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# EXPERT BRIEF

# IDENTIFYING RESEARCH NEEDS FOR A SUSTAINABLE EU PROTEIN TRANSITION

**IDDRI's contribution to the ESAD EU platform**

Working paper, not to be quoted

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# EXECUTIVE SUMMARY


In 2010, the average consumption of protein in Europe was 100 g/capita/per day, which represents about twice the nutritional references indicated by the European Food Safety Authority (EFSA, 2012). The overconsumption of protein is all the more problematic as it is largely based on animal protein (meat, egg, dairy, fish), which makes up 60% of the total protein intake while 40% are derived from plant sources (cereals and pulses). The exceeding levels of animal production pose a series of critical issues for the environment, including increasing GHG emissions, high land use and biodiversity loss, water and land pollution, as well as animal welfare concerns.

In this context, the notion of a 'protein transition' – i.e. the dietary shift from animal protein to plant-based and novel alternatives - has gained increasing traction and been established as a key pillar of a more sustainable food system. This has spurred the emergence of a fast-growing economic sector, in which venture capitalists and start-ups race to develop novel lab-based products, including *in-vitro* meat, insect and algae-derived proteins, yeast-based products, etc. These actors promote a specific conception of the protein transition rooted in the tenet that product innovation and efficiency gains will solve the rampant environmental crisis. However, the premises and promises of this 'technocentric' approach are highly questionable, as are its implications for the evolution of the food system as a whole, both from an environmental and a social perspective. Political arbitrations are therefore necessary to reorient investments and research in favour of a protein transition which supports broader transformations of farming practices and supply chains towards a sustainable European food system.

**Key messages**

- While the need for a 'protein transition' is gaining consensus, contrasting visions have emerged in the debate which promote starkly different protein alternatives and entail profoundly different implications for the food system. This *Issue Brief* outlines three archetypical framings of the protein transition: a plant-based vision, a technocentric vision and an agroecological vision.
- Lab-based alternatives stemming from the technocentric approach – ranging from insect-based products to *in vitro* meat – are increasingly capturing substantial investments and R&D efforts from powerful economic actors. However, such options face important shortcomings from an environmental, nutritional and social perspective.
- Public research into the protein transition must therefore go beyond product innovation to support the transformation of the food system as a whole, through structural changes at the level of farming systems, supply chain structures and trade patterns. Major research gaps thus lie in better understanding the economic, political and political economy levers (and lock-ins) to support the protein transition.

# ACKNOWLEDGMENTS

The European Sustainable Agriculture Dialogue (ESAD) is a multi-stakeholder platform created in 2019 that brings together 35+ key actors from across society – including industry, civil society, universities, and research centres – to discuss key topics, exchange views and standpoints, and recommend research needs to achieve sustainable agriculture.

ESAD is grateful to Pierre-Marie Aubert, William Loveluck and Elise Huber (IDDRI) for their outstanding work the past months to draft this paper. As an independent and external researchers to the ESAD group, they have provided an evidence-based and balanced perspective on the matters explored in this paper.

Selected members of the ESAD community, as part of a Task Force, were consulted and their inputs were taken into account by the external expert in the drafting process.

The paper does not reflect the views and opinions of single ESAD members that were consulted. As such, their contribution is not to be interpreted as an endorsement of the final paper.

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# INTRODUCTION

**This study explores the main research gaps to support an effective protein transition in the EU** – a topic that has been on the table for quite some years (see notably Aiking et al., 2006) but which has gained a growing resonance over the last 5 years.

By "protein transition", we mean here the progressive shift away from animal proteins towards plant based and novel sources of proteins in human diets (Aiking et al., 2006). While this definition primarily refers to a shift in diet, it is clear that the sort of transition it refers to in fact implies much broader transformations of all components of food systems, as pointed out for example by Manners et al. (2020).

**This report thus adopts a food system perspective** (Ericksen, 2008) to identify both existing evidence and key research gaps to support such a transition. Four main dimensions of food systems' functioning are considered throughout the report:

- dietary patterns / food habits;
- protein processing & supply chain organization;
- protein production/supply at farm level and beyond;
- trade patterns.

In order to identify the research gaps that a protein transition entails (on each of those components, then), the report proceeds in four steps.

**In a first section,** we recall the scientific evidence calling for a protein transition, and then specify the main levers / stumbling blocks / barriers already identified in the literature.

**The second section** identifies and briefly outlines three different approaches to the protein transition in the current policy and academic debates, and presents them as broad narratives.

**In the third section,** we further characterize each of the three identified narratives and show that each rests on different assumptions about the future, and in fact impies different research needs that are further made explicit.

**The fourth and last section** identifies the key convergences and divergences between the research needs identified for each narrative and calls for an open and transparent debate to prioritize those needs based on societal and policy debate. This analysis is notably based on a qualitative assessment of the strengths and weaknesses of each of the three narratives identified against the following key criterions: environmental sustainability, health,

**From a methodological point of view,** this study primarily relies on (i) expert / stakeholder interviews and (ii) a literature review. Seven interviews were carried out between March and May 2020 each of them lasting between one hour and an hour and a half. Four scientists were consulted and three stakeholders.

The literature review is based on both academic and grey literature. Given the broad range of issues covered by the topic of the protein transition, the papers considered were mainly meta-analysis and review papers. A few papers reporting on specific case studies have been considered especially on emerging research questions.

# 1. STATE OF THE ART IN THE RESEARCH ON THE PROTEIN TRANSITION

## 1.1 The protein transition: a sustainability imperative

**The sources of protein in current European diets are mainly derived from animal products** pulses and cereals (in lower proportion). Animals are however themselves fed with proteins contained in a variety of feedstuff, from legume fodder to cereals through roughage)[i],

As shown in Figure 1, the European average consumption of protein is slightly above 30 kg per capita per year, that is 100 g/capita/day. This represents twice as much as nutritional references, which indicate that 50 g would be enough to cover nutritional needs (European Food Safety Authority, 2012)[ii].

From a strictly nutritional point of view, there is thus some scope to significantly reduce the EU consumption – as well as production – of protein.

**The ability of the European food system to supply** that much protein to European citizens (and, on top of that, to export it to the rest of the world in the form of cereals, dairy products and, to a lesser extent, meat) relies on a massive input of nitrogen to the system, which is a basic compound for the synthesis of amino acids constituting proteins and nucleic bases of DNA. Two sources play a major role in providing nitrogen to the food system:

- synthetic fertilizer, which accounted for 63% of all N input in the system in the 2000s;
- the import of nitrogen in the form of soybeans from Latin or North America, which accounts for 15% of all inputs (and which roughly corresponds to a level of dependency of the EU in high protein content crops of 65-70% – Eurostat, 2019).

**Atmospheric N fixation by leguminous crops only accounts for 5% of all inputs**[iii], while roughly 45% of all N applied on land is recycled through manure management. According to the ENA, this N balance corresponds to an average 55-60% Nitrogen Use Efficiency, depending on the way this NUE is calculated – a significant share of the N applied being indeed lost to water bodies (for a quarter of all net input) and to the atmosphere through volatilization (for 20% of all N applied) – see graph below from the European Nitrogen Assessment (Sutton et al., 2011).

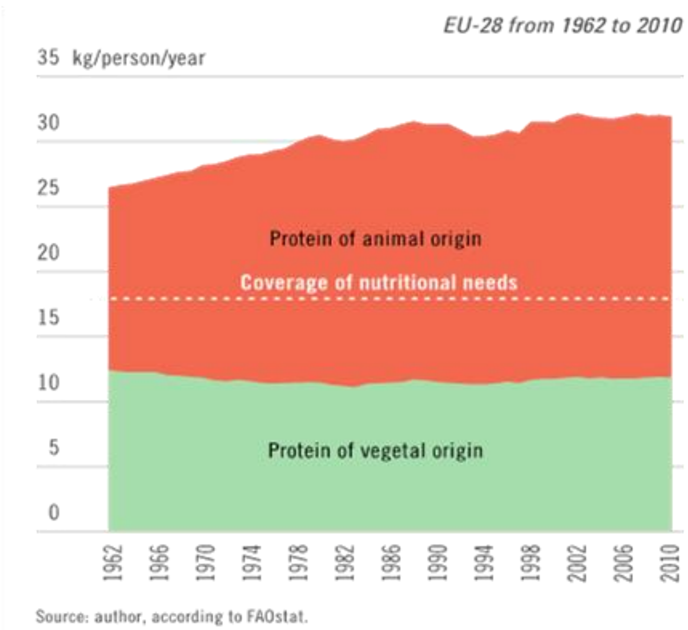


FIGURE 1
Average annual protein intake in the EU-28 (based on FAO data & (Poux & Aubert, 2018)

