Who is disrupting the food value chain: Regulators, Incumbents, Startups or Consumers? (RISC)

Mapping the Alternative Protein Ecosystem and its Disruptive Potential

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1 What is Disruption?

The Austrian economist Joseph Schumpeter first articulated the concept of creative destruction in his seminal work Capitalism, Socialism and Democracy (1942). He described it as the "process of industrial mutation that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one" (Schumpeter, 1942). This process, driven by entrepreneurial innovation, renders existing technologies, products, and business models obsolete while simultaneously creating new markets and value.

The project aims at identifying disruptive forces for the food system that impact on actors involved in the food supply chain. While we all have an intuitive understanding of what disruptive means, the term is neither in scientific literature nor in public discourse uniformly defined. Consequently, the term "disruptive" may be as widely interpreted as portraying a process of creative destruction that is based on new technologies that render the current technology obsolete. It would then be the result of ongoing innovation that develops the potential of technologies — which should include techniques to advertise, organise supply chains and internal structures etc. that all impact on the innovation output and competitiveness of a company — or new technologies that are most likely first used by entrants rather than incumbents.

This is actually not what Christensen — one of the first to define "disruptive" technologies — meant. In his book "The Innovator's Dilemma" he described situations where dominant incumbents were not able to compete with new entrants that used technologies that were inferior in the main attributes at the outset. The new entrants improved these technologies over time and were able to slowly surpass dominating technologies in specific markets while incumbents struggled to adapt.

Christensen's definition stresses the inferior nature of the disruptive technologies which resulted in not being classified as a threat by incumbents. It could be argued that most new technologies that have been labelled disruptive with hindsight were inferior to the incumbent technologies at some point in time. The problem for both entrants and incumbents is to assess the potential of the technology to appeal to potential customers. Consequently, the majority of decision makers in incumbents as well as new entrants, scientists or experts have difficulties forecasting the future course of new, potentially disruptive technologies. A prominent example is the IEA's failure to forecast the share of renewable energies.

Christensen‘s definition of disruptive technologies is particularly useful for studying the alternative protein product as many observers see them as inferior to the original in terms of taste, haptics and ingredients. In the following section paradigm shift in industrial sectors and the reaction of incumbents are outlined as well as industrial policy reactions. Additionally, the main reasons why the food system has to change in order to respect the limits of the planet are given. This is followed by an experimental mapping exercise of the alternative protein sector that use artificial intelligence-based methods of natural language processing. The resulting analysis sketches the structures of the alternative protein ecosystem and its development over time. The final section present conclusions.

1.1 Voluntary Paradigm Shift of Incumbents and the Sailing Ship Effect

Incumbent are most likely locked into the technological paradigm their products are built on. Switching to a new although promising technology is beset with all the risks involved in mastering and investing in a new technology that will at some later point cannibalise the existing product range that is working well for incumbents. The willingness of incumbents to adopt such a new technology will be limited without entrants that employ the new technology and threaten to take away profits.

Rather than waiting for new entrants to become competitive or adopting potentially disruptive technologies themselves, incumbents tend to invest in the technology they master to pre-empt market entry. This may render them prone to be hit by the sailing ship effect. The sailing ship effect indicates that whatever the efforts of the incumbent, past a certain threshold the new technology will prevail and confine the old technology to a niche. The concept was first observed in maritime history: the introduction of steam propulsion in the early 19th century prompted significant innovations in sailing ship technology, including the development of clipper ships that achieved unprecedented speeds but did stop the demise of sailing ships (see e.g. Mendonça, 2013; De Liso, Arima & Filatrella (2021); Kompella, 2025).

The reluctance to pro-actively adopt the new technology is caused by (correct) expectation that the new technology would cannibalise existing products and thus profits due to the present product portfolio. Managers tend to frame this as a timing issue, i.e. determining how long they should keep improving their existing products and reap high profit margins before switching to the new technology. The framing of the problem as a timing issue might come with the following problems:

- The intricate difficulties that lie in mastering the "inferior" technology entrants are using are often underestimated. The "inferior" technology may seem an easy technology to master but most likely turns out to be just the opposite. Legacy automakers have discovered that it is fairly difficult to produce a decent electric car once they realised that electro mobility is about to change their industry. This is partly due to problems in technological challenges associated with potentially disruptive technologies from the outset.

