAO food balance sheet and food loss and waste factors along the food supply chain)[4]. This calculatory EU food intake is shown in **table 4** on a per person per day basis (column 2) as well as on a total amount per year basis (column 4).

	„EU Food Intake Model“	**„Low Meat Model“**	**„ EU Food Intake Model“**	**„Low Meat Model“**
Food Intake	**[g / cap. / day]**		**1000 t / year**	
Animal-Based				
Pig meat	*61*	*7*	*11.343*	1.753
Poultry Meat	*38*	*29*	*6.945*	5.371
Bovine Meat	*22*	*7*	*4.033*	1.510
Mutton & Goat Meat	*4*	incl. in bovine meat	*664*	
Other Meat	*22*	0	*3.995*	
Animal Fat	*11*		*2.050*	926
Dairy	*433*	*250*	*80.137*	46.300
Fish, Seafood	25	28	4.578	5.186
Eggs	25	13	4.565	2.408

Table 4: Food Intake Reference Data for Diet Scenarios

[4] The underlying data was already documented in D5.1, chapter 3: “Activities for setting up an EU average food flow model”.

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	„EU Food Intake Model“	„Low Meat Model“	„ EU Food Intake Model“	„Low Meat Model“
Food Intake	**[g / cap. / day]**		**1000 t / year**	
Plant-Based				
Cereals, excl. beer	190	232	35.147	42.967
Cereals, incl. beer	24	0	4.434	
Starchy Roots	111	50	20.638	9.260
Sugars	112	31	20.760	5.741
Treenuts	8	25	1.493	4.630
Pulses	7	50	1.236	9.260
Oilcrops	9	50	1.577	9.260
Vegetable Oils	47	40	8.772	7.408
Vegetables	182	300	33.717	55.560
Fruits, excl. wine	155	200	28.728	37.040
Fruits, incl. wine	63	0	11.598	

Table 4 continued: Food Intake Reference Data for Diet Scenarios

A further point of reference is a "low meat model" also shown in **table 4** (see column 3 and column 5). This model is derived from the recommendations found in the recent report of the EAT-Lancet Commission[5] on food consumption patterns considered beneficial for human health and environmental sustainability. It reflects averages of the ranges given in the EAT-Lancet report.

4.2. Scenario assumptions

For the purpose and within the given scope of this study diet change scenarios only examine changes related to meat and cow milk intake. Substitution is calculated with averages of the P2F prototypes, i.e. averages across protein isolates of lentil (low yielding crop), lupine (medium yielding crop) and faba bean (higher yielding crop)[6]. The individual scenarios are shortly described below.

[5] EAT-Lancet Commission 2019: Food in the Anthropocene: healthy diets from sustainable food systems
[6] This is a relative classification within domestic legumes. Staple crops like wheat, maize or canola, which are main components of animal feed, have by far higher crop yields per ha.

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Business-as-usual ("BAU") Scenario

Environmental footprint of overall meat and cow milk consumption in the EU as documented for the "food intake model" in **table 4** with the following simplifications:

- Mutton and goat intake meat is added to bovine meat intake
- Other meat intake is added to pig and poultry meat intake with 50% each

Minus 10%-Reduction Scenario

Environmental footprint of an even reduction of meat and cow milk consumption by 10%. The thereby reduced amounts are substituted by equal amounts (on a mass basis) of P2F innovative food products in the following ratio:

- Reduced chicken meat: 100% replacement with VMA Extrudate prototype
- Reduced pig meat:
  - 50% replacement with VMA Extrudate Prototype
  - 50% replacement with VMA Spread Prototype
- Reduced bovine meat:
  - 75% replacement with VMA Extrudate Prototype
  - 25% replacement with VMA Burger Prototype
- Reduced cow milk: 100% replacement with Vegetable Milk Prototype

Strong-Reduction Scenario

In this scenario the environmental impact of reducing meat by 70% and cow milk by 40% (see **table 4** ("low meat model"). Replacement with P2F-Prototypes follows the same ratios as described for the "10%"-Reduction scenario.

Strong-Reduction Scenario + Pulses

This scenario is almost identical to the previous scenario with the exception that 50% of the protein provided by VMA Extrudate in the "Strong"-Reduction scenario is supplied by faba beans and peas consumed as grains, i.e. with only minor processing after harvest involved.

Strong-Reduction Scenario (P2F Optimized)

This scenario is derived from the "strong reduction scenario" but using Simulation 3 as described in the introductory section, i.e. P2F VMA extrudate and vegetable milk prototypes with

- improved crop yields per area
- improved protein processing
- improved use of side streams

Strong-Reduction Scenario (P2F Optimized) + Pulses

This scenario builds on the previous scenarios. Here again, 50% of the protein provided by VMA Extrudate is supplied by faba beans and peas consumed as grains.

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4.3. Results

Graphical results of protein food diet scenarios by environmental indicator are shown in figures 1 to 8. Each figure depicts a stacked bar per scenario, with the stacks showing the contributions of the individual protein food categories to the overall scenario result. The environmental indicators were already explained in D5.3. Therefore, the results are discussed with a focus on main differences between the diet scenarios.

Carbon Footprint (Climate change), see Figures 1 and 2

Protein intake with a diet of strongly reduced share of meat and cow milk would have only half or even smaller carbon footprint compared to the current average diet ("BAU"). Besides the reduced intake of animal protein in the scenario, also the switch to a high share of poultry and a significantly lower share of pig ("strong reduction scenario") contributes to the substantial reduction of the carbon footprint. The reduction would be even larger (in absolute numbers) if direct land use change would be accounted for.

NO_3-driven Water Footprint, see Figure 3

Along with the stepwise reductions of meat and cow milk in the diet, also less emissions of nutrients are likely to be emitted to fresh water bodies (which in addition to other benefits would substantially contribute to maintain or even improve the quality of drinking water). If a part of the legumes is prepared as grains (i.e. with only slight processing) the water quality would be even less affected.

The simulations of improved protein efficiencies ("P2F-Optimized" Scenarios) show that further reduction could be achievable especially through using legumes with higher or improved crop yields.

NH_3-driven Particulate Emissions, see Figure 4

Protein intake with a diet of strongly reduced share of meat and cow milk would cause only around a third of the fine particles emissions as compared to the current average diet ("BAU"). A larger avoidance of pig meat would help support such development.

Phosphate Rock Demand, see Figure 5

Similarly as for the other indicators, a strong reduction of meat and cow milk and substitution by plant-based proteins would cause only around a half of phosphate rock (used for production of mineral P-fertilizer) as compared to the current average diet ("BAU").

Non-renewable Primary Energy Demand and Process Water Footprint, see Figures 6 and 7

These two indicators give good hints on where differences between highly processed and only slightly processed food can show-up. Protein for VMA extrudate in the P2F prototypes is extracted and isolated from lentils and lupines. Lentils have a lower protein content than lupines, while the latter have a relatively high protein content but also a relevant content of oil. Thus, to obtain protein isolates from lentils requires a significant amount of energy and water (to a somewhat lesser extent in the case of lupines), whereas additional energy for de-oiling is required for lupines. On the other hand, direct consumption of legumes, e.g.in the form of grains, can substantially help save energy and water.

Demand for agricultural land, see Figure 8

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Results show that a replacement of 10% of meat and cow milk by P2F prototypes will not cause major changes in demand for agricultural land. A strong reduction however, that would reduce agricultural land demand visibly, would be through a shift from the remaining meat towards poultry, and especially increasing the share of consumption of whole grains of beans and peas. Furthermore, land use could be further reduced with improving the protein efficiency of P2F prototypes; and again especially through using legumes with higher or improved crop yields

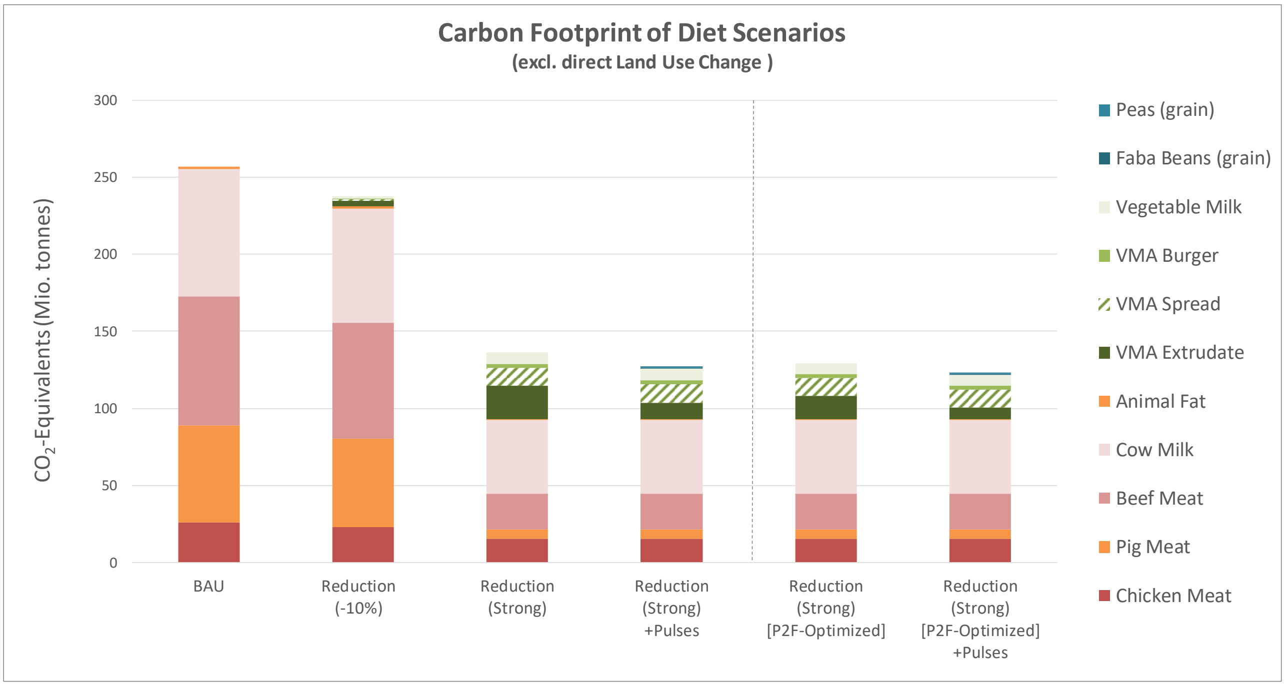

Figure 1: GHG emissions of different protein diet scenarios

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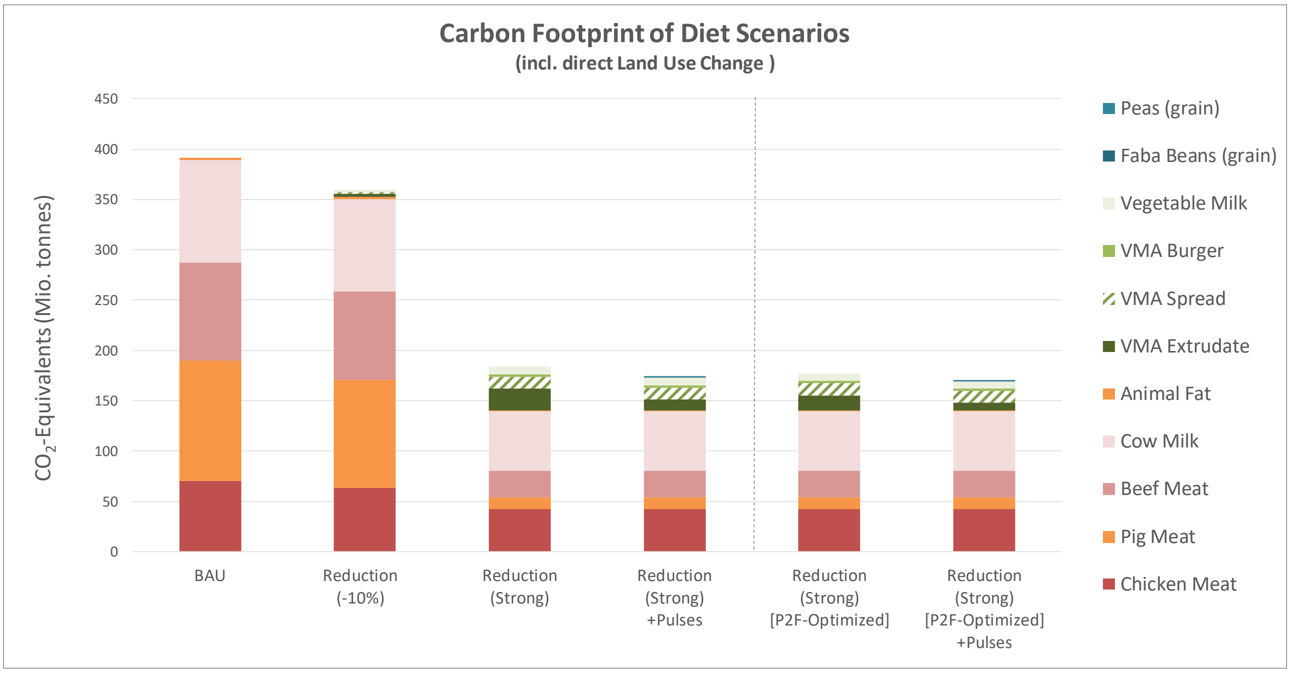