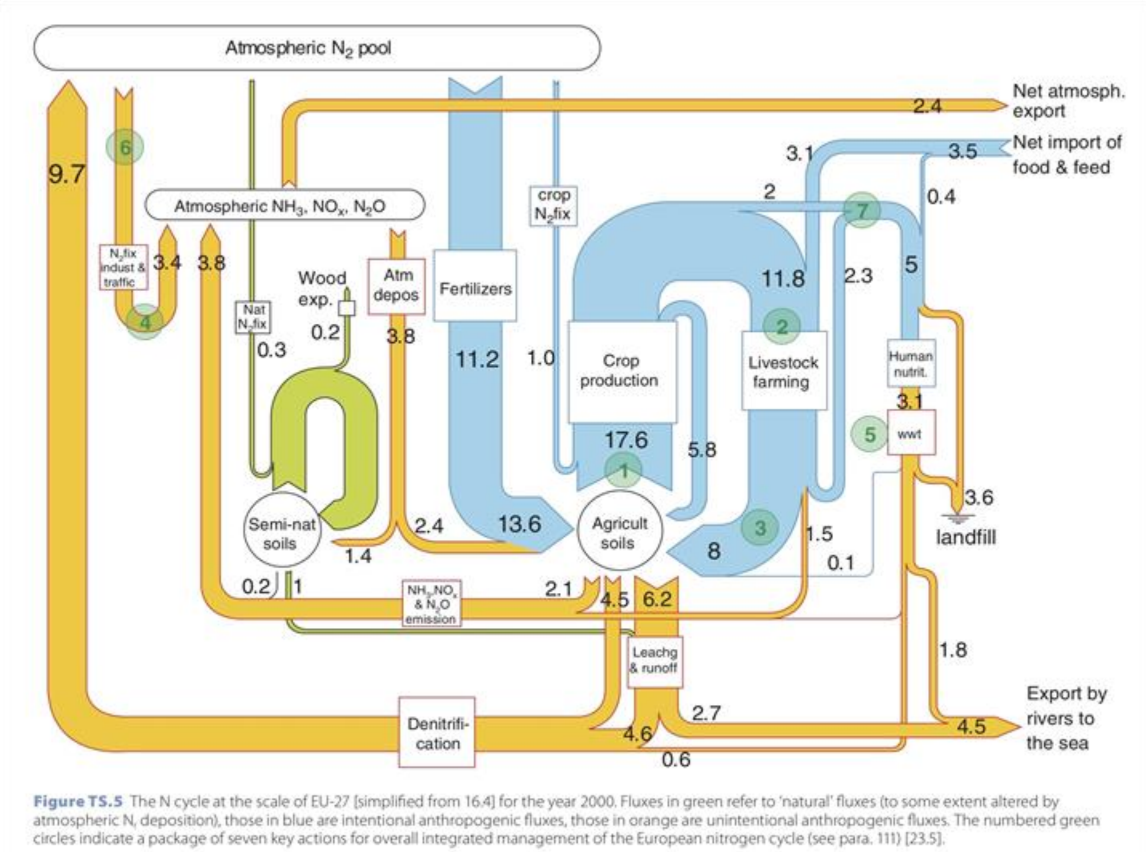


FIGURE 2

Average The simplified N cycle at the scale of EU-27 for the year 2000 {source: Sutton et al., 2011)

Overall, the over-production and consumption of proteins in the EU, and more particularly our over-reliance on animal sources of proteins, associated with the limited efficiency of the EU food system to convert nitrogen into proteins and its dependency on both imported and synthetic N, have overtime led to a series of environmental issues that are quickly recalled below.

**Important to note is also the fact that many of those problems** have to do with the massive opening of the N cycle that has been involved in the transformation of the EU food system (Sutton et al., 2011).

- The surpassing of the N-related planetary boundary for the EU – in a context where most N input at the EU level comes from agriculture (EEA & FOEN, 2020);
- GHG emissions from animal breeding systems (ruminants for their methane emissions and manure management in general);
- GHG emissions associated with synthetic N manufacturing and then application – the Haber-Bosch process is highly energy consuming (2T of petrol equivalent are required to produce 1T of synthetic N) & N application generates nitrous oxide emissions;
- High land use for producing animal feed at the EU and global level, which simultaneously contribute to agricultural land expansion outside Europe and agricultural intensification within Europe which also indirectly increases GHG emissions;
- Biodiversity erosion in agricultural landscape due to an overuse of synthetic N, as well as the fact that synthetic N used in agroecosystems is today associated with a high level of pesticides use to manage weeds and pests that benefits from the high level of N application;
- Animal welfare issues (animal handling and slaughter conditions in modern breeding activities)

**Those environmental problems are seen by the vast majority of researchers** as urgent reasons to undertake a protein transition at the EU level and beyond[iv] (see for a recent review based on the SDGs (Aiking & de Boer, 2018). They have also been recently placed high on the political agenda, notably through the publication of the Farm to Fork strategy which, amongst others, set the following two key objectives: to reduce the amount of red and processed meat consumption in the EU; and to reduce respectively by 50% and 20% nutrient losses to the environment and the use of fertilizers, by 2030 (European Commission, 2020).

## 1.2 What levers for a protein transition? Insights from existing researches

**This section reviews the main insights of the literature regarding the levers** that could be put into action to advance the protein transition, distinguishing between the four main components of food systems as identified in the introduction:

- dietary patterns / food habits;
- protein processing and supply chain organization;
- protein production/supply (including farming systems' organization, but also all novel sources of proteins which are not necessarily produced in "farms" per se);
- trade patterns and their regulation.

**It starts by mapping the main alternative sources of proteins** currently being considered for feed and food in view of the protein transition.

### ALTERNATIVE SOURCES OF PROTEINS

Proteins are used either as feed or as food, and were so far of two main types: animal or vegetal. The extent to which each existing source of protein is used depends on three main factors, whose respective importance varies in each case: its price, protein content and its nutritional quality.

**The main sources for feed today consist** of (mostly) imported soybean, legume fodder, oilseed and sunflower seed cakes, roughage, and in a smaller proportion peas and other alternative grain legumes (like fava beans). Overall, the progressive intensification of livestock system across Europe has resulted in a growing demand for highly palatable sources of feed, at the expense of left over, roughages and other types of fodder (Röös et al., 2016).

Given the high rating of soybean on all criteria as feed source (price, protein content and nutritional quality), it tends to surpass all other sources of proteins, hence the difficulty to replace it and Europe's growing dependency on protein-rich crops.

With respect to food, and as already discussed, animal products (meat, dairy, eggs, fish) now constitutes the primary source of proteins for EU citizens, surpassing vegetal sources, with an average ratio of 60:40 between the two. Vegetal sources of proteins include primarily cereals and, to a lesser extent, pulses.

**Over the last few years, research has explored different options** with respect to proteins, with different goals: increasing the overall protein supply in the EU, finding ways to (at least partly) substitute soybean as feedstock (hence limiting the EU's dependency), or developing alternatives to animal proteins in human foods. The range of options explored include land-based sources (pulses, cereals, oilseed crops), aquatic sources (duckweed, algae or seaweed), microbial / synthetic sources (from mycoproteins / fermentative proteins to cellular meat), insects-based sources and co-products (sugar beet leaf, spent brewers' grain etc.)[v].

Under the European Commission umbrella research funding, several projects have already been dedicated to the development of different protein alternatives. Specifically, the recent "Alternative protein for food and feed" program has focused on insects (SUSINCHAIN, NEXTGENPROTEIN), microalgae (PROFUTURE, NEXTGENPROTEIN), microbial protein (NEXTGENPROTEIN), fungi and pulses (SMART PROTEIN). Previous or ongoing projects such as PROTEIN2FOOD, LEGVALUE, TRUE and LEGATO also looked at promoting legumes/pulses (and seed crops such as quinoa, amaranth, etc).

Each of those options, and especially "novel" alternatives, are thus at a very different stage in terms of legislative approval and technical "maturity"/efficiency.

**In this respect, a good overview of different sources' technological readiness and environmental impact** is proposed by van der Weele et al. (2019), as summarized in the table below.

FIGURE 3 clearly shows that the easiest path to a protein transition from a technological point of view, as well as the most certain in terms of the sustainability gain it would offer, relies on pulses followed by plant-based alternatives and whole insects.

That said, the following section also shows that adding consumer preferences into the equation complexifies the picture given the multidimensional nature of consumption trends and behaviours.

| Sustainability gains | Required technological innovation | | |
|---|---|---|---|
| | Low | Moderate | High |
| High | Pulses | | |
| Moderate | Existing PBMA<br>Whole insects | Novel PBMA with highly refined ingredients | |
| Low | Cheese/ Dairy<br>Eggs | | |
| Uncertain | | Protein extracted from insects | Cultured Meat<br>Algae |

FIGURE 2 Sustainability gains and required technological innovations for alternative sources of proteins (from van der Weele et al., 2019)

## DIETARY PATTERNS / FOOD HABITS

At the consumer level, existing research addresses two main questions:

- how to reduce the level of protein intake *in general*, and *in particular* that of animal proteins?
- how to favour a progressive substitution from animal sources of proteins to plant based / alternative ones?

**First, important differences exist both within and between countries** regarding protein consumption at the EU level, both regarding the current situation, and how it has evolved over the last 60 years. Within countries, available data indeed shows a great variability in diets, which cannot be easily explained (Baudry et al., 2019).

For example, the French national study reveals a standard deviation of 30g of daily protein intake in the population observed in France (ANSES, 2017). Thinking only with averages thus tends to limit the ability to think concretely about what the protein transition means. Despite this, little data characterizing individual consumption profiles in contrasted countries is available.

**Between countries, there is a clear North / South divide:** Southern countries eat more vegetal proteins than Northern ones, and Northern ones also consume more milk, even though those differences have tended to decrease over the last 10 years (de Boer et al., 2006; de Boer & Aiking, 2018).

The evolution of meat consumption has also long been strongly correlated with the evolution of the GDP (Grigg, 1995), leading Southern Europe countries to gradually increase their average daily meat intake. This is however less and less the case, either at the global (Mathijs, 2015) or the EU level (de Boer & Aiking, 2018). The conceptual model put forth by Popkin (2006), considers that, through progressive behavioral changes in advanced economies, protein, fat, sugar and caloric intakes could gradually decrease to enable a healthier / better nutritional status of populations.

In line with Popkin's model, a survey carried out at the EU level (26,000 respondents) for the EC shows that, on average, 82% of EU citizens would be willing to eat "less but better meat" and 51% to replace meat (reported in de Boer & Aiking, 2018).[vi] Although those figures are only self-reported intentions, rather than actual behaviour, they give considerable weight to the idea of a protein transition.