- Incumbents frequently overestimate the remaining improvement potential of their established technologies while underestimating the trajectory of emerging alternatives. This cognitive bias is reinforced by historical success: past investments have yielded returns, engineering teams have deep expertise in the existing technology, and customer relationships are built around current product specifications. The sunk cost fallacy amplifies this tendency, as managers struggle to abandon capabilities built over decades. Moreover, incumbents often measure emerging technologies against current customer requirements rather than considering how customer needs might evolve as new capabilities become available.

- Large organizations are susceptible to groupthink, where the desire for conformity and consensus suppresses critical evaluation of strategic assumptions. When leadership is invested in a particular technological trajectory, dissenting voices warning about emerging threats may be marginalized or dismissed. Janis (1972) documented how groupthink leads to defective decision-making, and subsequent research has confirmed its prevalence in corporate strategy contexts. The Nokia case exemplifies this dynamic: engineers who recognized the iPhone's disruptive potential found their warnings filtered or diluted as information traveled up the organizational hierarchy. Breaking free from groupthink typically requires deliberate organizational interventions such as designating devil's advocates or bringing in external perspectives.

- Established industries often leverage their economic and political influence to shape regulatory frameworks in ways that protect existing business models and slow the adoption of disruptive alternatives. This can take forms ranging from direct lobbying for favorable regulations to funding research that emphasizes the risks of new technologies while minimizing those of incumbents. In the food sector, incumbent meat and dairy industries have successfully lobbied for labeling restrictions on plant-based alternatives (prohibiting terms like 'milk' or 'burger'), mandatory disclosure requirements that don't apply to conventional products, and subsidies that overwhelmingly favor animal agriculture. While such efforts may provide temporary protection, they rarely halt genuinely disruptive technologies and can damage industry credibility when they appear to prioritize incumbent interests over consumer welfare or environmental concerns.

Historical analysis reveals remarkable variation in how quickly transformative technologies achieve mass adoption. The telephone required approximately 75 years to reach 50 million users, while radio accomplished this in 38 years, television in 13 years, and the internet in just 4 years. More recently, social platforms have achieved 50 million users in months rather than years. This pattern of accelerating adoption rates has profound implications for incumbents: the window for adaptation continues to shrink with each successive technological wave (Grübler, 1990).

1.2 S-Curve, Wright's Law and the Incumbent's Struggle for Timing

The market success of disruptive technologies is mostly driven by unexpected performance increases and/or cost reductions of the disruptive technology. Electric cars saw rapidly decreasing prices of batteries that came along with impressive improvements in energy density which resulted in weight savings and/or range increases as well as extremely faster charging speeds that put them on par with internal combustion engine powered cars. Photovoltaic cells saw a price decline of about 80% in the 2010s while their efficiency increased substantially. The same holds more or less for CRISPR-based genetic engineering, chip development (Moore's law), artificial intelligence etc. Azhar (2021) coined the term "exponential technologies" for such rapidly developing fields of technology that may be highly disruptive for incumbents.

Moore’s Law and Wright’s Law are both describing performance increases and resulting cost reduction that are based on technological advances and cumulated learning throughout the production of goods and services:

- Moore's Law, articulated by Intel co-founder Gordon Moore in 1965, observed that the number of transistors on integrated circuits doubles approximately every two years, enabling exponential improvements in computing power at decreasing costs. This empirical observation has held remarkably well for over five decades and has become a paradigmatic example of exponential technological progress (Moore, 1965; Flamm, 1993).
- What is now called “Wright's Law” was first documented by Theodore P. Wright in 1936 who observed that in aviation manufacturing there is a constant percentage decrease in costs whenever cumulative production volume doubles. Wright found that labour costs in airplane manufacturing decreased by approximately 20% with each doubling of cumulative output. This is based on experience and learning that allows optimisation of the production process. This phenomenon, now recognized as a fundamental principle of learning curves, has been validated across numerous industries from semiconductors to solar panels. Lafond, Greenwald, and Farmer (2016) demonstrate that Wright's Law provides remarkably accurate predictions for technological progress across diverse sectors, often outperforming more complex forecasting models.

The (successful) diffusion of innovation — and developments in nature — follow mostly an S-curve (see Smil, 2020): fast growth at the beginning that hardly results in significant/visible market share at the beginning because of a low base are followed by massively increasing gain in market share beyond the lower inflection point. The exponential nature of diffusion processes, coupled with the perceived inferiority of the new technology and the not obvious cost savings that occur with increasing production volumes are the key ingredients for a misjudgement of the potential of a new technology.