Figure 2: GHG emissions including LUC of different protein diet scenarios

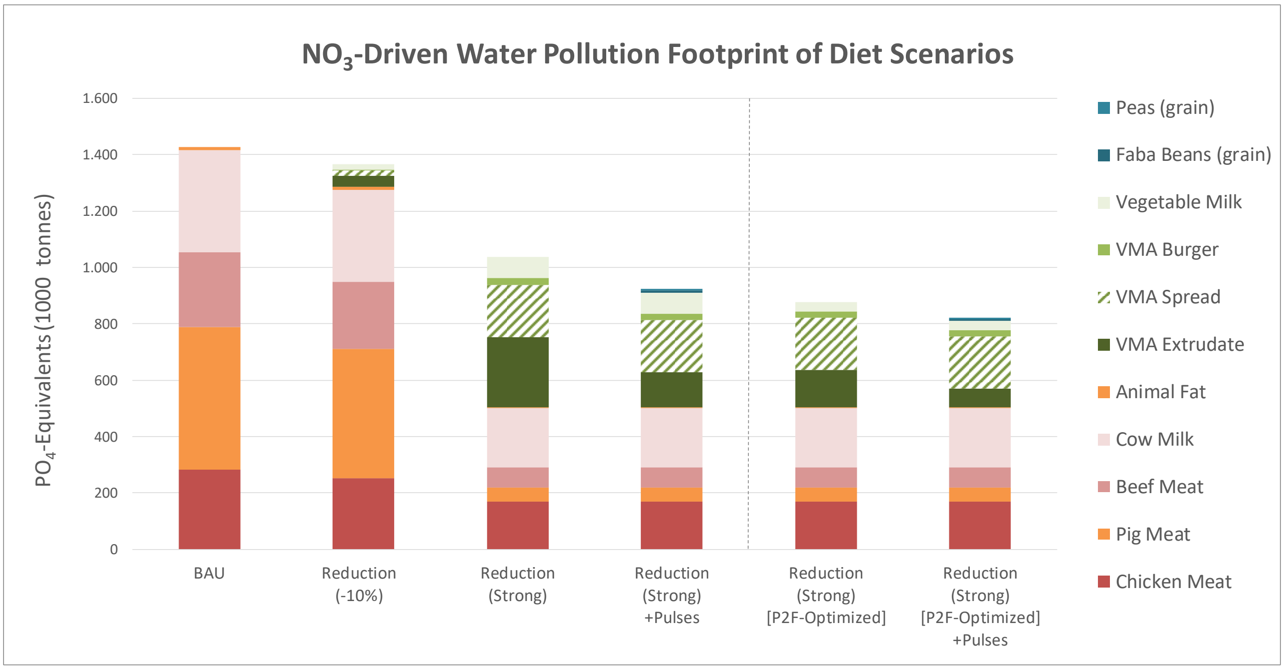

Figure 3: Aquatic Eutrophication of different protein diet scenarios

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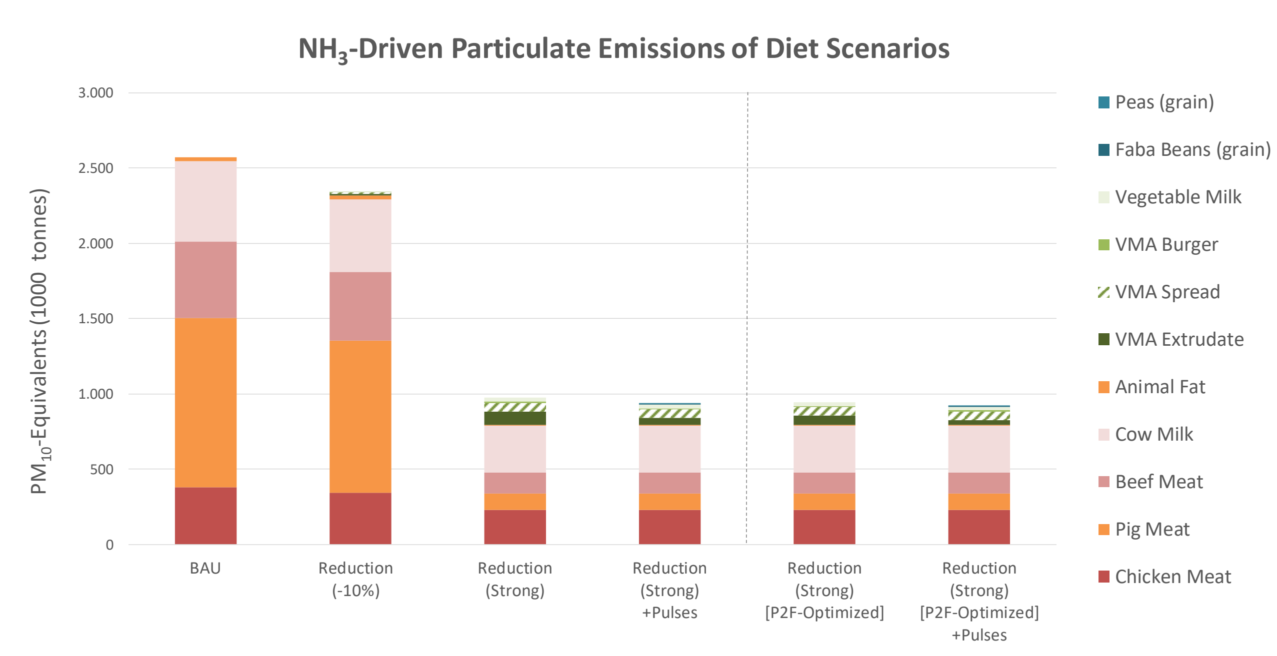

Figure 4: Fine Particles emissions of different protein diet scenarios

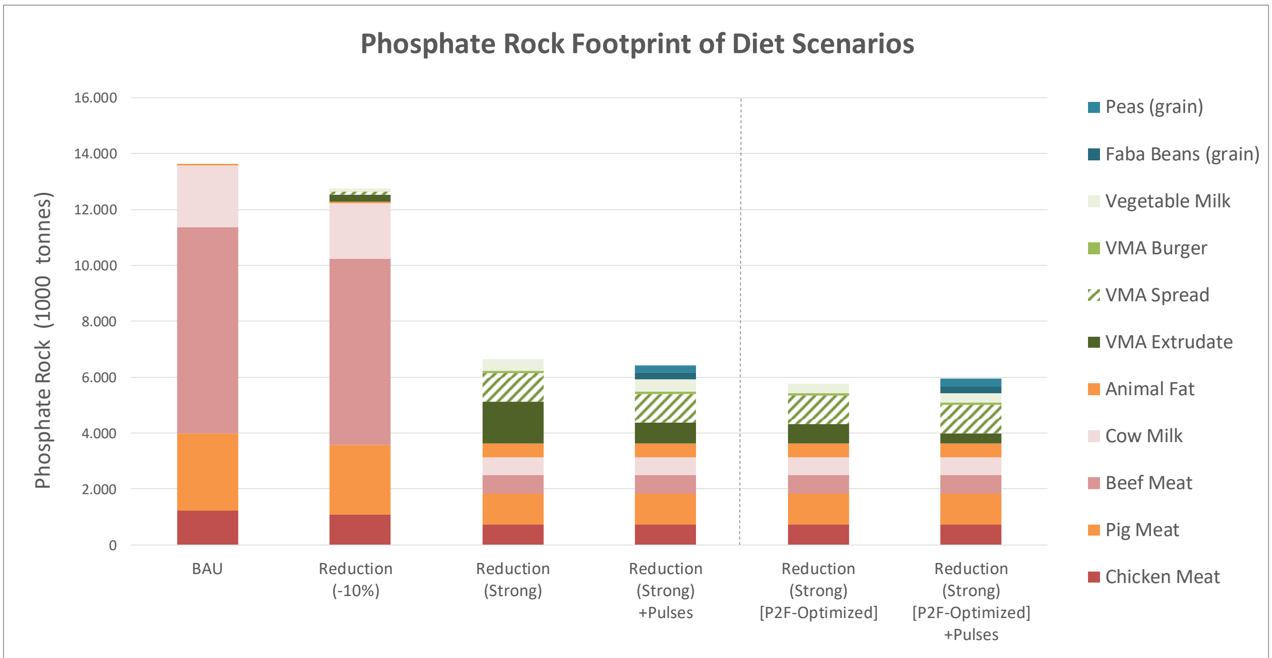

Figure 5: Phosphate Rock demand of different protein diet scenarios

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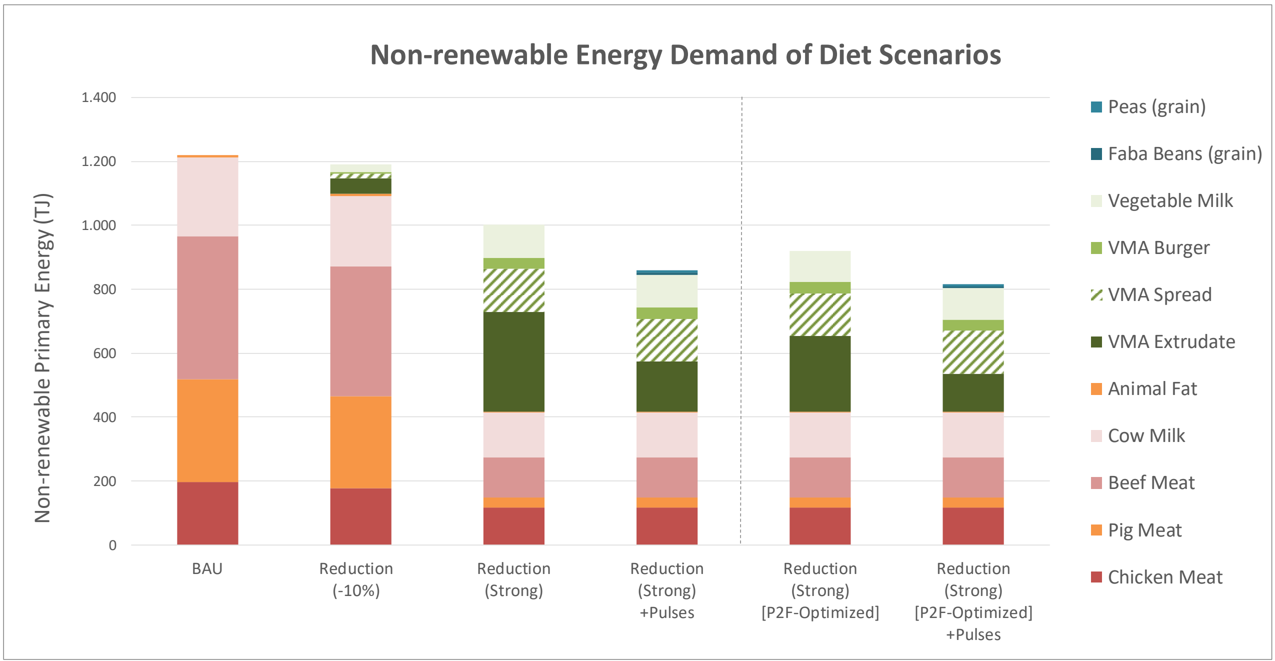