Different levers to translate those intentions into concrete actions have been explored, some efficient, other less. The extent to which such behavioural changes could effectively been "governed" remains an open question.

**Different approaches have been discussed** regarding how to decrease animal protein (and more particularly meat) consumption. They all rely implicitly or explicitly on an understanding of the main drivers of human consumption patterns. Diets are indeed the result of a set of determinants that interact on the individual level (the consumer's own tastes or budgetary constraints, for example),as well as the economic, social and material environment in which people are embedded (social norms or food supply in the availability, for example).

The hierarchy among these determinants is not unambiguous, with some scholars favouring certain explanatory factors over others to explain diets. Depending on the hierarchy favoured, the associated tools are different.

For example, those considering that dietary behaviours are primarily motivated by financial considerations, will tend to favour economic tools such as taxes. There are, however, other readings of the problem, such as that of considering that food behaviours are primarily an informational problem, or the result of a power asymmetry between consumers and agri-food manufacturers. In such a reading, one will thus tend to favour consumer information tools, such as labels or nutritional displays.

**1. Based on a literature review, Hartmann & Siegrist (2017) first show that environmental issues** are not seen as sufficient reasons for that (see also on that Austgulen et al., 2018). This is notably due to the low level of consumer awareness about the environmental footprint of their consumption habits. On the contrary, information based on health arguments and, to a lesser extent, animal welfares ones, was reported to be quite influential on consumers' choices (Bianchi et al., 2018; Latvala et al., 2012; Vainio et al., 2016) or willingness to pay (Rolland et al., 2020).

However, most of this research is based on self-reported motivations rather than actual behaviour monitored in real life. Yet, it is well known that differences between intents and actual behavioral changes are high, and that on average, the actual impacts of nutritional information campaigns have largely gallen below expectations Capacci et al. (2012) and de Boer et al. (2013) also explored strategies based on the promotion of either smaller portions of meat or meatless meals / days. They show that both approaches can prompt interesting results but they depend on the final consumer target.

**2. Policy approaches based on taxes have recently gained wie-spread attention in the debate,** pushed by different stakeholders and scholars, either for environmental or health reasons (Godfray et al., 2018; Springmann et al., 2018; TAPPC, 2020; Wellesley et al., 2015). While the impacts such taxes could have on climate mitigation or population health is well documented through modelling, the extent to which – and the mechanisms through which – they would actually bring about change in consumers' behaviour is not yet well understood, mainly because few experiments have been carried out.

A review by Smith et al. (2018) on products other than meat (for which experiences exist) points out that (i) taxes have mostly been effective in decreasing consumption of the targeted products (though differently depending on wealth levels as in Hungary`, see Bíró, 2015) but (ii) their positive effect on health is largely influenced by the extent to which their application leads or not to different forms of substitution. In the case of meat, and given its high degree of substitutability with other products, different papers conclude that the regressive impact of a meat tax wouldn't be too high.

Conversely, increasing alternative proteins uptake has been repeatedly reported as a challenge in the literature. Five such alternative proteins are mainly considered (with different impacts on sustainability, as will be discussed below): cultured meat, insects, plant-based meat and pulses.

**1. The role of nudges has been investigated as a way** to increase meat-free dishes consumption. While no global synthesis currently exists given the range of approaches that can be used and developed under the "nudge" label (Vandenbroele et al., 2020), the existing empirical results show that there seems to be an important potential which could be further examined (see below section IV for research priorities).

Kurz (2018) has for example demonstrated that only changing the way in which vegetarian dishes are presented in restaurants can increase their share by up to 6 points over a period of 6 months (from 13,9% before to 20% after), and that this change can continue post-intervention: vegetarian dish orders remain 4 points higher than what they were prior to the experiment.

Yet, in their systematic review of nudges for healthy food choices, Vecchio & Cavallo (2019) consider that there are still methodological limits and a lack of maturity in the field, which limit nudges' applicability through public policy and give directions for future developments.

**2. Several studies have highlighted the importance of consumers growing** accustomed to meat alternatives, which can be achieved by repeatedly offering them (Hoek et al., 2013). When trying to reach new consumers, meat alternatives should also be presented in a form and with a taste which is either similar or at least "recognizable" by consumers, which is not always the case for existing products made from insects, worms or other types of plant-based proteins (e.g. lentils) (Hoek et al., 2011).

This can be achieved by offering consumers "blended" products that combine a small portion of red meat, with meat substitute making up the bulk of the product (Caparros Megido et al., 2016; de Boer et al., 2013; Graça et al., 2019; Vainio et al., 2016). This also means that there will be no protein transition without product innovation, as consumers willingness to eat what they consider today as "weird" (a category in which pulses can be included) is currently limited.

**3. For what concerns pulses in particular, the misleading** (and often negative) way in which they have long been presented in national nutritional guidelines (as starch products rather than protein sources in France for example) is considered as one explanation for their limited consumption level across countries (see Magrini et al., 2016; Meynard et al., 2017). Researchers have thus suggested that a change towards more "positive" promotion of pulses in these guidelines could have the reverse effect and foster their adoption by consumers.

## PROTEIN PROCESSING TECHNIQUES AND SUPPLY CHAINS ORGANISATION

Several sources of alternative proteins are now available to consumers (including plant-based dairy products and meat) or for animal feed, and new products are still under development.

A general look at the recent research which has been conducted at the supply chain level in the EU, including specifically under the European Commission umbrella programme, reveals that research on protein has focused extensively on innovations at the downstream level of the supply chain to improve the extraction/fractionation/processing of protein from various sources, with the objective to develop a wide range of protein-rich ingredients and foods. This evidently follows a growing market trend since, in the past few years, the market for protein ingredients has experienced significant growth and is expected to reach $76 billion globally by 2027 (Grand View Research, 2020).

**As such, all of the projects from the "Alternative protein for food and feed" programme** mentioned earlier focus on developing protein ingredients to be incorporated into food or feed: for example, PROFUTURE aims to use microalgae (spirulina, chlorella, etc.) for the development of single-cell proteins and protein isolates to be incorporated in food and feed as novel ingredients, NEXTGENPROTEIN looks at microalgae, single cell protein and insects produced through the bioconversion of industrial waste streams to develop protein meal, etc.

PROTEIN2FOOD also designed industrial techniques for the fractionation and processing of legumes and other protein seed crops (lentils, faba beans, quinoa, etc.) in order to provide protein ingredients (flour, isolates and concentrates) and foods with improved functional and sensory properties.

**In addition, SME support under EU research funding** has been allocated to the development of:

- a novel technology for the production of functional protein isolates derived from oilseeds (FIDOs)
- pea based protein processed into flakes as alternative components of breakfast cereals, health-value drinks industries, etc. (PROVEGFLAKE)
- a commercial technology for the extraction of protein from rapeseed for human consumption (ALSEOS)
- vegetal protein hydrolysates (VEGPROTEIN)
- etc.

In comparison, the amount of research and funding which is directed towards understanding and unlocking the upstream/midstream lock-ins of supply chains for already existing plant protein sources is much less significant.

Only a couple of projects have been devised in this matter in the programme "Legumes - transition paths to sustainable legume-based farming systems and agri-feed and food chains" - LEGVALUE and TRUE - as well as the LEGATO project, focused on identifying priority issues limiting grain legume cultivation and devising solutions in terms of novel varietal development, culture practices and food uses.

Therefore, while European research has and is continuing to play an important role in supporting the development of innovations in processing to incorporate new protein sources into food products, much less funding is going into supporting the uptake of political, economic and agronomic "innovations" upstream/midstream in legume supply chains so as to unlock the barriers to their production. In a context where 70% of protein-rich products used for feed are imported, there seems to be a clear need to invest more research in this area.

## PROTEIN PRODUCTION/SUPPLY

At the level of production systems, numerous different options are considered to improve the environmental impact of protein supply as part of a protein transition. Here, there are three components to be apprehended: livestock systems, cropping systems and the interconnections between them.

In the debate on the protein transition, livestock productions are typically viewed negatively given their high climate impact and perceived inefficiency in valorizing resources. As such, two general options are put forth:

1. *improving* current animal productions (i) by increasing their resource efficiency and (ii) improving their local environmental and animal welfare impact
2. or *replacing* them directly with plant protein production or by developing more efficient nutrient recyclers such as insects, fungi, etc.

**Regarding the first strategy**, the research to improve current animal production systems has mainly focused on enhancing resource efficiency (Westhoek et al., 2011). The research has thus extensively aimed at: improving feed conversion and animal diets (reducing feed use through more precise management, optimizing digestion for ruminants, reducing the protein content of feed, etc.) as well as more generally improving husbandry systems and management of manure (developing more optimizing animal breeds, adapting housing systems, etc.) (Westhoek et al., 2011).

**Taking a closer look at the specific field of animal welfare**, scientific and policy research have seen significant advancements in the past decade. Indeed, while researchers were still pointing at the crucial lack of solid welfare assessment systems and indicators a few years ago (Blokhuis et al., 2008), multiple methodologies have emerged to this end.

Beyond a number of voluntary private certification schemes, 'Welfare Quality' - the largest European integrated research work on animal welfare - has provided a generic approach defining a set of specific performance indicators (resulting from different management practices, breeding strategies, etc.) so as to harmonize animal welfare measures (Velarde & Dalmau, 2012).

**However, this does not imply that a common understanding and definition** of the most optimal animal welfare system has been established – this is indeed still the subject of debate (Nøhr et al., 2016). For example, there is a clear dividing line in terms of whether precision livestock farming (PLF) may provide an adequate welfare status via continuous automated monitoring of animals' state and behavioural signs (Berckmans, 2014). Proponents of this approach and of 'efficient farming' more broadly consider that "conflicts between animal welfare and production may be resolved by future developments in genetics, management practices and new technology." (Dawkins, 2017).