Once the threat of a disruptive technology is visible to the plain eye it might actually be too late to counteract: the market dynamics will be in favour of entrants resulting in massive market share losses while attempts to harness the benefits of the disruptive technology by incumbents may be far more difficult than forecasted. What seemed a simple and easy to copy technology has developed into something where mastery is difficult and resource consuming.

1.3 Scope of Change and Foundational Characteristics

So far a number of technologies were cited as being disruptive here: e-mobility, CRISPR, the internal combustion engine, the iPhone, the ICE car and now the electric car. While there seems not to be much controversy in labelling these products/technologies as disruptive, the scope of the taking over process is vastly different. The advent of the iPhone — or more generally — of touch phones changed the usability but not the main function of mobile phones. Cars replaced horses and led to a fundamental shift in agriculture, the transportation system and personal mobility.

Disruptive technologies can reshape existing industries or create new sectors like automotive at the beginning of the last century. At that time nobody had a proper understanding of which characteristics define a car. There were hundreds of companies producing cars with different engines, designs and specifications. Only when a consensus emerged was a kind of standardisation of what constitutes a car possible. Once a car was defined — standardised — by customers and producers, the industry had a basis for growth and consolidated. Geroski (1995) provides foundational analysis of how markets for technology evolve, demonstrating that the emergence of a dominant design typically triggers industry consolidation and shifts competitive dynamics from product innovation toward process optimization (see also Murmann & Frenken, 2006).

This entailed a consolidation of the industry and more focussed development activities with continuous improvements along the technological paradigm chosen. Few focussed on the dominant technology that was being displaced by cars — horses in their different roles in personal transport and agriculture. For decades cars were not able to compete with horses. Only when the dominant design evolved and was combined with mass production did cars reach a level of utility/versatility and a price point that allowed broad adoption. Within 10 to 20 years, cars replaced horses in almost every part of the economy. Arbib & Seba (2017), in their RethinkX analysis, document similar patterns in contemporary technology transitions, arguing that the convergence of electric vehicles, autonomous driving, and ride-sharing platforms will trigger a disruption in personal transportation comparable to the horse-to-car transition.

At the beginning of a technology that might become disruptive, many startups may try to come up with the winning design for the new offering that still are very different from each other. This is due to the fundamental uncertainty innovations/new technologies are beset with. It is fair to say that nobody actually knows what specifications the new technology/product must develop in order to succeed on the market.

Up to now, and this will be analysed in the following sections, alternative proteins have seen a strong increase in the number of companies between 2010 and 2022. It remains to be seen if this technology – or better: these technologies – are truly disruptive. Even if they grow strongly in the immediate future, the market for animal-based products is huge and it will take a long time until substantial inroads will have been made.

2 Economic Policy Context and Rationales

2.1 Externalities and Market Failure

The reduction of externalities is one line of argument for public support in the line of market failure motivated policy intervention. The basic argument is that the market left to its own devices will produce outcomes that are socially not desirable. This may be due to high risks associated with e.g. investments in research and development or indivisibilities, making needed investment too big to be shouldered by a company alone or diverging social and private return (i.e. high social and too low private returns). The majority of support schemes for innovation in Europe is based on these arguments.

Most of the time, this line of thinking ignores the externalities that are associated with supported innovation projects. If a project that supports the improvement of more efficient internal combustion engine (ICE) cars is taken as an example, the fact that an innovation is supported is the necessary condition while the impact of the improved and therefore more popular ICE powered cars on GHG emissions and the depletion of finite resources is ignored. Looking at the state of the planet overall, it is fair to conclude that the market failure argument delivers a strong incentive for economic policy intervention but that the evaluation of the outcome has to encompass the systemic effects of this support in a holistic way (see Leo, 2022).

2.2 Deglobalisation and Industrial Policy

The arguments for an active industrial policy have been strengthened in the recent decade. Successful catching-up countries like China — but earlier Japan, Korea too — have demonstrated that industrial policies targeting specific industries may be successful if well planned and executed. Europe and the US have for a long time restrained from "picking winners" (i.e. championing sectors and companies) and rather focussed on a horizontal industrial policy.