Figure 6: Non-renewable Primary Energy demand of different protein diet scenarios

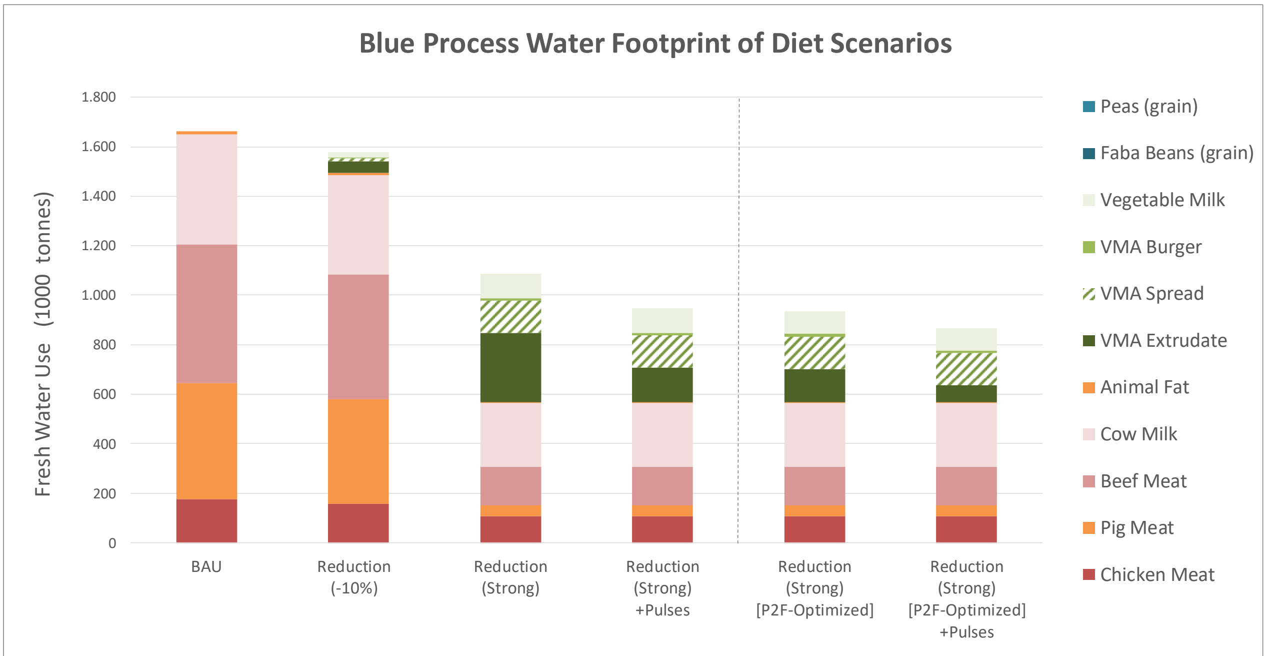

Figure 7: Blue Process Water demand of different protein diet scenarios

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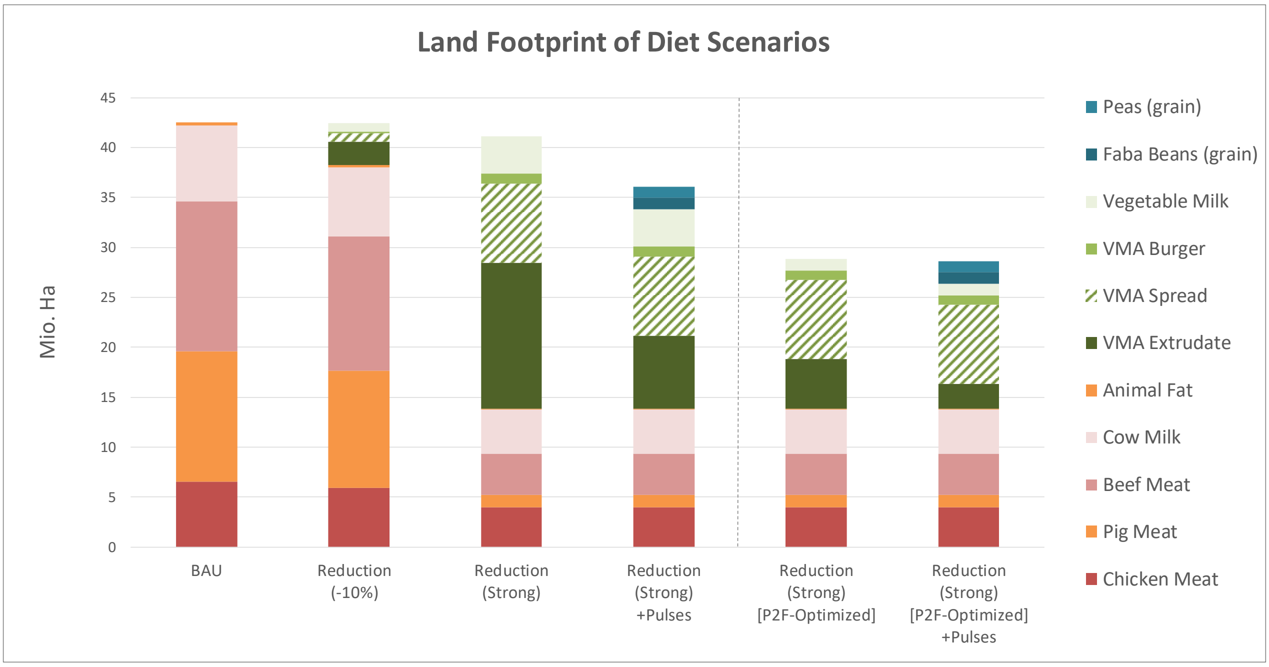

Figure 8: Agricultural area demand of different protein diet scenarios

4.4. Outlook

The innovative P2F meat and cow milk replacers examined in the project show significant overall environmental advantages over the animal-based counterparts. Therefore, a change of protein diet at EU level shifting from animal based to a more plant-based protein consumption would help reduce large amounts of emissions in areas which are of current concern regarding environmental or human health and which are subject of political decision-making, such as greenhouse gases, fine particulate matter or nitrate in water bodies. At the same time, increasingly scarce resources like phosphate and blue water would be preserved at a larger extent.

However, such fundamental environmental improvements would require fundamental dietary shifts. These should not just encompass an exchange of animal-based foods by highly processed vegetable protein replacers, but also a share of mildly processed legumes and pseudo-cereals.

This shift would require a major change of our agricultural landscape. Even with optimized protein efficiencies, arable land occupied by legumes and pseudo-cereals would be 10 to 20 times of the current area occupied by legumes in the EU. Therefore, this will only be possible if agricultural land is carefully managed, including new crop rotation strategies and producing crops most suitable to the individual locations.

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B. Policy Synopsis

This section/document is a brief and easy-to-read stile report of the content and findings of the PROTEIN2FOOD project, with a focus on sustainability aspects. Its intended audience are decision-makers from politics, industry and research, who usually have little time available and therefore can benefit from condensed and focused information.

1. Summary

P2F prototypes may be produced using a diversity of domestic legumes and EU-grown pseudo-cereals. All innovative P2F meat and cow milk replacers examined in the project show significant overall environmental advantages over the animal-based counterparts. VMA burger shows the best results with far less impact for all environmental indicators when compared to the beef burger.

On the other hand, the differences are smallest in the case of VMA extrudate against chicken breast, with even 3 of 12 indicators showing a higher impact for VMA extrudate. Yet, those (few) higher impacts could be converted into lower impacts with using legumes with crop yields of above 2 t/ha if combined with optimized protein extraction during protein processing from legume crops.

Low processed soy products overall have a better environmental profile than those of the corresponding P2F prototypes. However, when P2F prototypes are compared against products with soy isolates, i.e. higher processed soy products, no clear environmental difference between both types of protein food can be found.

Regarding socio-economic factors, the study showed that, when assuming a switch from animal-based to plant-based protein consumption, farmers most likely are the most negatively affected stakeholders and consumers the most positively affected ones. This particularly applies for replacement of meat and less for replacement of cow milk. Furthermore, these differences may be more or less accentuated in individual regions as is shown using the example of Spain compared to Europe as a whole.

2. Introduction and Objectives

Deliverables 5.1, 5.2 and 5.3 contain a huge amount of rather detailed, often highly technical data and information. The policy synopsis is designed to be an easy-to-read and highly condensed overall summary of work package 5.

3. Activities for solving this task

Activities for solving this task include the creation of graphical result formats enabling a better synopsis of the environmental and socio-economic positioning of plant-based protein foods. Furthermore, sustainability of P2F prototypes is discussed from a larger market and societal perspective.

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4. The PROTEIN2FOOD project

Goal and Scope

The P2F project aims at developing prototypes of innovative, nutritious and **protein-rich plant-based food,** as an alternative to conventional animal-based foods such as meat and cow milk. The prototypes are made from **domestic legumes** such as lentils, faba beans and lupines, combined with **pseudocereals,** such as buckwheat, quinoa and amaranth. Only buckwheat is currently stably domestic to the EU but quinoa and amaranth production is increasing and introduced around Europe.

The prototypes serving as meat and cow milk replacers developed in the project are:

1. Extrudated vegetable meat alternative („**VMA-extrudate**")
2. Paté-type vegetable meat alternatives ("**VMA-spread**")
3. Vegetable burger alternatives („**VMA burger**")
4. Vegetable milk alternatives („**Vegetable milk**")

The prototypes in the course of the P2F project have been subject to taste testing and sustainability assessment amongst others variables.

Sustainability Assessment

The sustainability assessment aimed at better understanding of the environmental and socio-economic advantages and disadvantages of domestic legume-based food in order to;

a. identify **environmental hotspots** and **optimization potentials** during the development of the P2F prototypes, and
b. directly **compare** the expected sustainability performance of **P2F prototypes with** that of "**traditional animal-based food products**"

The sustainability assessment was based on a product life cycle approach and comprised both, an environmental and a social Life Cycle Assessment (hereafter referred to as **LCA** and **sLCA**). **Environmental footprints** and **socio-economic impact profiles** of the examined products were calculated and displayed using a set of meaningful **indicators**.

The LCA covered the process steps of

- agriculture,
- crop processing and
- food production.

These were investigated because the main differences between P2F prototypes and traditional animal-based products were expected to occur during those stages. The sLCA additionally included the consumption phase to be able to include aspects such as health and consumer choice into the assessment.

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5. LCA findings at a glimpse

5.1. Environmental footprint of P2F prototypes

The environmental footprints of P2F prototypes and those of their animal-based counterparts are shown in **figure 9** and **figure 10**. The comparisons were conducted on a mass basis[7].