For instance, the need for further research into the development of new sensors and new algorithms to extract and combine relevant information is pointed out (Blokhuis et al., 2019). Interestingly, it is acknowledged that this perspective results notably from the fact that animal welfare science has itself largely developed out of the Western model of industrial, intensive and technologized farming. And in this respect, it has, to some extent, actually proven effective at making intensive livestock farming socially acceptable by limiting/mitigating its excessive harms (Buller et al., 2018).

**On the policy side, the issue of animal welfare** has also undoubtedly gained increasing legitimacy and resonance, not only through an institutionalization process at the national level[vii] but also in the international arena (cf. the "ground-breaking" 2016 UN Recommendation on 'animal health and welfare'). While the original 'Five Freedoms' framework has traditionally been widely used as the foundational principles for national regulations and UN recommendations, the recent development of more encompassing and output-based methodologies mentioned above have increasingly been integrated, especially in private standards.

There still remains, however, a lack of international consensus on an equivalent public standard of animal welfare which could be applied universally and systematically. But new governance responses have emerged to build consensus, such as the development by the OIE (World Organisation for Animal Health) of Welfare Standards included in its Terrestrial and Aquatic Animal Health Codes recognized by the UN. Furthermore, the political agenda around animal welfare has been progressively incorporated into mainstream policy debates around sustainability, food safety, and human health as demonstrated by the One Health agenda (Buller et al., 2018).

Therefore, overall, significant policy innovations have been developed to integrate animal welfare into the political agenda, which have led to successful results.

**Concerning cropping systems,** different options are also put on the table in order to enhance the efficiency/sustainability of protein production:

Increasing the overall Nitrogen Use Efficiency (NUE) of crop productions

- Increasing the protein content of cereals and oilseed crops such as canola
- Increasing the share of pulses in EU rotation
    - Indeed, the share of pulses in EU rotations has been decreasing continuously over the last decades, despite (some) efforts to reverse that situation. This is mainly due to socio-technical lock-ins and an unfavorable policy/market environment
    - Yet, the environmental benefits of increasing pulses' share in EU rotations (or in association with cereals) are undebatable in the face of many challenges including climate change mitigation and decreasing the EU's dependence on imported protein
- Developing alternative plant productions such as algae

**Finally, research has shown that crop-livestock systems connections/integration**, which used to be employed globally for centuries, shows huge advantages to enable the recycling of nitrogen in farming systems through manure management (Russelle et al., 2007) / biogas development, and thus play a role in developing an N-circular economy.

In this respect, recent research has investigated the possibility of designing crop-livestock integration at the farm and territorial levels, and has notably brought attention to the need for organizational innovations and social coordination supported by effective public policies to support farm diversification (Moraine et al., 2016).

## TRADE PATTERNS AND THEIR REGULATION: THE EU PROTEIN DEFICIT AND HOW IT IS ADDRESSED IN THE DEBATE

In the political debate, there are contrasting visions as to whether the protein transition should go hand in hand with a greater protein autonomy of Europe, and therefore, with changes in the structure of global trade patterns.

While both aspects are linked from a biophysical point of view, in effect, these are two distinct discussions in the policy arena; and while the question of the protein transition still lacks political resonance, the protein autonomy issue attracts supporters at different levels because it is central to environmental and socio-economic considerations.

To contextualize this discussion, it is essential to stress that the EU is indeed currently and has historically been a net importer of proteins, as clearly shown by the graphs below.

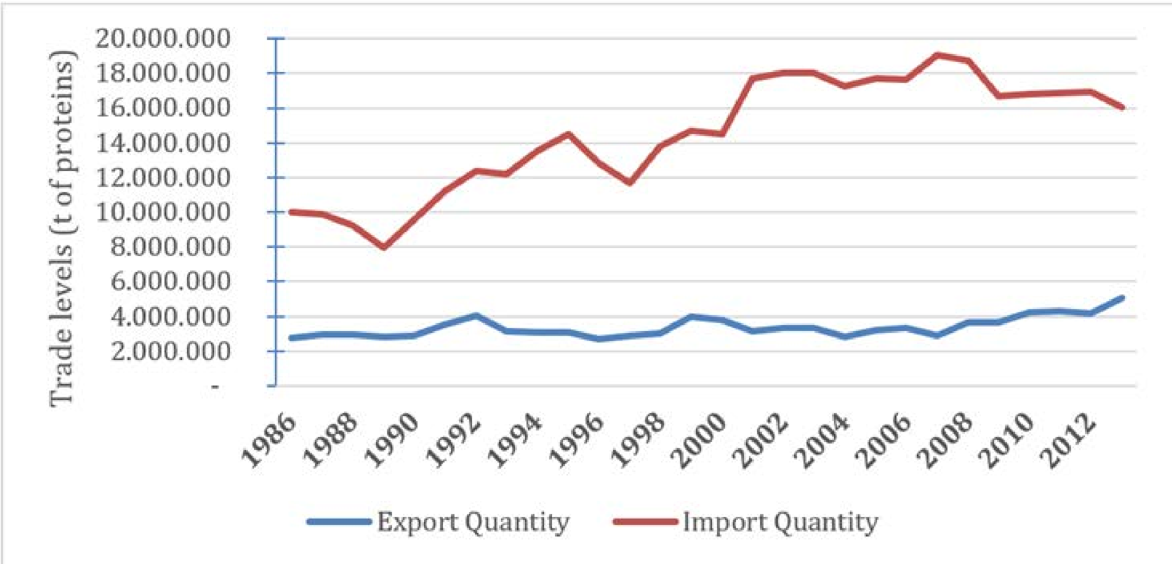


FIGURE 4
Protein balance of the EU (source: authors, based on FAOstat)

More specifically, while Europe is a net exporter of protein in the form of cereal and animal products, its overreliance on soy imports to sustain its livestock sector overshadows all other protein sources.

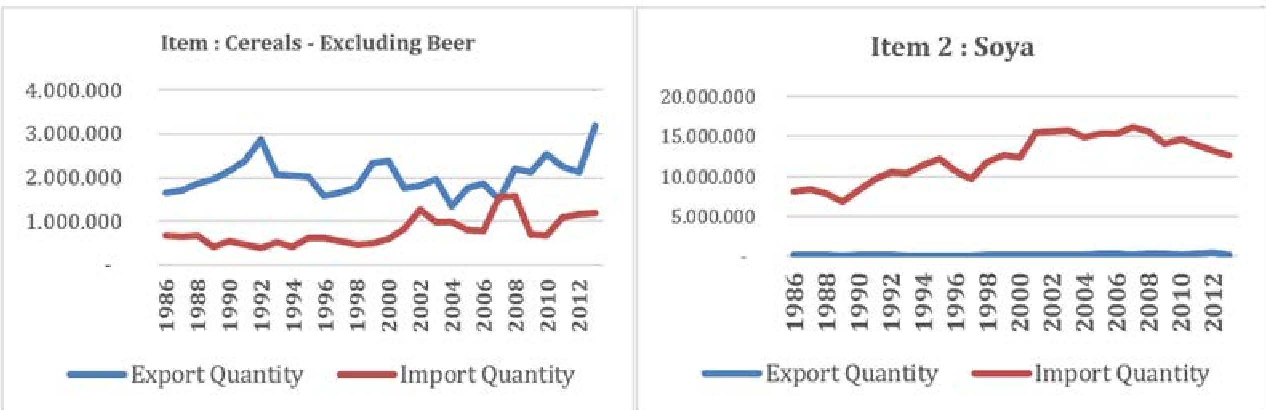


FIGURE 5
Protein balance for cereals (left) and soybean (right – including grain, cakes and oil) expressed in tons of proteins (source: authors, based on FAO stat)

While the figures only display trade patterns up until the mid 1980s because of data limitations (FAO stat data from before 1986 does not enable to get trade data at the EU level without intra-EU trade levels), the origin of this protein trade imbalance dates back to the 1960s. In the 1980s and 1990s, research was carried out to account for it, taking a political economy perspective. It emphasizes the role of the US-EU deal forged in the post war period, through which the US granted Marshall aid to European countries with the conditional obligation to purchase American agricultural surplus commodities, notably feedstuff/soy.

**This deal was then reflected in the Dillon Round GATT agreement** (1962) which exempted American soy and maize from any import controls/tariff barriers in exchange for the US's support in protecting European cereal/wheat[viii]. Magrini et al. (2016) well demonstrated how this historical decision has in fact shaped the EU agriculture throughout the late 20th century and has had consequences until today with respect to the development of protein-rich crops in the EU. Friedmann (1993) identified two reasons why this deal was made in such a way in the 1960's.

On the one hand, she contends that the United States needed to find outlets to dispose of its production surpluses after the war in order to maintain its national farm support programs, and therefore forged a framework of international rules consistent with its domestic market.

**On the other hand, she demonstrates** that at the time, this measure did not constitute a huge constraint as European farmers used very little soy and mainly raised livestock on grass, cereal, and legume fodder and grains. But the ensuing modernization of farming methods (including the introduction of synthetic fertilizers), as well as the decreasing price differential between American soy and European cereals[ix] progressively led farmers to abandon the production of legume fodder and legume crops in favour of soy in animal feed.

Over time, this deepened Europe's protein deficit, a situation that gradually became political, especially after the American embargo on soy in 1973 which suddenly and compellingly shed light on the strong dependency of Europe's livestock production on imports.

**Since the 1990s, little research** has been carried out in this area to understand how and why such a situation could be reversed *from a political economy perspective*. In short, while the EU – and France in particular – made several attempts at rebalancing its protein deficit from a purely technical perspective, notably by pushing for the development of oilseed crops, few discussions – if any – targeted more specifically the economic and political lock-ins to be addressed.