The tide is changing here too for two main reasons: the success of China and the increasing decoupling of the economic spheres or — expressed differently — the end of globalisation. This process has been heavily driven by the US where both parties to different degrees want to focus more on domestic issues, shed the burdens of being the only remaining superpower and reverse the export of blue collar jobs due to globalisation.

China has been so successful in establishing itself as the workbench of the world, that many products are only produced in China in sufficient quantities. Additionally, China has managed to almost monopolise the value chains for rare earth, battery production, photovoltaics, or battery production for electric cars. Consequently the US and European dependencies create potential to be blackmailed by China.

2.3 European and US Policy Responses

Europe has positioned itself as the leader in the decarbonisation of the economy and society until it more or less cancelled the Green Deal. The Green Deal was the guiding strategy for the first term of Ursula von der Leyen setting ambitious goals in order to meet the zero emission target by 2050. While Europe has long considered itself as a leader in green technologies and decarbonisation, the implementation of the Green Deal was beset by a number of problems: First and foremost, there was no immediate implementation of the strategy because operationalisations were missing or delegated to the member countries. Second, increasing green investments were highly advantageous for Chinese producers particularly in the field of photovoltaic, battery production and increasingly electric cars.

European efforts to establish production in these fields have been clumsy, tedious and far from an overall success story. The main vehicles have been Important Projects of Common European Interest (IPCEI) in various fields where Europe is lacking and the European Chips Act. The preparations for establishing an IPCEI take up to two years before the actual work can start. The immediate impact is difficult to discern and a prominent failure — the insolvency of the battery producer Northvolt — has left European policy makers with little to present in this domain.

The US has skipped the strategy formulation phase and jumped directly into the implementation of the Inflation Reduction Act (IRA). Despite its misleading name, IRA offers production subsidies for a wide range of technologies that are important for the green transition and for reducing dependence on Chinese producers. Production subsidies offer a specific subsidy whenever a pre-specified product is being produced. The big advantage compared to e.g. IPCEIs is that companies can immediately start to set-up their production rather than going through a lengthy and tedious process before they can start building new operations.

The IRA has been somewhat obliterated by the Trump administration which is — it seems — interested in maximising the climate impact of the US system rather than mitigating its impact. Permissions to build offshore wind parks have been revoked in the midst of the building process. The subsidy for purchasing electric cars was just revoked.

2.4 Why the Food Industry Must Change

So what is happening in the food industry? Are there new technologies that compete with cows, chicken, pigs etc. or phrased differently, are there a bunch of new not yet standardised technologies that may disrupt the food industry? Representatives of the alternative protein landscape frequently describe their offering as being based on technologies that outcompete animals in terms of raw material, energy, water etc. inputs and far more environmentally friendly and less cruel to animals than incumbents.

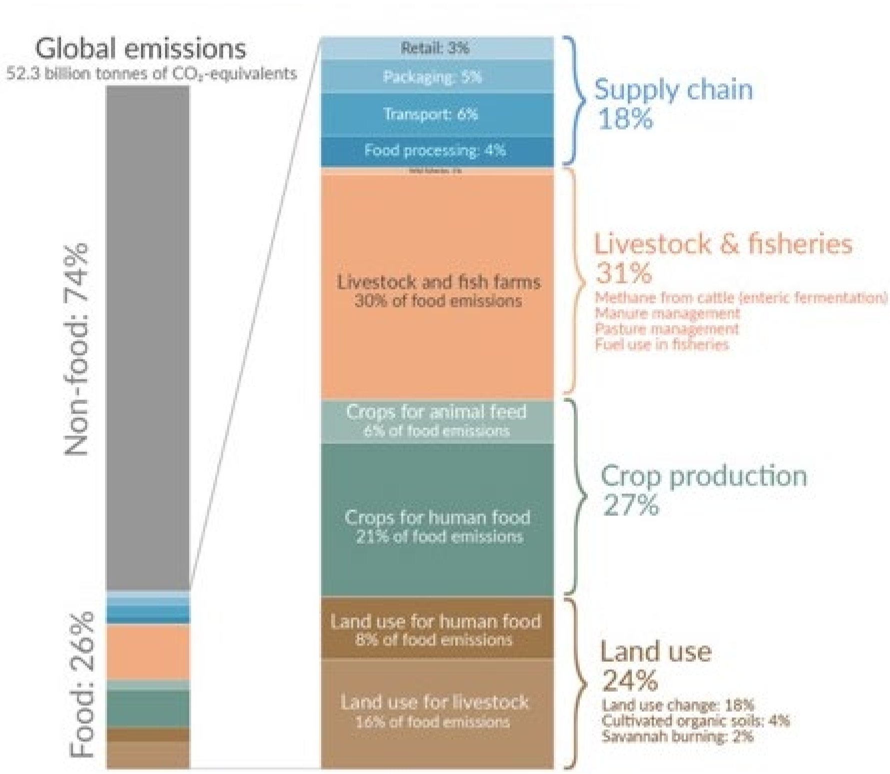
Agriculture and the food sector have been flying under the radar in the climate debate. Globally, a third of man-made greenhouse gas emissions are attributable to this sector. Food production and consumption account for 26%, the remaining 5 percentage points are caused by outputs not intended for consumption (e.g. biofuels) or deforestation. Animal husbandry is responsible for 56-58% of these emissions (Poore & Nemecek, 2018).