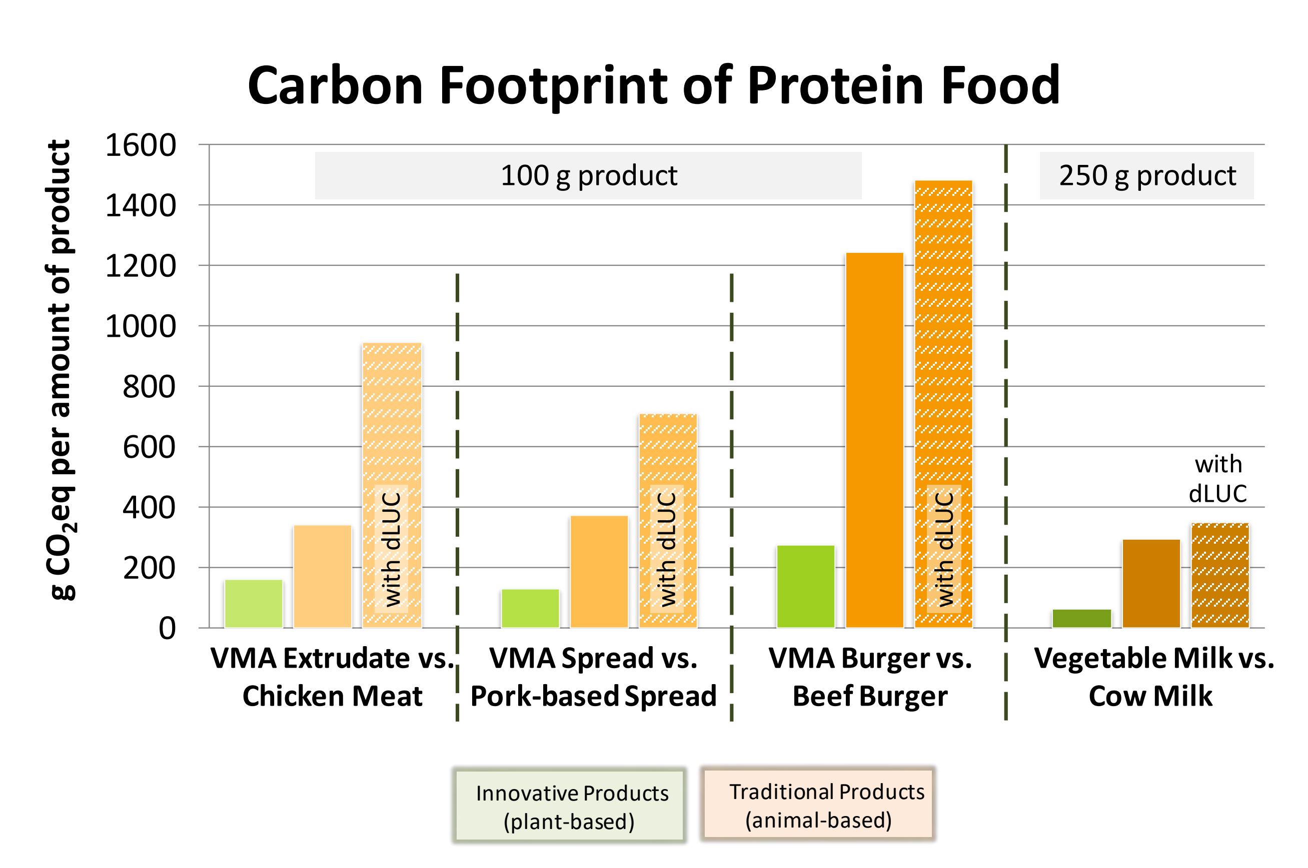

Figure 9: Carbon footprint of P2F VMA prototypes versus animal-based alternatives (dLUC: direct land use chance associated with imported soy and palm oil feed)

From **figure 9** it becomes clear that P2F prototypes have a far better carbon footprint than those of bovine meat and cow milk in particular. The advantage is the smallest when compared against chicken meat. However, if direct land use change associated with overseas soy import for feed is taken into account, carbon footprint of each type of meat is manifold as compared to P2F prototypes.

In **figure 10** the relative differences of four P2F prototypes and their animal-based counterparts are shown using spider-diagrams. Each diagram displays a pair of P2F prototype (average of several variants of the same prototype) and animal-based product (average of high intensive and medium intensive husbandry) with the worse result per indicator set to 100% and the better result shown as

[7] As P2F meat replacers tend to have a higher percentage of proteins, which on the other hand might be slightly less digestable than animal proteins the mass based comparison deems appropriate.

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percentage of it.

The resulting patterns all show a similar shape, with the VMA burger showing the best results with far less impact for all indicators when compared to the beef burger. On the other hand, the differences are smallest in the case of VMA extrudate against chicken breast, with even 3 of 12 indicators showing a higher impact for VMA extrudate.

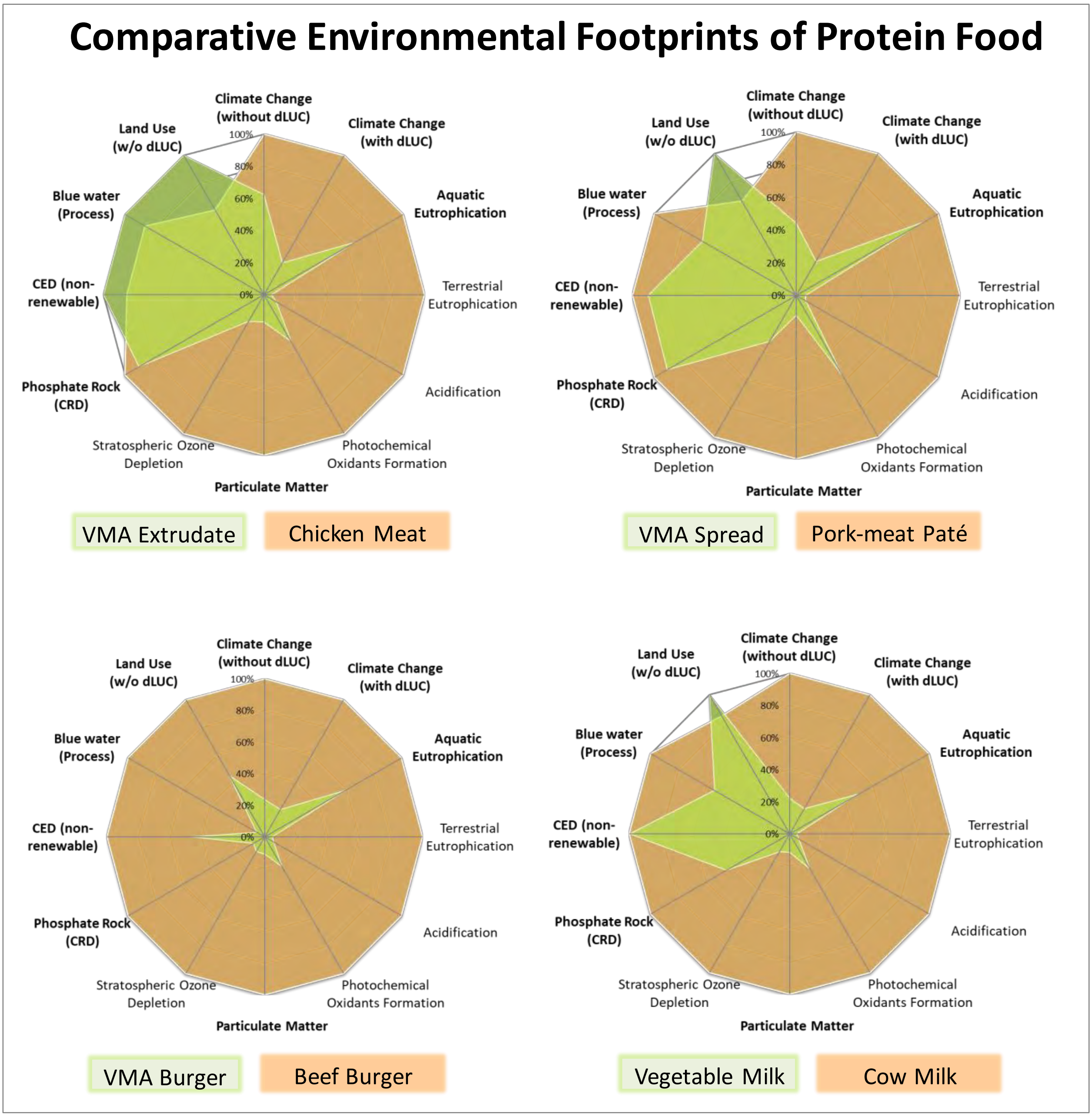

Figure 10: Environmental footprint of P2F VMA prototypes versus animal-based alternatives (Diagram shows worse impacts at 100% (outer circle) and smaller environmental impact in the centre)

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This situation can be explained by the fact that

- of all meat, poultry tends to have the best environmental profile
- of all 4 VMA prototypes, VMA extrudate has the highest content of protein isolates. Isolates require a substantial effort for processing as compared to simple grinding of grains to mixes of starch and protein.

It should be mentioned here, that the environmental assessment also encompassed a biodiversity assessment applying a semi-quantitative approach[8]. Not surprisingly, it was discovered that legume and pseudo-cereal containing protein-rich food provides huge opportunities to improve biodiversity on land.

5.2. Environmental footprint of P2F prototypes versus soy-based products

P2F prototype style food, i.e. protein-rich food made from domestic legumes, will have to compete with vegetable products, mainly from soy, already on the market and available on the shelves. For this reason it was also of interest to find out, how P2F prototypes would compare with soy-based products.

<u>P2F prototypes versus relatively lowly processed soy products</u>

Soy products such as soy milk and tofu burgers have been on the markets for several years now. In both cases, the main processing step is extraction of a part of the oil contained in the beans, which has a high market value on its own. Almost all remaining soy components, i.e. mainly soy protein and starch, are used to produce soy milk and soy tofu burgers, undergoing only minor processing such as coagulation in the case of tofu.

Figure 11 shows that these soy products overall have a better environmental profile than those of the corresponding P2F prototypes.

<u>P2F prototypes versus relatively highly processed soy products</u>

Recently, an increased presence of soy products containing soy protein isolates and concentrates can be observed. Soy burgers imitating beef burgers are probably the most outstanding example. The processing steps here are rather similar to those applied for P2F prototypes. As is visible in **figure 11** the environmental profiles of P2F burger and soy isolate burger do not show a clear overall advantage or disadvantage of one over the other.

[8] See deliverables 5.2 and 5.3 for more information

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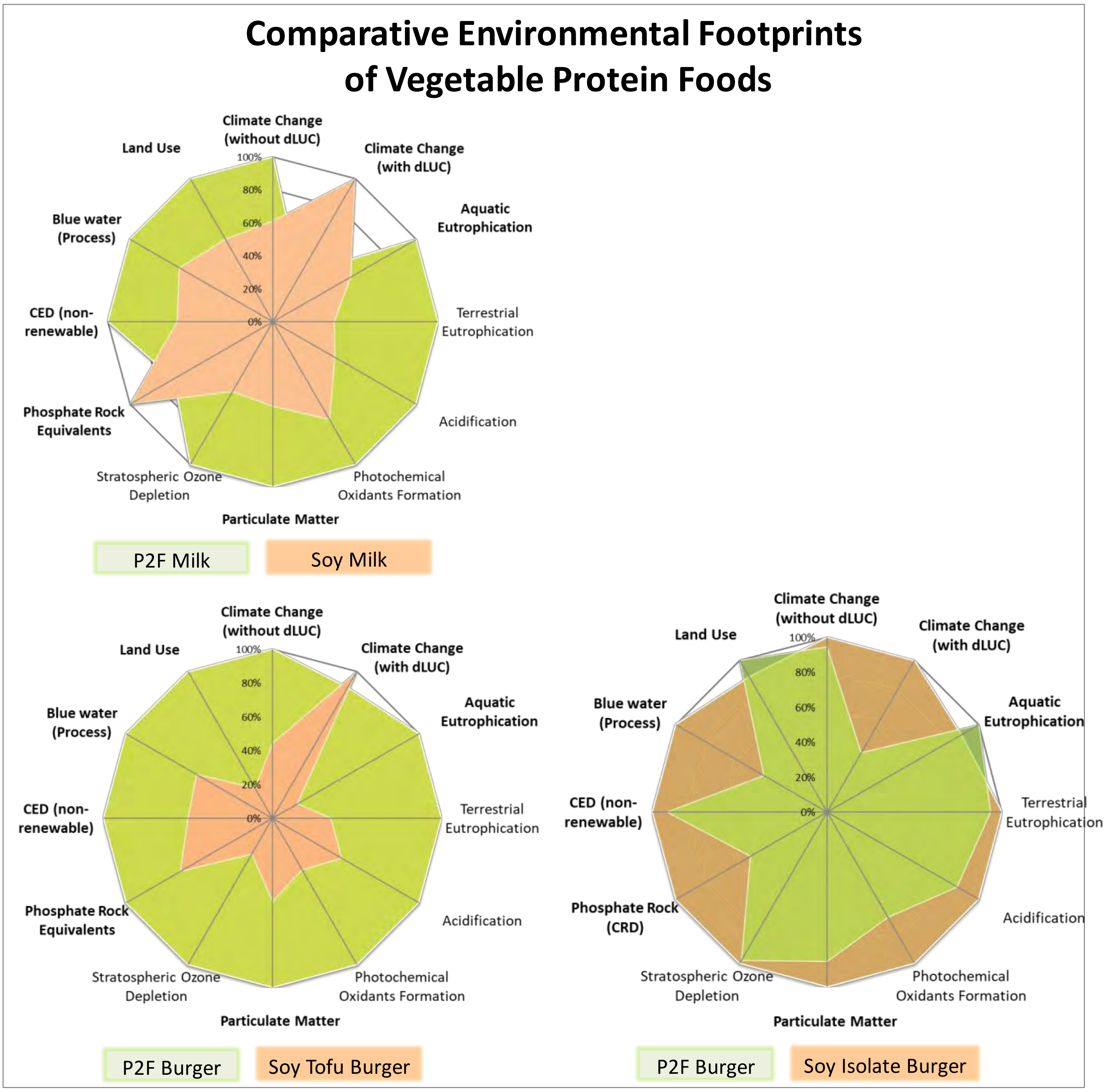