**This is especially problematic** given that, in the political debate, from an economic perspective, there is a relatively wide consensus (particularly amongst farmers' organisations and unions for example) on the importance of decreasing the vulnerability of the European livestock sector, especially because of its dependence on a single raw material and because of a context of high price volatility. Other actors (environmental NGOs, the European Parliament, the French Ministry for the Environment, etc.) also approach the issue from an environmental point of view, especially by considering the extra-European consequences of a protein dependency on the rest of the world and its impact on the environment and biodiversity especially in South America (deforestation, intensive monoculture production).

Lastly, social considerations of a European protein autonomy are defended by international solidarity NGOs (such as Via Campesina) by highlighting the harmful social impacts of soy production in South America and by defending the idea of a greater food security and sovereignty in countries from both the Northern and Southern hemispheres.

However, not all actors align with the general objective of a European protein autonomy and necessarily perceive the protein deficit as a problem. This category of actors endorses a liberal vision of the agricultural sector (defending the further liberalization of agricultural markets) and put forward a protein transition (when they support it) based on the specialization of regional production around comparative advantages and competitiveness.

For those actors, even though prices and price volatility of soy may present an economic risk, the situation is not alarming as such and should regulate itself through the market.

## 2. THREE CONTRASTED APPROACHES TO THE PROTEIN TRANSITION

The idea of a protein transition is pushed on several fronts and by multiple actors, institutions and organisations. But this is a rather multidirectional appeal, which can be framed in different ways.

Schematically, **one can distinguish different approaches** based on how authors consider (implicitly or explicitly) the following two questions:

- To what extent are animal proteins replaced by alternative sources of proteins? Or, in other words, what is the targeted diet in terms of the ratio between animal and vegetal proteins?[x]
- To what extent is the shift in protein intake in diets is associated with a reinforcement of the level of protein autonomy of the EU and, more generally, the development of a truly circular economy for nutrients at the EU level?

**Based on how those two questions are framed** by an author or a group of authors, a number of other dimensions of food systems are in fact more or less directly affected. Those includes, amongst others:

- The level of geographical connection between production and consumption, and the role of trade therein;
- The way different environmental issues are approached and prioritized between each other: climate change mitigation / adaptation, biodiversity conservation, water quality, soil health;[xi]
- The envisioned transition pathways of production systems from both an agronomic and a socio-economic point of view – in particular livestock systems (sustainable intensification, agroecology, etc.) and the origins of animal feed therein
- The way consumption habits might change (or not change) / the way value chains might change (or not change), in particular with respect to the role of new potential sources of protein

According to these dimensions, and based on our literature review, we propose here to distinguish between three potential – and highly archetypal – protein transition pathway "narratives" that are represented in the table below – all of them assuming an overall reduction of the EU average protein intake.

| | **Vegetal protein clearly dominates** | **50/50 vegetal & animal protein intake** |
|---|---|---|
| **Increased protein autonomy, N cycle management considered at the territorial level** | **Agroecological scenario** | **//** |
| **No clear increase in protein autonomy and N management at the global level** | **Plant-based scenario** | **Technocentric scenario** |

FIGURE 6
Three contrasted approaches to the protein transition (source: authors)

Based on the literature, archetypal diets have been reconstructed for each of those three narratives, which are presented in the graph below.

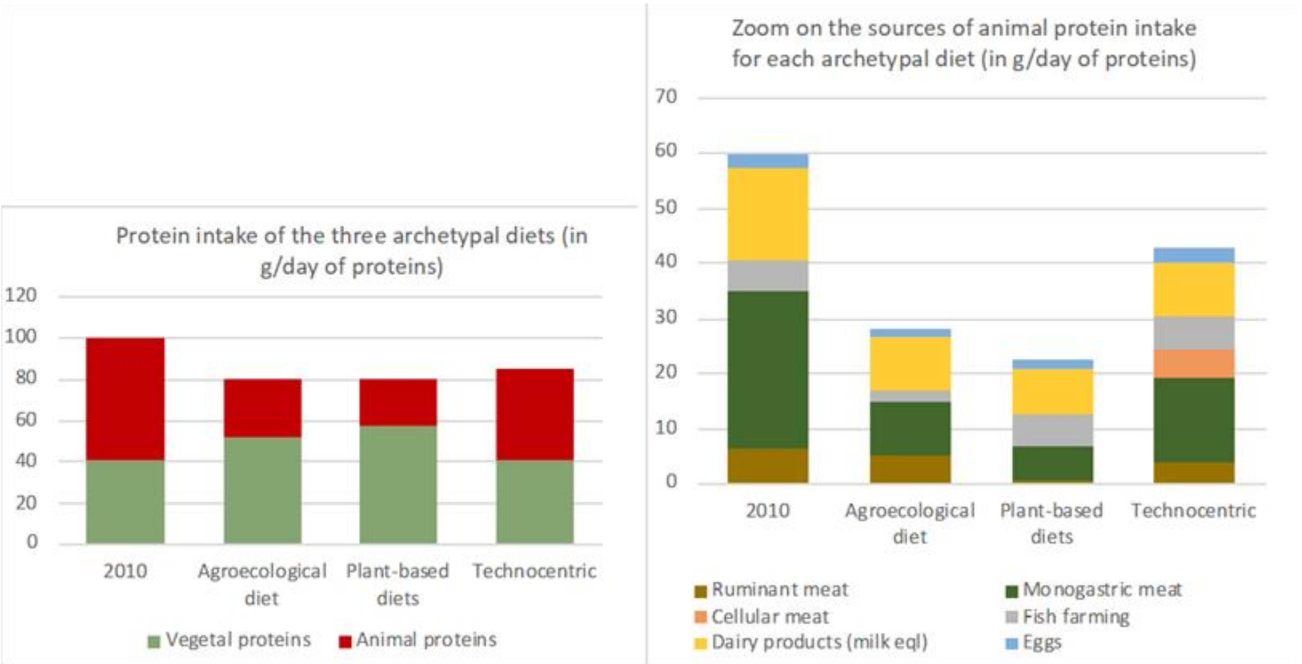


FIGURE 7
The protein content of the three archetypal diets
(source: authors, based on (Willett et al., 2019); (Poux & Aubert, 2018); interviews)

European nutritional references - as well as WHO recommendations (WHO & FAO, 2002) - state that an intake of 0.83 g of protein/kg of body weight/day is sufficient to cover nutritional needs[xii] (European Food Safety Authority, 2012). However, because there is currently no clearly defined maximum limit for a healthy protein intake (the EFSA considers that current data is insufficient to establish a Tolerable Upper Intake Level (UL) for protein (European Food Safety Authority, 2012)), the decrease of total protein intake does not stem from a nutritional standpoint but rather from an arbitration between various factors.

While all narratives imply a decrease in the total intake of protein as well as a decrease in animal protein, they do not present the same final level of protein intake (in g/day) nor the same sources (animal, plant, cellular, etc.) or form of protein (whole, processed, ultra-processed). The following graph positions each of the narrative in terms of the societal changes it implies with respect to diets, as put forth by some of their promoters.

The idea that the technocentric diet implies the least disruption is consumption habits is itself debated (see above), but it is indeed through this justification that stakeholders frame the relevance of the technocentric narrative.


FIGURE 8
The three archetypal diets with respect to the societal changes they are deemed to imply
(source: authors, based on interviews and van der Weele et al. (2019))

# 3. RESEARCH NEEDS ACCORDING TO EACH NARRATIVE

### WHICH RESEARCH NEEDS FOR WHICH TRANSITION?

The approach delineated above notably implies that research gaps to foster the protein transition are different (or in some cases emphasized differently) within each narrative rather than stand out in a unilateral direction. As such, there is no “research gap” in itself, but rather research ‘needs’ tailored to the targeted transition.

To explore those needs, and as outlined in the introduction, this report takes a food system perspective, i.e. an approach that considers that changes in the diets cannot be considered separately from changes in the whole food system.

As above, **research needs are analyzed / identified** with respect to the four components of food systems we have considered in this paper:

- dietary patterns / food habits;
- protein processing & supply chain organization;
- protein supply techniques / technologies;
- trade patterns and their regulation

These research needs have been identified through a review of the literature and a careful analysis of past or existing ongoing EU projects on the question, as well as through interviews with scientists and stakeholders.

**Important to note is that in the section below**, we only stress the *most important research needs* emphasized by the particular narrative being described.

Aspects that are common to all and form the backbone of any approach to the protein transition are not recalled.

**This includes three main items:**

- further research to foster the decrease in animal protein consumption at the consumer level (exploring potentially all the levers identified in the previous section);
- reflecting on the changes that such a decrease in animal product consumption will imply along agrifood chains in terms of logistics, stranded assets / divestments and job provision. On this last point, it is worth reiterating here that 35% of all jobs provided within the agrifood industry today takes place within animal products processing, and that the agrifood industry is also the most important manufacturing industry in the EU in terms of job provision;
- further research to foster the reduction of food waste and loss along agrifood chains in the EU (Stenmarck et al., 2016), a topic which is not specific to the protein transition question (see also (Ishangulyyev et al., 2019).

## 3.1 The agroecological narrative

Key words & the narrative in a snapshot:

**Intermediate dietary changes**

**Protein autonomy**

**End of synthetic nitrogen**

**Recoupling of crop and extensive livestock production**

In this narrative of the protein transition, animal protein consumption and production is reduced and the ratio between animal and protein vegetal is reversed, from 60-40 to 40-60. In contrast with many approaches yet, the bulk of the reduction comes from monogastric rather than ruminants.