Although the food system has kept pace with the steady increase in the world's population — measured in calories per capita — more than 800 million people are still undernourished. The number of overweight people, on the other hand, has passed the 2 billion mark. Unhealthy diets are a greater risk of morbidity and mortality than unprotected sex, alcohol, drug and tobacco use combined (The Lancet Commission, 2019).

Of particular importance is the large land use of animal products: The feed production for animals takes up about 80% of agricultural land while only 37% of protein and 18% of all calories are provided. Obviously, many more people could be nourished when plants would be consumed directly by humans and not through animals. For example, it takes seven plant calories to produce one beef calorie. The ratio is somewhat better for pork — about 3:1 — but again the detour via animals requires substantially more input for food production than the direct consumption of plants by humans.

Figure 1 illustrates the distribution of greenhouse gas emissions across the global food system. According to Our World in Data analysis based on Poore & Nemecek (2018), food accounts for 26% of global GHG emissions. Within this, livestock and fisheries contribute 31% (primarily from enteric fermentation in ruminants and manure management), crop production accounts for 27% (including on-farm energy use and fertilizer application), land use changes represent 24% (mainly deforestation for agricultural expansion), and supply chain activities contribute 18% (processing, transport, packaging, and retail). The visualization demonstrates why addressing animal agriculture is central to any serious climate mitigation strategy in the food sector — livestock alone accounts for more emissions than all other food production activities combined.

Figure 1: Global GHG emissions from food production



Source: Our World in Data, based on Poore &Nemecek (2018)

While it is obvious that the large share of animal products are the main reason why western diets are not sustainable, currently observed trends are very disconcerting: Oxford University researchers (Springmann et al. 2016) show that if current dietary trends continue, greenhouse gas emissions from this sector will increase by 51% by 2050 (compared to the 2005/2007 period). Even with adherence to a dietary "minimum consensus" among nutrition experts, the targeted maximum temperature increase of 2°C is not feasible. Only a purely plant-based diet brings this scenario within the realm of possibility.

The high proportion of animal products — especially meat — is not only environmentally and climate damaging in production, but also problematic in consumption. If the consumption of meat were to be reduced globally to the recommended "minimum consensus", then not only would disease-related costs (treatment and care costs, productivity decline) decrease, but life expectancy would also increase. However, this would require a 56% reduction in meat consumption, a 25% increase in the consumption of fruits and vegetables, and a 15% reduction in calorie intake overall.

Overall, there is no sector where appropriate government intervention has so many positive “side effects” on the environment, biodiversity, climate, animal welfare and human health. Rational policy makers can not avoid being avid supporters of food system reform.

2.5 Technology as Disruptor

Meat is appreciated for its sensory attributes and nutritional value. In order to produce a desirable meat substitute, its properties should be like those of meat: fibrous texture, taste, appearance and equivalent nutritional value primarily in terms of protein content. In imitating and substituting meat, a key factor seems to be the formation of a pronounced fibrous structure in order to resemble its characteristic mouthfeel (Fiorentini et al., 2020). Hence, two challenges must be solved: a) selection of suitable and sustainable protein sources and b) selection and application of appropriate processing technologies for texture generation (Don & Goot, 2020).