Figure 11: Environmental footprint of P2F VMA prototypes versus soy-based alternatives
(Diagram shows worse impacts at 100% (outer circle) and smaller environmental impact in the centre)

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5.3. Optimization potential of P2F prototypes

In this section below, optimized scenarios of the P2F prototypes are presented. The background is that the P2F prototypes developed during the project, especially the “VMA extrudate” and “vegetable milk” prototypes, mostly contain protein isolates from lentils and lupines. However, lentils have particularly low crop yields (around 1 t/ha) causing a relatively high land footprint per unit of protein.

The improvement potential of P2F prototypes through optimized protein efficiencies is therefore explored in form of scenario simulations with the following assumptions:

- Simulation 1: higher protein crop yield (3t/ha as e.g. achieved by faba beans)
- Simulation 2: higher crop yield combined with a more efficient protein extraction
- Simulation 3: higher crop yield + more efficient protein extraction combined with improved use of sides-streams

The resulting environmental profiles of P2F prototypes produced from lentil proteins (base case) as compared to the optimization simulations are shown in **figure 12** with the example of VMA extrudate versus chicken meat and **figure 13** with the example of vegetable milk versus cow milk. In both cases the assumption of higher yields prove to be decisive for achieving a better land footprint than that of the traditional counterparts. Simulations 2 and 3 show further improvements for all environmental indicator though at less extent.

Interestingly, non-renewable energy demand of P2F prototypes stays rather close to that of the traditional counterparts despite the quite far-reaching assumptions for optimization. This is related to the fact that protein extraction and isolation requires a substantial amount of energy.

Looking at the same comparative scenarios, **figures 14 to 16** show absolute result numbers for the carbon footprint, land footprint and aquatic eutrophication (NO_3-footprint). Those results again point to the importance of crop yields, not for the carbon footprint, which is favourable per se for P2F prototypes, but also for the land footprint and – in the case of VMA extrudate – for the emissions of nitrate to water bodies too. The results indicate that the land footprint of P2F prototypes require crop yields of around 2 to 2,5 t/ha in order to be better than that of the traditional counterparts.

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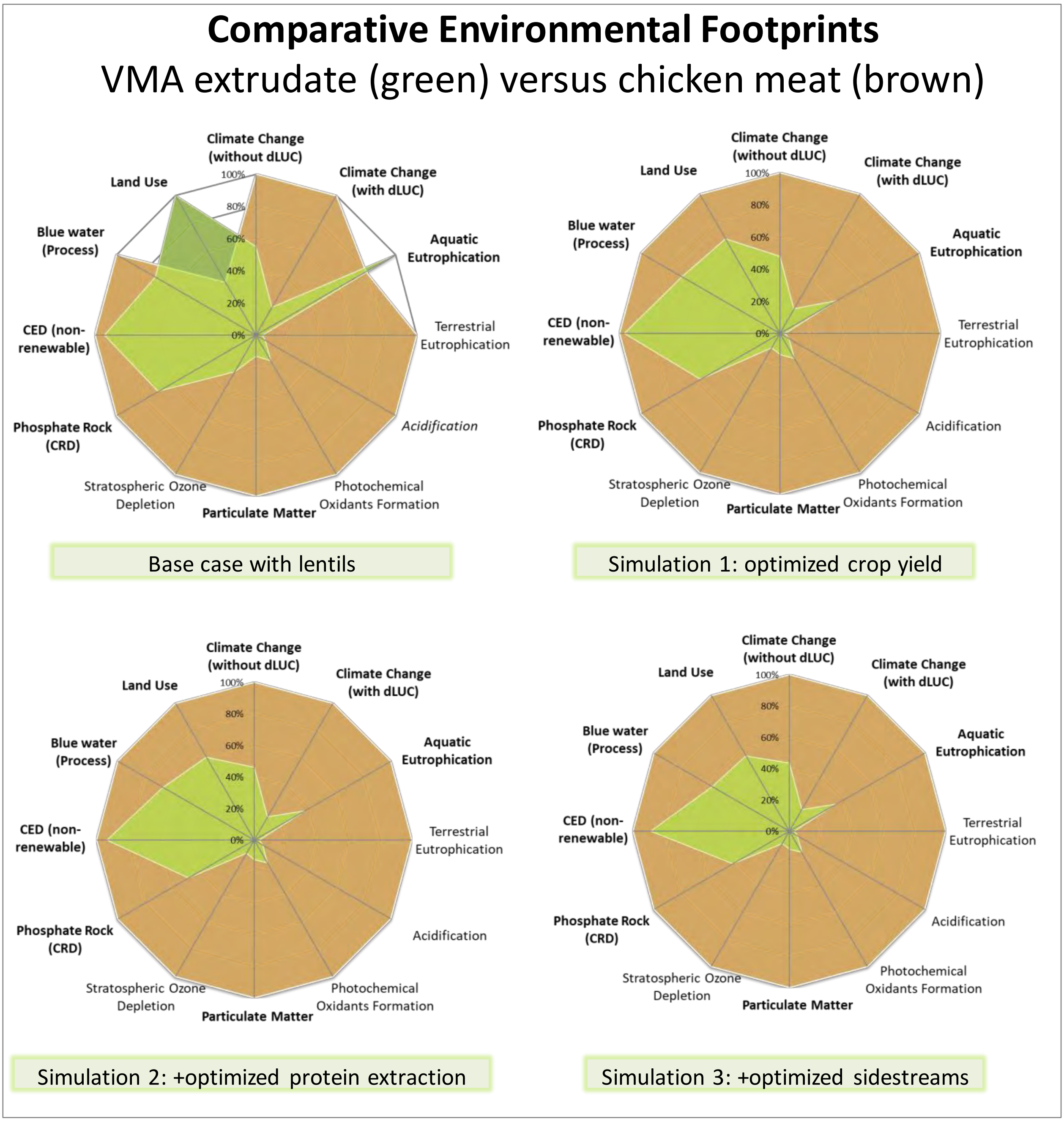

Figure 12: Environmental footprint of VMA spread variants versus chicken meat (Diagram shows worse impacts at 100% (outer circle) and smaller environmental impact in the centre)

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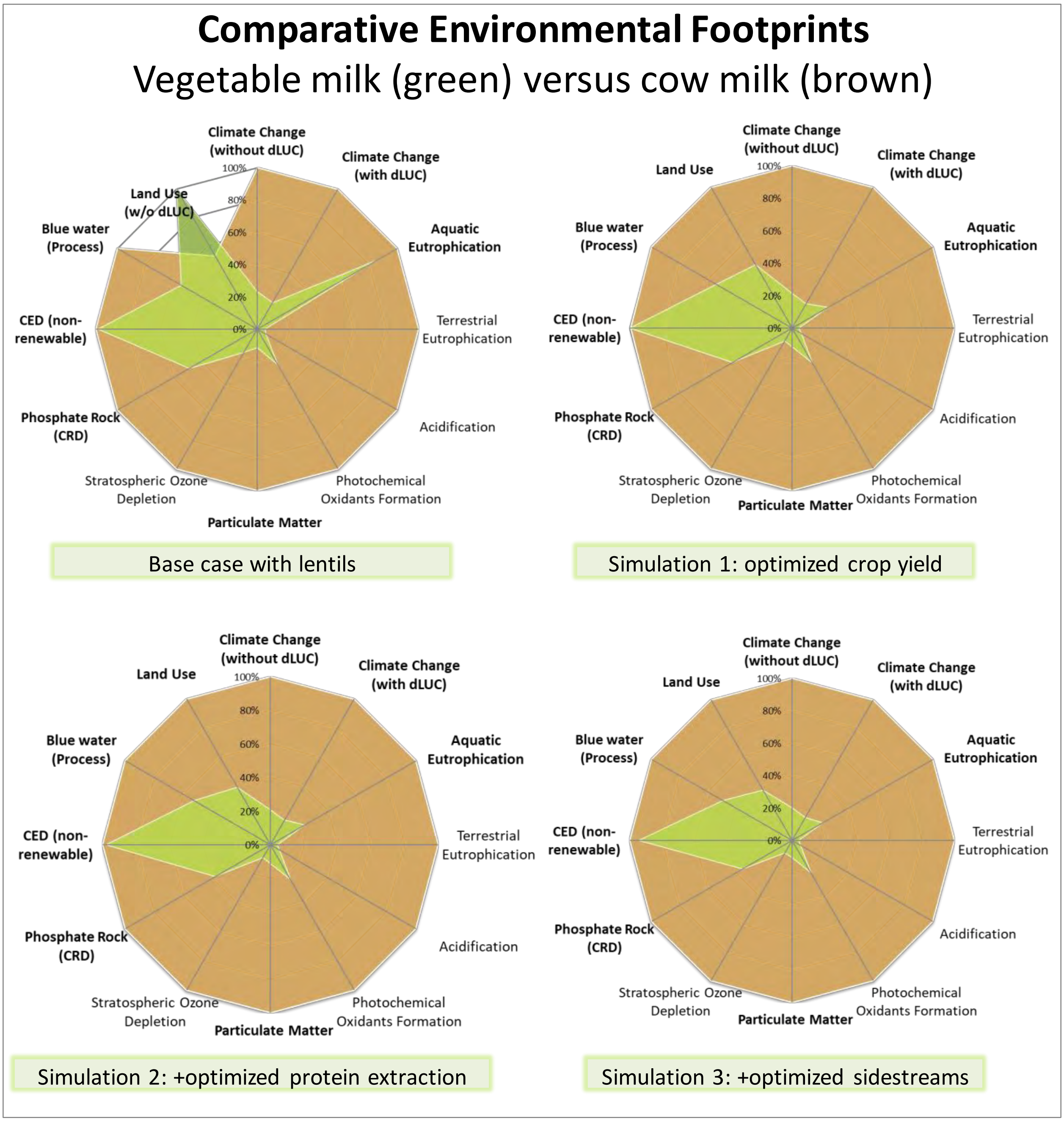

Figure 13: Environmental footprint of vegetable milk variants versus cow milk
(Diagram shows worse impacts at 100% (outer circle) and smaller environmental impact in the centre)