Indeed, extensive pasture-based ruminant systems are maintained because of the fundamental role they play in the functioning of agroecosystems with respect to N fixation and transfer from permanent grasslands to croplands, biodiversity conservation in permanent grasslands, both for its “existing values” and as a production factor in itself. In the same time, the protein transition is seen as inseparable from a greater protein autonomy and a progressive phase out of synthetic nitrogen (for its environmental impacts) and both are sought through the development of legume crops and the reconnection between cropping and livestock systems at the territorial level. **A strong Nitrogen Use Efficiency is achieved** through a N recycling a relatively lower yields than today (as the NUE usually decreases when very high yields are sought).

To this end, although the specific agronomic levers are largely known for this transition, there is a strong research need to decipher the conditions and implications of the development of legume crops/fodder and sustainable livestock supply chains from both an industrial an economy/political economy perspective.

### FARMING SYSTEMS

The central assumption of this narrative is the fact that the protein transition at the consumer level should go along with structural changes in current production systems, considering in a balanced way climate change, biodiversity and health. On this basis, this narrative implies a strong decrease in the mobilization of synthetic nitrogen (as in Solagro et al., 2016) –up to its complete phasing (as in Poux & Aubert, 2018)– which is considered as a crucial target to reach climate efficiency and avoid widespread water and soil pollution due to nutrient overuse.

Nonetheless, to ensure continued nitrogen input, two different levers would sustain the production system:

**Lever 1:** a large-scale re-introduction of legume crops and legume fodder (which naturally capture nitrogen from the atmosphere).

Here, research needs would mostly entail:

- Quantifying the yield performance and associated economic gains as part of the preceding-crop effects of various legume species (also including the positive impacts of legume crops/fodder on soils (microfauna and microflora as well as humus), carbon storage and biodiversity) (Magrini et al., 2018; Nemecek et al., 2008)
- Identifying ways to increase the share of leguminous crops in rotations, in mixed cropping, for services (as nitrate traps, N fixation, weed and pest control), including non-GMO soy production to reduce dependency on imports (Duc et al., 2010) This notably includes designing appropriate policy levers, including the potential mobilisation of carbon markets and the establishment of Payments for Environmental Services (PSE) for the N fixation of legume crops

**Lever 2:** a reconnection between crop and livestock production in order to ensure adequate fertility transfers at a territorial/farm level through ruminant manure (Moraine et al., 2016)[xiii].

This is notably why, although this narrative assumes a significant reduction of livestock farming (and of animal products consumed), a number of ruminants are kept for the valorisation and maintenance of biodiverse grasslands, a resource which cannot be directly valorised through human consumption (see the concept of 'low-cost livestock' or livestock fed on 'ecological leftovers', (Van Zanten et al., 2018)).

In terms of research needs, they would include:

- Designing alternative connections between cropping and livestock systems implying changes in land use and practices at the territorial level to assess the delivery of ecosystem services (soil fertility and biological regulation) and new types of socioeconomic performances (e.g.: through the introduction of alfalfa into current cropping systems for example) (Moraine et al., 2016)
- Analysing the conditions for mixed crop-livestock farming continuation/development (Ryschawy et al., 2012)

As is clear from the aforementioned points, the agronomic rationale for both levers are already largely understood - and therefore do not imply much additional research at this level.

The main research needs concern our understanding and deployment of economic incentives along the production system and supply chains to spur such changes in farming systems.

## VALUE CHAINS

Transformations at the value chain level (as well as at the policy level, see below) are considered central in this narrative to ensure the viability of legume and sustainable livestock systems that support the protein autonomy of Europe.

**Specifically, significant research is needed to structure the pulse supply chain**, identify investment needs and job creation opportunities (a key topic in the context of post-COVID recovery plan design).

To this end, research needs are centered around :

- Varietal research on legume crops to enhance their adaptability to different pedoclimatic conditions in Europe (including soybeans), with traits favouring resistance to biotic and abiotic stresses and their adaptation to a diversity of cropping systems (Magrini et al., 2018)
  - *indeed, the small size and low number of breeding programs in private and public European organizations still hinder genetic progress on these species (these varieties are self-pollinating, making the creation of hybrids impossible - which is therefore less economically interesting for seed producers)*
- Developing technical and economical references and decision support tools concerning the integration of legume crops in rotations and farming management. This aspect would require research on new information support from advisory services, such as accounting systems to calculate the multi-year effects of practices. (Magrini et al., 2018; Meynard et al., 2013; Zander et al., 2016)
- Adapting logistical organisation of cooperatives to deal with a variety of legume crops (multiple storage, potential cross-contamination, etc.) and quantify both the *investment needed* and the number of jobs it would create in downstream farms.
  - *the practice of intercropping is also limited because logistics are not adapted for pulse sorting by harvesting/storage firms and market organizations (Meynard et al., 2013)*
- Developing new research on how to use legume fodder (alfalfa in particular) for animal compound feed either for monogastric or ruminants in order to partially replace soybean (and thus decrease land use need, as alfalfa's protein yield is more than twice that of soybean
- Research on the integration of production contracts (on specific varieties, qualities…) in order to secure the investments of cooperatives.
  - *NB: if the production is ensured, the cooperative might then invest in human capital to develop advice services.*

## CONSUMPTION HABITS

In this narrative, the dietary changes considered are significant but not as drastic as in the plant-based narrative. Indeed, this narrative considers that distinct cultural attributes including the consumption of animal products are likely to persist in European countries (Hartmann & Siegrist, 2016).

Changes in protein consumption are therefore largely based on existing plant and animal protein products rather than novel products and are simply geared towards a reduction of animal protein and an increase in plant-based protein.

This is notably based on the fact that reducing animal protein consumption does not, in practice, require substitution with alternative sources as total protein intake is unnecessarily high in European diets[xiv] (Westhoek et al., 2014) and that a majority of European consumers demonstrate willingness to simply reduce their consumption of meat (Van Zanten et al., 2018).

Furthermore, given the strong cultural anchorage and the difficulty of changing consumption patterns, this narrative frames dietary transformations as a shared responsibility between all actors in the supply chain (including retailers and processors) and should thus be supported politically at the supply chain level, and not just at the level of the consumer. This is meant to make more sustainable protein choices (i.e. pulses and sustainable animal products) *in fine* more obvious to consumers.

To this end, aside from the research needs pointed out above, additional research needs on:

- the development of specific labels on sustainable animal products, and notably valorising the use of pasture for ruminant meats
- at the retailer level, the design and evaluation of 'soft' interventions to guide consumer choice
- the design and implementation of price signals to promote the consumption of sustainable protein sources

Finally, from a consumer health perspective, further evidence-based research is needed to evaluate the nutritional properties of pulses (Magrini et al., 2018).

#### TRADE FRAMEWORK

As mentioned above, the protein transition in this narrative is considered indivisible from a broader move towards a stronger protein autonomy of Europe, i.e. a decrease in protein imports notably in the form of soy from the American continent.

Regarding research needs to enable the reduction of an overreliance on protein imports, aside from the above-mentioned research needs at the farming system level to develop the production of legume crops and fodder, there is a necessity to look into trade mechanisms (beyond tariff barriers) to limit/discourage the *imports* of soy into Europe.

- In this respect, further research is needed on potential competition and trade policy measures such as:
- Redefining the notion of *like products* in WTO (World Trade Organisation) regulations in order to integrate product-related or non-product-related PPMs (Processes and Production methods) as an instrument to design potentially discriminatory trade measures (including potential trade restrictions) on unsustainably produced products. The definition of PPMs could notably include an assessment of the environmental impacts of differentiated production processes (Charnovitz, 2002; Gaines, 2002)
- Further research into the competition-agriculture-environment policy nexus and hierarchy in international law, in order to consider:
    - The recognition and inscription of the primacy of international environmental, social and human rights law within trade agreements
    - The design a sector-based exception for agriculture (*'exception agriculturelle')* within the international trade policy framework in order to recognize that food products are not like all other commodities. This could enable the requirement of the respect of European rules for imported products for example.
- Research on the potential establishment of a carbon border tax at the European border

## 3.2 The plant-based narrative

Key words:

**Substantial dietary changes**

**Sustainable intensification**

**Efficient nutrient application**

**Reducing food lost & waste**

This narrative assumes the strongest societal transformations at the consumer level as the protein transition is mainly driven by a substantial change in demand towards a plant-based diet (i.e. no to small amounts of meat). Furthermore, in order to respect the nitrogen boundary, the 'sustainable intensification' (i.e. producing more food per unit of resource used) of the global production system is promoted, which notably implies drastic efficiency improvements in the application of nitrogen fertilizer and avoiding loss of nutrients in a context where the use of synthetic nitrogen is maintained.

Finally, reducing food loss and waste all along the supply chain is promoted to avoid nutrient loss. In most work published along those lines, the protein transition does not imply a greater protein autonomy and in particular the re-territorialization of N cycles.

As such, no specific hypotheses are made regarding the re-introduction of legumes in rotation, and the bulk of protein plants consumed in Europe still comes from abroad (Springmann et al., 2018, supp material).

### FARMING SYSTEMS

The plant-based narrative on the protein transition puts a strong emphasis on drastically reducing the consumption of animal products to limit the environmental impact (GHG emissions and land use per kg/product) of livestock production systems, and especially ruminant production (Nijdam et al., 2012).

Conversely, the consumption of plant proteins (legumes and nuts) increases significantly.

Although this narrative does not necessarily engage in reflections around the implications of such changes on farming systems from either an agronomic or a socio-economic perspective, research needs could be similar to the agroecological scenario in terms of:

- designing levers to allow the development of pulse production (not on legume fodder in this case), see above;
- more specifically in this narrative, a socio-economic prospective assessment of the induced transformations of farming systems, and especially the near disappearance of livestock farms would be needed.