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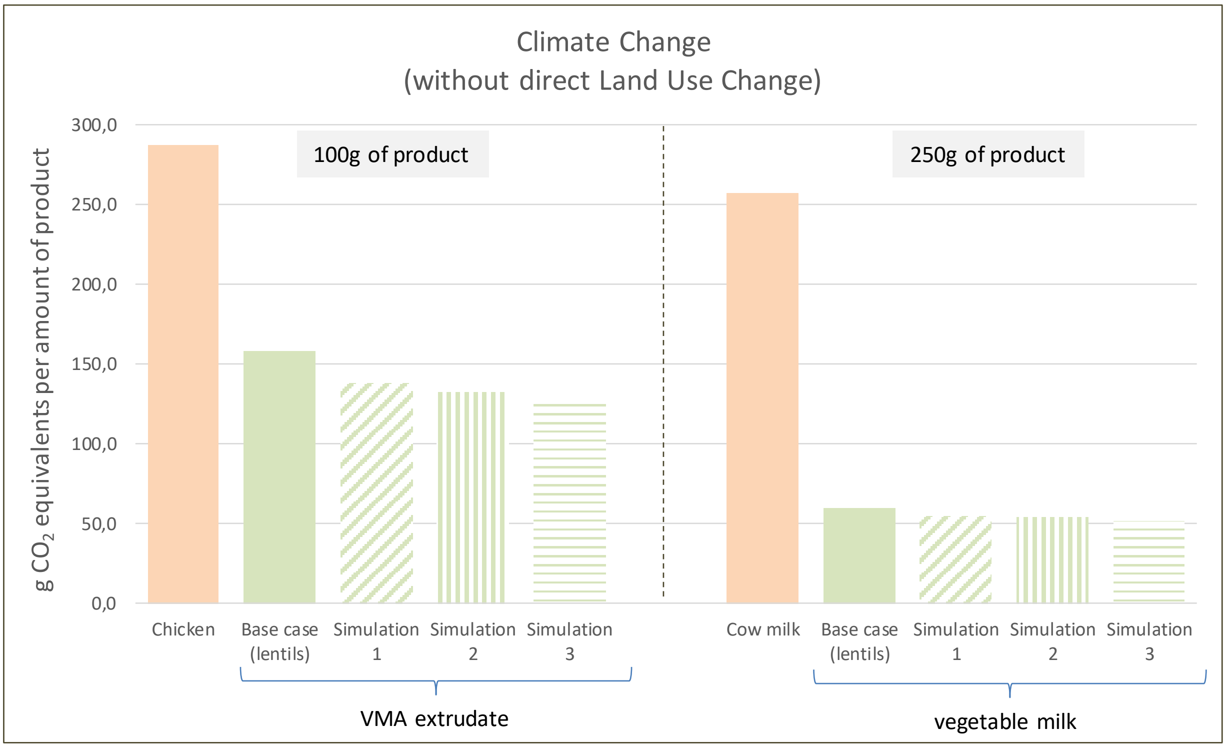

Figure 14: Carbon footprint of P2F prototype simulations versus animal-based alternatives
Base case: proteins from lentils; Simulations: improved higher crop yield (1), protein extraction (2); sidestream use (3)

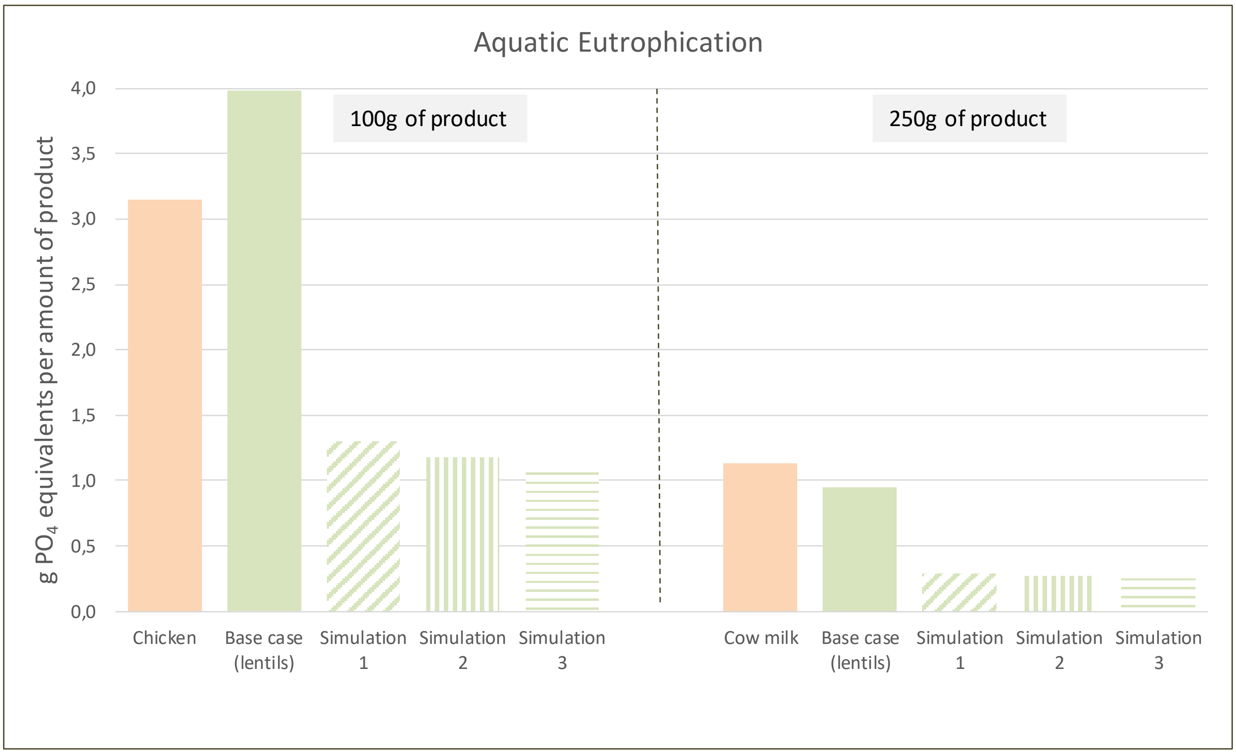

Figure 15: Aquatic eutrophication caused by P2F prototype simulations versus animal-based alternatives
Base case: proteins from lentils; Simulations: improved higher crop yield (1), protein extraction (2); sidestream use (3)

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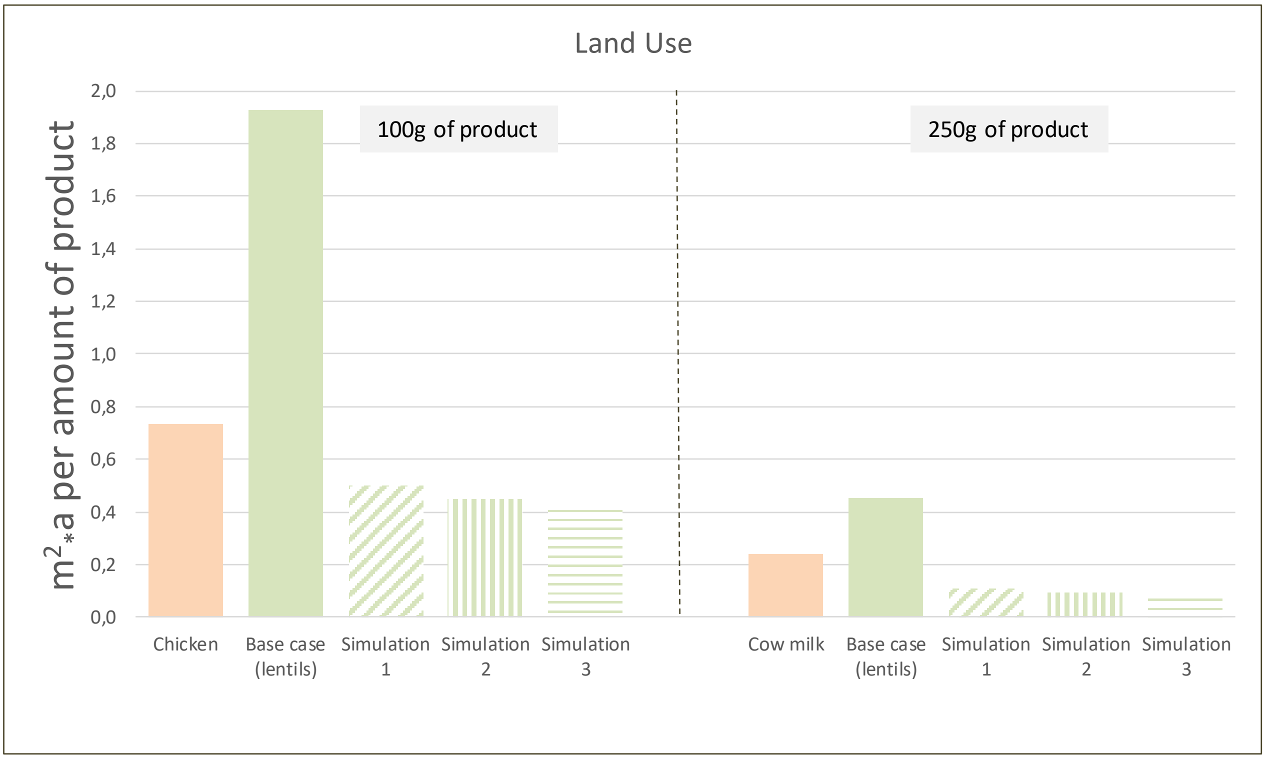

Figure 16: Land footprint of P2F prototype simulations versus animal-based alternatives
Base case: proteins from lentils; Simulations: improved higher crop yield (1), protein extraction (2); sidestream use (3)

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6. s LCA findings at a glimpse

The diagrams below show the comparison of the socio-economic impacts along the life cycle of four protein-rich products. First, *VMA extrudate ("Fiber-like vegetable meat" in the graph)* compared to *traditional meat alternative*, second, *P2F VMA-spread type Leberwurst* compared to *Traditional spread type leberwurst variant 1*, third, *P2F prototype fresh vegan pasta*[9] compared to *traditional fresh egg pasta*, and lastly, *P2F prototype vegan milk* compared to *traditional cow milk ("dairy" in the graph)*.

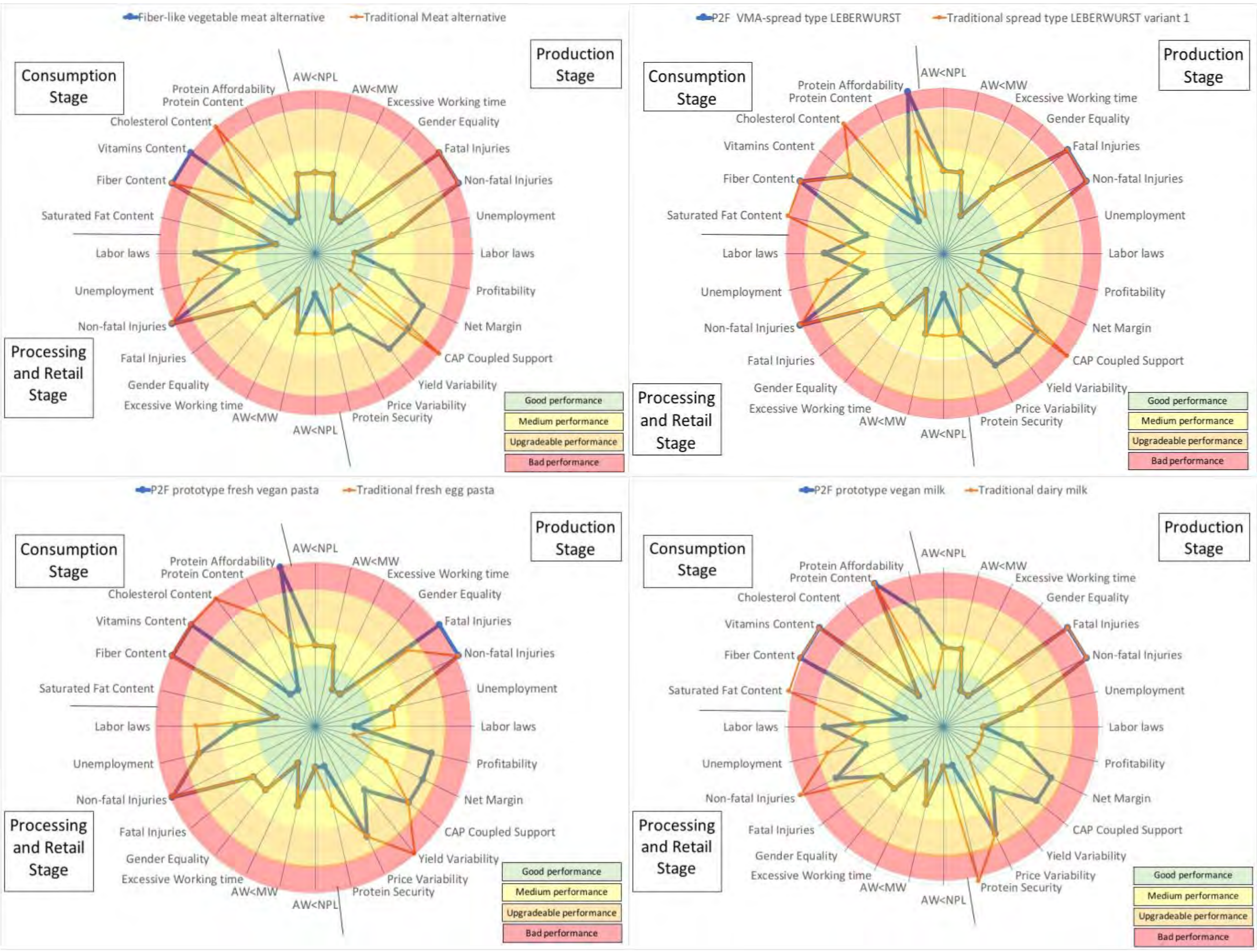

Figure 17: Socio-economic profiles of P2F VMA prototypes versus animal-based alternatives

A comparison of all the spider diagrams helps identifying patterns along the products. Here can be seen four product comparisons: Paté, Pasta, Milk and Meat. The first interesting fact is that vegetable

[9] Pasta is also covered in the LCA (see Annex of D5.3.). On request by the reviewers the case of burgers was put into the focus of the environmental assessment instead. This request came in a very late phase when D5.3 was already mostly finished and could therefore not be included into the sLCA.

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product have a worse performance profile regarding farmers indicators ("profitability", "net margin", "Cap Coupled Support", "yield variability", and "price variability"). Also, fatal and non-fatal injuries can be considered a hotspot for agricultural worker, and non-fatal injuries a hotspot for P&R workers. On the contrary, vegetable products seem to have good performance regarding saturated fat and cholesterol content, which affects consumers. However, this should be interpreted carefully as the addition of nutritional values such as aminoacid profile, phytosterol content, or others could drastically change the results.

Having detected that the impacts are more related to stakeholder category than to impact category, we separated stakeholder to investigate how each of them would be affected by a decrease in consumption of animal-based products and an increase in consumption of vegetable-based products. **Figure 18** below shows the negative impacts on stakeholders of each protein-rich product. Each colour represents a product comparison, solid coloured for animal based and horizontal striped for vegetable-based products.

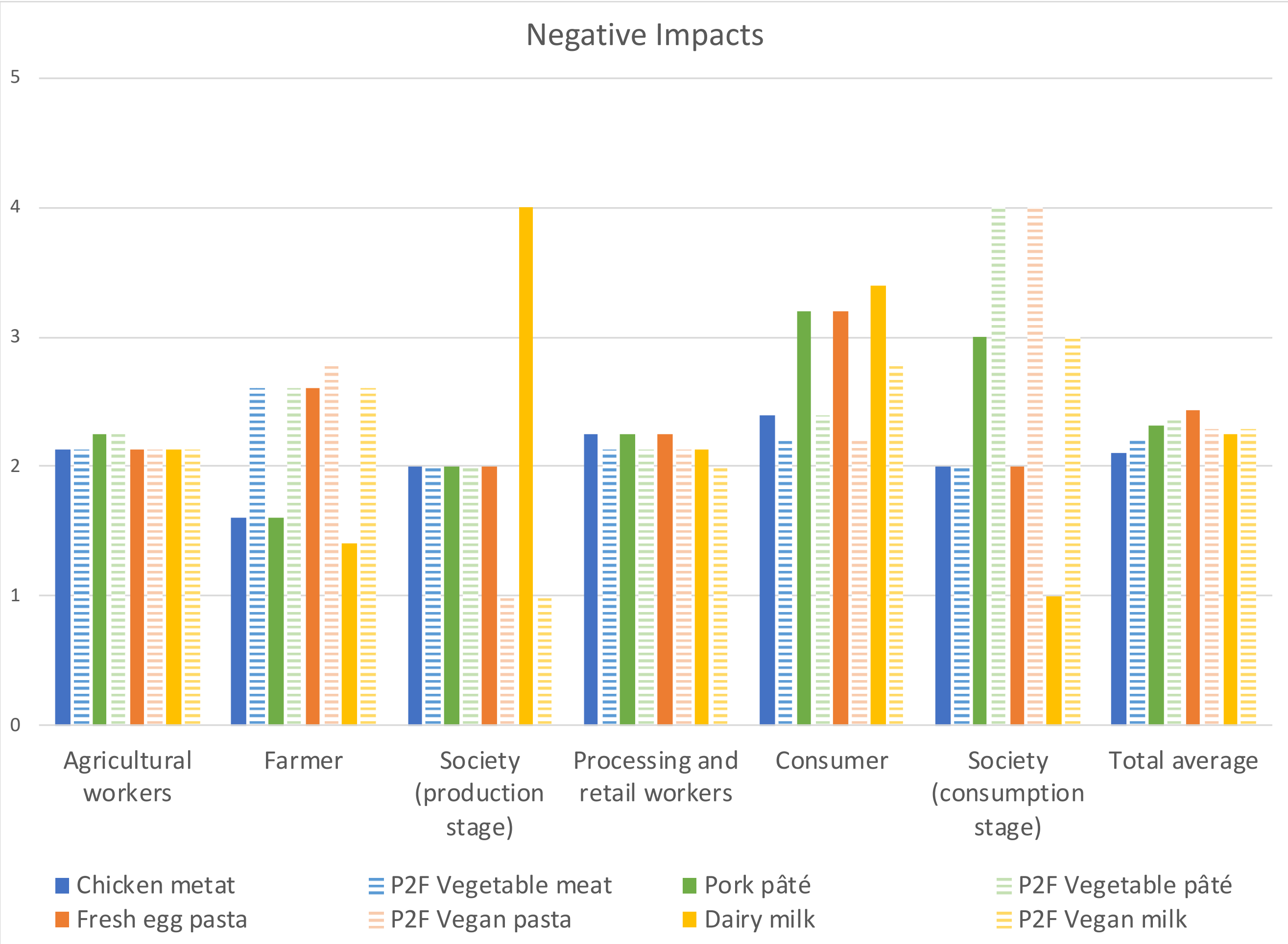

Figure 18: Selected socio-economic indicator results of P2F VMA prototypes versus animal-based alternatives

As this is a representation of negative impacts, an increase between animal and vegetable products means an increase in negative impacts. On the contrary, a decrease means a decrease of negative impacts (or increase of positive impacts). From there, it can be seen that stakeholders such as farmers and society at a consumption stage are negatively affected, while P&R workers and consumers would be positively affected. Society at a consumption stage refers to all those indirectly affected by the consumption of these products (e.g. increase in protein supply could eventually affect other products´

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prices), while society at a production stage refers to all those affected by the production of P2F products (e.g. new job creation could eventually boost local economy). This reinforces the idea that special attention should be put on the production stage of plant-protein based products, mostly regarding profitability, yield and price variability.

Looking at the average value per product (right side of **figure 18**), it can be seen that (discarding bread), 3 out of four vegetable products have a worse overall performance profile than their traditional counterpart, with Pasta as the only exception. Negative impacts would increase a 5% for meat, 2% for paté and milk, and would decrease 6% in the case of pasta.

It is especially interesting to compare the impacts on stakeholders at different spatial scales, in this case European and Spanish scale. This cross-scale comparison was made for four products (vegan and dairy milk, and vegan and chicken meat) (Figure 19).

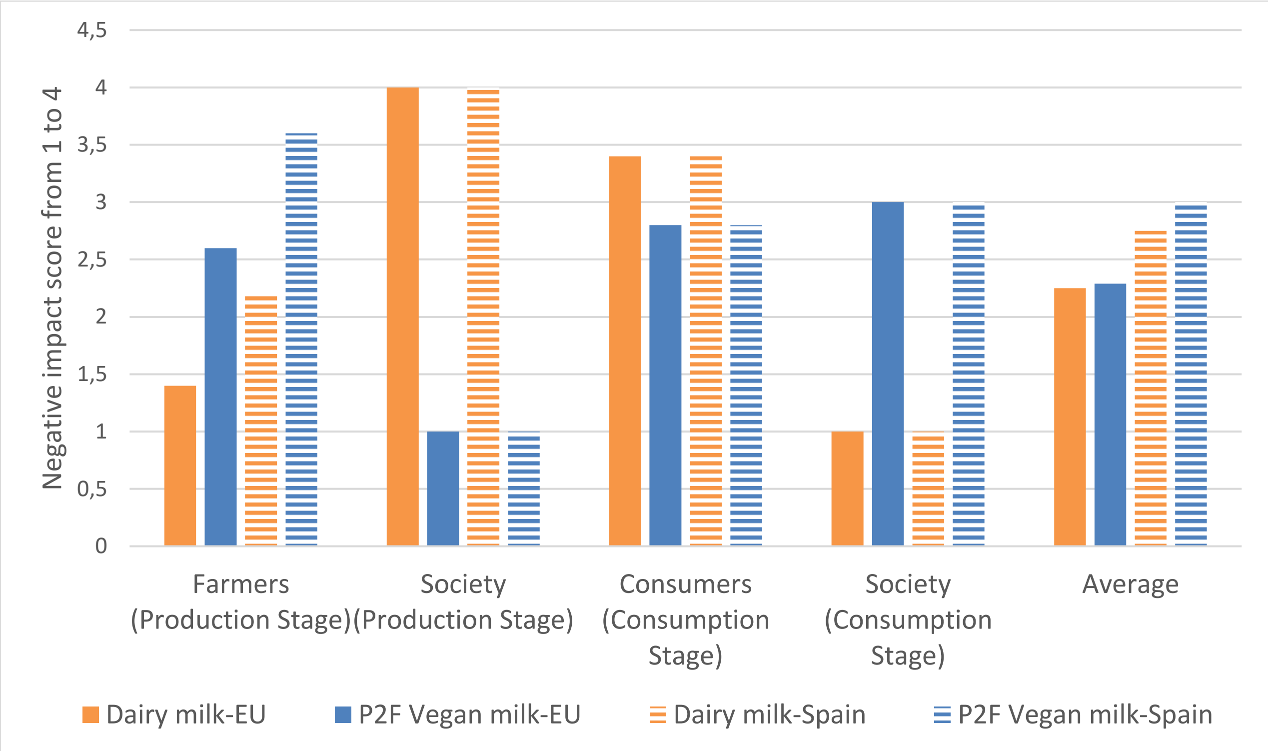

Figure 19: Negative socio-economic impacts of dairy milk and vegetable milk by stakeholder category in the EU and in Spain - Source: Sangro, S. (2019)[10]

It can be seen that at both EU and Spanish scale, farmers and society at a consumption stage would be negatively affected, and consumers and society at a production stage would be positively affected with vegetable based protein products (Figure 19). Furthermore, all stakeholders except farmers seem to have a similar assessment profile at both Spanish and European scale, as no differences can be found in their final scores, despite raw data being slightly different. For instance, European scale animal and vegetable protein price (society in the consumption stage) is different than at a Spanish scale, but given the evaluation scale in each case, they are similarly assessed (good and upgradeable for animal and vegetable protein respectively at both scales). Lastly, when looking at the average

[10] Sangro, S., 2019. Socio-economic Life Cycle Assessment (S-LCA) of plant protein rich products and of animal-based products. Master's Thesis. Agricultural Economics. Polytechnique University of Madrid. Available at: www.oa.upm.es

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overall scores, it can be seen that differences between animal and vegetable products are bigger at a Spanish scale than at a European scale. Specifically, when moving from animal protein to vegetable protein, average negative impacts increase in less than 2% at a European scale (going from 2.25 to 2.29 in a scale from 1 to 4) while at a Spanish scale, average negative impacts increase in more than 9% (going from 2.75 to 3 in a scale from 1 to 4) (Figure 20).