**Furthermore, in order to optimise nitrogen use** at the production level while keeping high yields, this scenario assumes more generally the 'sustainable intensification' of the agricultural system, which seeks to produce "more with less" by enhancing the efficiency of input and resource use (Garnett et al., 2013).

**Research needs for the production of protein** are therefore especially articulated around efficiency improvements and precision agriculture strategies such as:

- for crop production systems
  - *plant breeding to improve crop yields and eventually develop high-yielding varieties of protein crops (legumes and nuts)*[xv] *(Magrini et al., 2018)*
  - *optimising the use and application of synthetic nitrogen through technology-driven increases in use efficiency (Mueller et al., 2012)*
- to a lesser extent, for animal production
  - *increasing the efficiency of animal breeds and feed*
  - *improving the management of livestock and manure (Bodirsky et al., 2014)*

**Such large-scale modifications at the production level centered** around a logic of intensification would induce significant impacts on farming systems, especially from a socio-economic point of view. Because of this, more systemic research should be conducted:

- an environmental assessment of the widespread impact of intensification on agroecosystems/agricultural biodiversity (including soil microbiomes, pollinators, birds, etc.) and landscape diversity
- a socio-economic assessment of the impact on capital and labour intensity of farms (including potential decrease in farm labour, level of capital investments needed and impact on the viability of different farm structure, etc.), economic resilience, etc.

### VALUE CHAINS

In this narrative, although the importance of engaging the whole supply chain to move away from animal-sourced and towards plant-based protein at the consumption level is acknowledged (Willett et al., 2019), it is not emphasized as a stepping stone of the protein transition in itself. As this narrative presents no particular focus on protein autonomy (at the international/European level, but also the national, territorial and farm level), the emphasis is not put on how to re-structure new plant protein supply chains.

Nonetheless, the radical transformations of protein production and consumption implied in this narrative would produce important shifts in value chain (re)organisation and therefore imply research needs on those aspects.

Given the stronger decrease envisioned for animal products consumptionthe impact of a transition away from livestock production on value chain reorganisation should be a strong matter of attention.

Furthermore, in order to avoid nutrient loss at a system level - which constitutes one of the priorities of this scenario -, another strong research priority is the development of strategies to reduce (and recycle) food loss and waste, not only on farmers' fields, but more generally across the value chain.

**To this end, suggested research pathways include:**

- testing and evaluating effective strategies to reduce food loss and waste at each stage in the supply chain
- the research and design of infrastructure solutions to improve logistics and storage, for instance through collective storage facilities, investing in cold chains, developing optimised food processing technologies, etc.
- at the production level, investing in education, training and extension services for producers to improve harvesting and storage strategies
- in terms of *recycling* nutrients, the emphasis is put on designing technologies to improve sewage systems in order to recycle available nutrients

### CONSUMPTION HABITS

In the plant-based narrative, dietary shift is a central assumption: indeed, substantial changes in consumer patterns (both in terms of products consumed and reducing food waste) are a key driver of transformations in the food system - more so than in other narratives. In order to support this change in consumer preferences, this narrative thus envisions both technological and policy changes in a complementary manner.

On the one hand, technological improvements are geared towards the processing industry at the downstream level of the value chain to develop innovative plant-based products and integrate pulses into existing products (pasta, etc.).

**To this end, research needs thus still include:**

- processing technologies
    - while major species such as wheat and rice have benefitted from innovations in varieties and in food processing to reduce cooking time and offer new products, little research has been done for pulses (Magrini et al., 2018)
    - Need for additional research to improve sensory desirability, protein solubility and functional synergies between plant and animal proteins and other biopolymers (Chardigny & Walrand, 2016)
- Other properties of pulses: e.g. there is still limited knowledge available on the composition, structure, properties and uses of pulse starches compared to cereals (Hoover et al., 2010)

At the policy level, this narrative assumes a very strong 'top-down' role and impact of institutional and political levers on consumer behaviour and industrial strategies through strong international coordination.

To this end, an incremental combination of soft policy interventions (education, information, labelling) and hard policy interventions (laws, fiscal measures) are put forward.

**Research associated with such a pathway** from a policy point of view include:

- evaluating and updating dietary guidelines and defining a European standard on healthy and sustainable diets
- designing soft measures (national informational/educational campaigns) as well as hard regulatory measures, notably strong fiscal incentives (taxes and subsidies) to encourage a dietary transition
- modifying standards of public and private sector procurements and contracts to promote sustainable protein consumption in schools and workplaces (Willett et al., 2019)

#### TRADE FRAMEWORK

This narrative does not consider Europe's protein dependency as an issue in itself: as such, the global macroeconomic framework maintains current trade flows and furthers the liberalization of agricultural markets.

Because livestock production decreases significantly, protein imports are no longer predominantly based on feedstuff; however, Europe continues to import great amounts of plant proteins (including for human consumption) from across the globe according to each region's specialization based on differentiated factors of competitiveness.

Thus, research needs to ensure the sustainability of protein imports include:

- At the level of Regional Trade Agreements (RTAs) established to further liberalize trade exchanges between partners:
    - research on tools to integrate deforestation-free conditionality and carbon neutrality for imported (protein) products, for example either by connecting carbon markets between parties of the RTA or by developing joint initiatives to tax international maritime and air transport emissions (which are not covered under the Paris Agreement) (Bellmann et al., 2019)
    - Research on the potential use of trading agreements as a tool for environmental diplomacy and cooperation: for example, through the inclusion of suspension clauses in bilateral agreements in case of a partner country's violation of established international environmental (climate and biodiversity) commitments (Fondation Nicolat Hulot pour la Nature et l'Homme & Institut Veblen, 2019)
- Investing in certification schemes and labels as well as developing strong and cost-effective traceability measures/technologies to ensure respect for international environmental/social/human rights norms of all products imported and commercialized in the European Union

## 3.3 The technocentric narrative

Key words:

**Biotechnology**

**Increased protein content**

**Upcycling industrial by-products**

**Resource efficient**

**Cultured meat**

In this narrative, the protein issue is mainly framed around the fact that the current valorisation of protein and nitrogen resources within the food system is *inefficient*.

As such, the protein transition is viewed as a matter of *optimising* the system (instead of *structurally* changing it), mainly through large-scale technological investments (at the upstream, midstream and downstream levels of the value chain) to increase general protein availability.

To enhance resource-efficiency - which is the core principle of this narrative -, the development of new production systems such as insects, algae, fermented protein and cultured meat production is a key aspect.

### FARMING SYSTEMS

At the production level, this narrative considers that current agricultural systems - including the production of protein - are inefficient.

Notably, livestock production is considered as inherently sub-optimal because of its low conversion ratio of nutrients into protein, high land use and significant GHG emissions. In this context, the research needs in this narrative are mainly focused on the creation of new, more *resource-efficient* production systems to produce "novel" protein sources (Pyett et al., 2019).

**This specifically implies the development of :**

- insect production systems (crickets, black soldier flies, mealworm);
- and aquatic farms (for seaweed, kelp or microalgae)

The interest in developing such production systems notably lies in i) the fact that they are able to valorise a wider variety of protein sources than livestock, and ii) the perceived interest of pushing the traditional boundaries of a limited nitrogen supply.

For example, the production of protein based on algae would imply a widespread modification of the terrestrial constraints of arable land (Huyghe, 2017).

To go even further and have "protein production... be decoupled from land and sea resources" (Pyett et al., 2019), novel protein sources also include the development of:

- cellular (tissue engineered) meat;
- and/or acellular (fermentation-based) products, synthesised through recombinant yeast, fungi/mycoprotein or bacteria (Tuomisto, 2019).

**Before the commercial scale development** of these novel production systems, specific research needs are required to evaluate their global socio-environmental implications, including:

- A holistic assessment of the impact of the insect, algae, microbe and cultured meat production on the environment (including land use, GHG emissions, etc.):
  - current research indeed suggests that the environmental sustainability of cultured meat may potentially be limited, especially because of high levels of transformation and processing (Westhoek et al., 2011).[xvi]
  - a more general research challenge is the need to have a more holistic assessment of on the global food system which would sustain the production of inputs (for bioreactors, aquatic farms, etc.). As of now, the development of such novel protein products is largely disconnected from the territorial level and to a more systemic analysis of the *type* and *origin* of inputs - which is crucially needed.
- Assessment of the impact of integrating various agricultural products in bioreactors on agricultural systems and value chains

**Additionally, significant investments in technological R&D are needed** if such production systems are to become indeed resource- and energy-efficient as well as cost-effective, including:

- developing low-energy conversion technologies to extract proteins from algae (Pyett et al., 2019)
- Improving the conversion ratio of cultured meat (the long-term objective being to reach a 1:1 conversion ratio between plant protein and cultured meat protein)
- remaining research to optimise the *in vitro* meat cell culture process: developing an industrial-scale, cheap and efficient alternative to blood serum for the culturing process (to reduce dependency on animals), mimicking the in-vivo myogenesis environment to allow animal cell adhesion and proliferation, etc.

## VALUE CHAINS

This narrative also focuses on the fact that there is an inefficient valorisation of protein sources along the value chain, notably because of food waste and loss as well as the lack of valorisation of industrial by-products.

As such, research needs at the value chain level focus on (re)designing industrial processes which allow:

- at the upstream level, plant breeding to increase the protein content or yield of crops (including protein crops, oilseed crops and cereals).
  - this indirectly implies a strong increase in the use of synthetic nitrogen/fertiliser in production systems.
- at the midstream level, the up-cycling/recycling via circular by-design systems of industrial by-products (e.g. rapeseed press cake, potato processing water, brewers grain, etc.) and post-consumer food waste for feed (for livestock production) or as inputs into insect/cultured meat productions
  - this implies research into the necessary regulatory changes notably to i) authorise the use of certain industrial by-products as feed, and ii) authorise the production and commercialisation of novel foods for human consumption (Stephens et al., 2018). Legislation is already headed in this direction, particularly for insect productions as the European Food Safety Agency (EFSA) is set to endorse whole or ground mealworms, locusts, crickets and grasshoppers as safe for human consumption (Boffey, 2020)
- at the downstream level, the design of innovative industrial processes to develop attractive plant-based and cell-based products

## CONSUMPTION HABITS

Contrary to the plant-based scenario, a strong tenet of the technocentric narrative is that the protein transition should occur without (radically) changing consumer habits.