Figure 20 shows how stakeholders are affected by the life cycles of vegan meat and chicken meat at both European and Spanish scales.

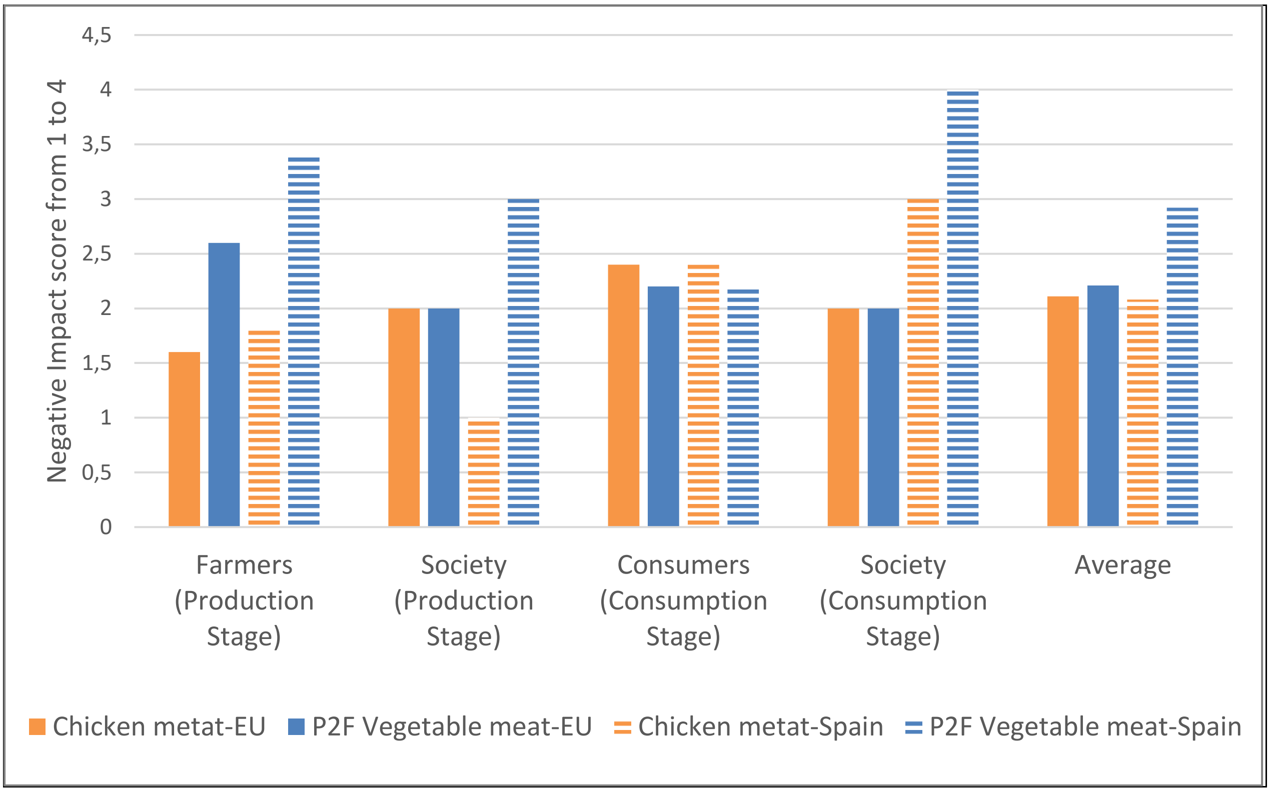

Figure 20: Negative socio-economic impacts of dairy milk and vegetable milk by stakeholder category in the EU and in Spain - Source: Sangro, S. (2019)[11]

When comparing P2F vegetable meat with chicken meat, at an European scale, farmers would be negatively affected, consumers would be positively affected, and society would be neutral as it will be affected neither in the production nor in the consumption stages. Things are slightly different at a Spanish scale where consumers are positively affected but farmers and society both at production and consumption stage are negatively affected. In this case, society at a production stage is negatively affected due to the low crop yield of lupine in Spain, which translates into a low overall protein yield compared to other products of this analysis. Society at a production stage is negatively affected due to higher prices of plant-based high protein products in Spain in comparison with the German market, which has been used as a proxy in the European scale S-LCA.

Lastly, when looking at the average overall scores, it can be observed that differences between animal and vegetable products are bigger at a Spanish scale than at a European scale. Specifically, when moving from animal protein to vegetable protein, average negative socio-economic impacts increase

[11] Cf. ibid.

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in less than 5% at a European scale (from 2.11 to 2.21 in a scale from 1 to 4) whereas at a Spanish scale, average negative impacts increase in more than 40% (from 2.08 to 2.92 in a scale from 1 to 4).

Findings of this analysis can be summarized as follows:

- **Farmers**, the most **negatively affected** stakeholder, and **consumers** the most **positively affected**. Same pattern than at European scale.
- **More differences in meat category than in milk category** between vegetable protein products and animal protein products. Same pattern at different spatial scales.
- **More differences in Spain than in Europe** between vegetable protein products and animal protein products.

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C. Conclusions (of part A and B)

The P2F project managed to develop several innovative food prototypes suitable for replacement of pig, poultry and beef meat as well as cow milk. This comes just at the right moment in time, as the P2F prototypes broaden the supply of sustainable protein-rich food options. Obviously, other vegetable alternatives have been on the market for quite some time already, mostly recurring to soy as well as – but with much lesser market share - peas and wheat protein as a protein source. The strength of P2F prototypes lies in their high quality protein but low fat content, as well as attractive textures and tastes. It is important that – at the same time - they may be produced using a diversity of domestic legumes and EU-grown pseudo-cereals. Furthermore, the recent trend towards highly processed soy products, especially burgers with a meat-like feel, shows that P2F prototypes are likely to meet a growing demand for vegetable food for being appealing also to ´meat lovers´.

All innovative P2F meat and cow milk replacers examined in the project show significant overall environmental advantages over the animal-based counterparts. The same is true for the soy-based products examined within P2F. Yet, in the opinion of the authors of this deliverable, there are three main areas, which deserve further attention to enable sustainable vegetable protein consumption, that could not only feed the still relatively small amount of vegetarians, but everyone. These three areas are described below.

1) Need for improved efficiencies

Relevant factors here are:

- *Crop yield*
  Crop yield of legumes is between 1 t/ha (lentils) and >3 t/ha (faba beans), which is far smaller than that of a staple crop like wheat for instance.

- *Protein content and protein quality*
  Crop yield of dry grains of legumes is between 24% (lentils, faba beans, peas) and up to 40% (lupines, soy), which is far better than that of a staple crop like wheat (around 12%) but in itself a relatively wide range. On the other hand, lupines and soy contain vegetable oil, which has to be separated from the protein to allow for concentration.
  Protein quality is often considered to be best in soy, but P2F results indicate that lentil proteins are highly nutritious and show good food design properties.

- *Role of domestic legumes*
  All legumes with the exception of soy have a certain intolerance if grown during continued cropping. However, this can be overcome by larger crop rotation cycles, which would also contribute to increasing agricultural diversity and eventually bio-diversity.

For all of the points mentioned, strategies should be developed for improving yields and establishing new concepts for crop production. In the long run, this could help reducing agricultural land needed for protein supply, while reducing harmful environmental impacts such as aquatic eutrophication.

2) Need for targeted agricultural and food policies

A change of protein diet at EU level shifting from animal based to a more plant-based protein consumption would help reduce large amounts of emissions in areas which are of current concern regarding environmental or human health and which are subject of political decision-making, such as greenhouse gases, fine particulate matter or nitrate in water bodies. At the same time, increasingly

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scarce resources like phosphate and blue water would be preserved at a larger extent. However, such fundamental environmental improvements would require fundamental dietary shifts. These should not just encompass an exchange of animal-based foods by highly processed vegetable protein replacers, but would also require a share of mildly processed legumes and pseudo-cereals. Overall, the main elements of such a shift would be:

- Reduction of consumption of meat and cow milk by more than 50% each
- Poultry with highest share in the remaining meat mix
- Convenience foods with high contents of plant proteins from EU grown protein sources, which are appealing to traditional meat lovers
- Return to traditional dishes with whole grains of legumes and pseudo-cereals.

However, this shift would require a major change of our agricultural landscape. Even with optimized protein efficiencies, arable land occupied by legumes and pseudo-cereals would be 10 to 20 times of the current land occupation in the EU. Therefore, this will only be possible if agricultural land is carefully managed, including new crop rotation strategies and producing crops most suitable to the individual locations.

3) Need for improved socio-economics

In principle, under the current CAP regulation, cultivation of legumes is acknowledged as a means for greening of EU agriculture and electable for specific green payments. Nevertheless, this is currently not sufficient to steer farmers towards a substantial increase in growing of domestic legumes. Therefore, further support is necessary to remove economic risks, related to factors such as yield variations and fluctuating market prices, from farmers.

Current prices of innovative vegetable protein foods on the retail shelves might conflict with the purchase power of the average EU consumer, especially if meat is offered at cheaper prices. Making protein crops profitable for farmers and high protein vegetable foods accessible to a broad range of consumers is a great challenge. This is especially true within the frameworks of existing international trade agreements (e.g. reduced taxes for imported soy or the recent EU-Mercosur agreement) on one hand and national interests of EU member states on the other.

On the long run, a true pricing framework within the EU, in order to internalise of external costs and potentially also by raising taxes on feed imports into the EU, could trigger major changes.

The wider implications of all this are further elaborated in the section "policy implications" within Deliverable 4.3.

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D. Delays and difficulties

The deadline of this deliverable has been met. Relevant Milestone 25 was delayed, but has been submitted. However, the overall timeline of the P2F project was not be affected by this delay.

E. Impact and outreach

Despite involving several steps of processing from crop to P2F prototype, the overall environmental profile of innovative protein-rich foods from domestic legumes is favourable compared to traditional animal-based products. This not only contributes to a healthy diet and a broader product portfolio for consumers, but also to a reduced environmental impact by food consumption.

These new protein sources and prototypes developed as part of Protein2Food could potentially boost a shift towards diets with more-sustainable protein ingredients that are also domestically sourced (EU-zone). However, to achieve this, a supporting framework will be helpful in addressing aspects such as crop yield and farmer income on one end and affordability to consumers on the other.

Plant protein food is also increasingly present in public media channels. Recently ifeu was contacted by ZDF (one of 2 big state television channels) due to its involvement in Protein2Food. In an interview Andreas Detzel (PI of Ifeu) had the chance to talk about plant-based burgers and the environmental advantages of EU domestic legumes as a protein source. Part of the interview was broadcasted in WISO on October 8th and provided a great opportunity for disseminating the key messages of the project and the importance of sustainable diets.

An upcoming conference participation of ifeu takes place at AVNir Conference, Lille, Nov. 6, 2019 with the title "Development of a biodiversity assessment method with focus on crop cultivation for innovative and modern vegetable and animal-based food products", where key findings of the study will be presented. Furthermore, an abstract will be submitted by end of 2019 for participation in the Food LCA 2020 conference in Berlin.

LCA results on lentil proteins were published in Miravalles et al., 2019[12]. Further papers in process together with UCC are

1) „Ingredient paper 1" , First author Martin Vogelsang O'Dwyer (UCC), will cover faba bean isolate and faba bean protein-rich flour
2) "Ingredient paper 2", First author Martin Vogelsang O'Dwyer (UCC), will cover blue and white lupin isolate
3) Plant milk publication, likely Q1 2020, also with UCC

[12] Membrane filtration and isoelectric precipitation technological approaches for the preparation of novel, functional and sustainable protein isolate from lentils. European Food Research and Technology (2019) 245:1855–1869. https://doi.org/10.1007/s00217-019-03296-y

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