Indeed, proponents of this narrative consider it unrealistic to change consumption/social behaviours, and especially the desire for meat and animal products, to the extent that is needed to a have an effective transition towards sustainable protein sources (Tuomisto, 2019; Waschulin & Specht, 2018).

This is why this narrative maintains a level of total protein intake which is only slightly below current protein consumption.

In this respect, research needs are framed around technological change rather than societal change to produce plant-based and cell-based products which are as close as possible to current options.

This implies:

- developing innovative products (plant-based and cell-based) which perfectly mimic traditionally consumed products from a sensorial (taste, colour, texture) and nutritional perspective (indeed, based on current processes, cell-cultured products differ significantly from traditional products, including on the basis of its nutritional composition) (Fraeye et al., 2020)
- in order to gain full consumer acceptance, the ultimate objective of research in this field is to make cell-based products biologically equivalent to traditional animal products (Fraeye et al., 2020)
  - this implies finding biotechnological solutions to bypass the current addition of texturising ingredients, colorants, flavouring and nutrients to mimic sensorial and nutritional properties

It is important to note however that despite the underlying assumptions of this narrative on its perpetuation of current consumption habits, the adoption of novel protein sources is likely to imply greater social change than other existing alternatives (van der Weele et al., 2019).

### TRADE FRAMEWORK

Like the plant-based narrative, the technocentric narrative also maintains the current structure of trade flows and the underlying dynamic of further liberalization of agricultural markets.

Because the consumption of animal products is maintained (even though to a lesser extent) and cultured meat (which also relies on regular feedstock) increases, imports of soy remain relatively significant.

Therefore, the priority in terms of policy research needs concerns:

- In furthering the priority given to biotechnologies, relaxing regulatory constraints around the import of GMO (soy) products

# 4. CONCLUSION: RESEARCH PRIORITIES AND THE NEED FOR POLITICAL ARBITRATIONS

From a general perspective, there are of course strong commonalities that transpire from all three narratives on the protein transition.

**Those can be considered as overarching priorities for European research programs.**

They notably include:

- Consolidating strong evidence-based evaluations of the health and nutritional benefits of diets based on lower quantities of animal proteins and different protein sources;
- Identifying levers and fostering changes in food consumption patterns towards plant-based sources of protein and away from animal protein;
- Optimizing the nitrogen cycle especially by identifying ways to reduce and recycle food waste and losses across the supply chain as well as by limiting nitrogen leakage/avoiding nutrient (be that synthetic or not) overuse at the production level;
- Integrating legume crops in farming systems and value chains with a clear understanding and integration of their co-benefits;
- Improving the varietal selection of pulse and legume crops.

However, although all narratives of the protein transition share strong common points in their respective research needs, there are also significant differences between them.[xvii] Investing in one area of research rather than another will thus contribute to shaping the transformation of the European food system at large and will have broader implications for its sustainability, resilience and autonomy.

Arbitrations between different approaches should not only be based on the desirability of each scenario (whatever criterion are considered), but also on the actual scale of change required to attain it.

In short, two main dimensions would need to be considered in the definition of research priorities:

- the potential sustainability gains of each scenario (*desirability dimension*)
- the required level of technological and social-institutional change associated to each scenario (*plausibility dimension*)

**The genuine ex-ante evaluation of both aspects is however out of the scope of this paper.**

We can nevertheless bring a few reflections on those by way of conclusion.

The table below stresses how each narrative address different sustainability issues and prioritize them:

- while the plant-based and the technocentric narratives might offer good solutions to tackle climate change issues, they have considered with less attention biodiversity challenges, as well as those associated to landscape structures and water quality.
- Socio-economic dimensions are in general poorly integrated either in terms of food affordability, jobs provision at farm level or capital investment needed. One can however notice that the sort of transition pathways incurred at the farm level by

the technocentric and agroecology narrative would result in higher capital intensity of farms, lower number of farms and jobs on farms due to the high degree of specialization and investments they rely on.

- On the health dimension, the technocentric narrative and, to a somewhat lesser extent, the plant-based narrative focus on the integration of protein-rich ingredients/products in current diets to cause the least disruption possible in consumer habits. This focus on ingredients, rather than (whole) foods follows a reductionist approach to nutrition which assesses health potential of a product solely based on its nutrient composition (Fardet & Rock, 2015).

  For example, this is how the benefits of cellular meat are promoted thanks to the improvement it would bring (by adding omega-3 fatty acids for example) (Chriki & Hocquette, 2020). On the other hand, the agroecological and plant-based narratives adopt a more "holistic" approach to nutrition which focuses on promoting *whole* sources of protein (notably, whole pulses as well as animal products) and limiting "protein ingredients" incorporated into (ultra-)processed foods. In this approach, the evaluation of the health benefits of different protein sources is derived from *both* macro- and micro- nutrient composition as well as food structure properties (Fardet et al., 2015).

In terms of the feasibility, while the technocentric narrative is evidently based on significant technological breakthroughs, **the agroecological scenario relies on drastic changes in how trade flows are organized** and could thus be considered as highly challenging from a political perspective.

# 5. SOURCES


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[i] It might be worth reminding here that on average, more than 70% of all vegetal products used in the EU (whether produced locally or imported) are used as animal feed.

[ii] The definition of protein requirement is based on total nitrogen as well as indispensable amino acid requirements (European Food Safety Authority, 2012). It is usually expressed in terms of grams of proteins needed by kg of body weight and by day. This value evolves with the age of persons, but an average value of 50g/pers/day is considered a good proxy (see Westhoek et al., 2011).

[iii] The remaining 12% comes from atmospheric deposition.

[iv] The form of the protein transition in other geographies must be different from that which needs to happen in Europe for current diets there are quite different.

[v] Different actors are also calling for a re-authorization of meat bone meal for animal feed as a viable alternative source of proteins. This falls out of the scope of this paper. It however only represented less than 2% of all raw ingredient used in the making of compound feeds in the 1990's

[vi] Those figures particularly challenge the suggestion made by Beverland {, 2014 #7035} that consumer willingness to adopt meat-free or low-meat diets was limited by the fact that such diets were considered as a deviation from the norm. While this was potentially true at the time the data were collected – a decade ago – things are changing quite quickly.

[vii] although some of the most important livestock producing countries such as Brazil, China and India still do not feature any legislation on animal welfare

[viii] Indeed, during the Dillon Round (1960-61), the US pressured Europe to obtain advantages in exchange for a CAP agricultural policy which they deemed too protectionist. The article XIV-6 led to the consolidation of a null tariff barrier on soy grains, oilseed cakes and cotton.

[ix] While the protein content of soy is significantly superior to that of cereals

[x] On top of that, the category of "animal protein" could itself be broken down into subcategories: eggs and dairy products on the one hand can be distinguished from meat, and ruminant and granivorous meat shall also be considered separately. See below.

[xi] In particular with respect to climate mitigation, GHG emissions reduction can be approached very, whether it relies on the reduction of $N_2O$ primarily, $CH_4$ primarily, or both, through e.g. the reduction of (synthetic) N inputs, that of cattle, etc.

[xii] This level of intake corresponds to the Population Reference Intake (PRI) which is the calculated level of nutrient intake that is adequate for virtually all people in a population group. It is not defined as a nutritional recommendation as such by the European Food Safety Agency, but is meant to be used by Member States to issue recommendations.

[xiii] The disconnection between crop and livestock production at the global level has been identified as one of the leading causes of nitrogen surpluses and inefficient use (Lassaletta et al., 2014)

[xiv] It is estimated that over-eating is as much a contributor to food system losses as consumer food waste (Alexander *et al.,* 2017) and that intake of animal products can simply be reduced by at least one third without necessitating any substitution (Van der Weele, 2019)

[xv] "The impact of dietary changes resulted in small reductions in cropland use of 0-2%. The reason that we did not observe greater reductions from dietary change aone was that the reductions in cropland demand by countries with high portions of animal source foods were compensated by increases in cropland demand by countries that consume poor quality diets high in grains. By food group, the reductions in cropland use for feed crops was, to a large extent, compensated by large increases in cropland use for legumes and nuts which are relatively low-yielding varieties. Redirecting investments towards higher-yielding varieties of those crops could be an effective strategy for reducing cropland use in the context of changes towards healthier diets which contain larger amounts of legumes and nuts." (Willett et al., 2019)

[xvi] "the priority given to meat alternatives with limited sustainability potential does not just raise questions of technological optimisation of production systems, but is also a second-order problem of the framing of search directions." (Van der Weele et al, 2019)

[xvii] Regarding for example:

- the place and use of synthetic fertilizer in the protein transition in the technocentric scenario, one key research need consists in increasing the protein content of crops that are already massively grown in EU like wheat or rapeseed. However, this would lead either to no decrease or, potentially worse, to increasing needs of N synthetic fertilizers (if the promises of a genuine "sustainable intensification does not hold) and therefore go against the development of agroecological farming systems which relies on the reintroduction of legume crops in rotation to limit their use mineral fertilizers.
- the development of fodder legumes and the maintaining of pastures implied by the agroecological scenario for landscape diversity / biodiversity reasons is antagonistic with the drastic decrease of ruminant meat consumed in the plant-based scenario.