There are basically three technological approaches that are important for the alternative protein sector:

- **Plant-based:** Apart from soybeans, chickpea, hemp seed and lupin (He et al., 2020), meat substitutes can also be produced from protein sources like mycoprotein or cultured meat. The production of meat substitutes based on plant proteins requires a reformulation including the modification of texture, flavour and appearance. Production of plant-based meat continues to rely on twin-screw extrusion for high-moisture applications (Sandoval Murillo et al., 2019). Recent systematic reviews have examined the nutritional profiles, sensory attributes, and consumer acceptance of plant-based meat alternatives (Boukid, 2021; McClements & Grossmann, 2021). Onwezen et al. (2021) provide a comprehensive meta-analysis of factors influencing consumer acceptance of alternative proteins, while Sha and Xiong (2020) review the technological advances in plant protein texturization.

- **Precision fermentation:** Uses microorganisms or fungi to produce amino acids. These in turn are the building blocks for proteins. This allows the basic materials to be developed with which milk, cheese, eggs, etc. can then be replicated and replaced. At the end of 2024, precision fermentation is at the beginning of the scaling phase. Some companies or their investors, and in some cases also the public sector, have provided funds for the construction of large-scale production facilities. Academic literature documents both the technical potential and remaining challenges for scaling precision fermentation. Tubb & Seba (2021) project significant cost reductions as the technology matures, while Humbird (2021) provides techno-economic analysis highlighting the capital intensity of fermentation infrastructure. Järviö et al. (2021) assess the environmental footprint of microbial protein production.

- **Cultured meat:** The multiplication of meat cells in a bioreactor is one approach for producing alternatives to meat from animal husbandry or fishing. Cultured meat is currently only produced on a laboratory scale and will only be found in supermarkets once all problems have been solved. Currently, there are still major challenges in the efficiency of cell multiplication and the associated costs. Post (2012) provides foundational analysis of cultivated meat technology, while Stephens et al. (2018) examine the technical, regulatory, and social challenges facing the sector. Tuomisto & Teixeira de Mattos (2011) conducted early life cycle assessments, and more recent work by Risner et al. (2021) and Humbird (2021) examines scaling challenges and production economics.

Extrusion is the most commonly used texturing technology for meat substitutes. The reasons are a broad spectrum of raw materials, the meat-like product texture, as well as the efficiency of extruders on an industrial scale. For downscaling approaches, 3-D printing concepts are in development that allow the creation of meat substitutes based on additive manufacturing at a smaller scale (Shahbazi et al., 2021).

The reformulation of meat substitutes bears huge potential for a more tailored and targeted production. Building meat-like structures from scratch based on protein molecules or even on specific amino acid sequences is not only a step towards climate-smart food systems but also allows smart production towards personalised foods. Based on a 'digital-twin' approach, desired characteristics and properties of a food product can be turned into a virtual model of the product that can be used for re-design and reformulation based on reverse engineering concepts.

3 Ecosystem Analysis

Ecosystem analysis of emerging technologies is a demanding task. Numerous data sources have to be analysed and integrated with the intention of drawing both the big picture as well as delivering detailed and granular insights.

The startup ecosystem concept has emerged as a means of explaining and managing entrepreneurship at a regional level by looking at the interaction of different actors and conditions. An entrepreneurship or startup ecosystem can be defined as "a set of networked institutions […] with the objective of aiding the entrepreneur to go through all the stages of the process of new venture development. It can be understood as a service network, where the entrepreneur is the focus of action and the measure of success" (Isenberg, 2011).

Figure 2: Dimensions of startup ecosystems

Source: Isenberg 2011

This framework identifies six interconnected dimensions that shape entrepreneurial ecosystems: Policy (government support, regulatory framework), Finance (venture capital, angel investors), Culture (success stories, societal norms), Supports (infrastructure, professional services), Human Capital (educational institutions, workforce), and Markets (early customers, distribution networks). These domains interact dynamically, with strength in one area potentially compensating for weaknesses in others.

At the figurative centre of the startup ecosystem is the entrepreneur (and his team), who founded a startup or spin-off company with the ambition to grow it successfully (Führlinger, 2016). In terms of the supporting environment — the ecosystem — two levels can be distinguished:

- **Level 1: contextual factors** that differ in each country or region and determine the conditions in which entrepreneurial activities take place. These factors can be divided into **a) political & legal framework, b) cultural & institutional environment and c) economics & regional dynamics**
- **Level 2:** The various actors who **support directly** — to varying degrees — the **entrepreneurs and their new venture**. These actors/institutions can be divided into different areas: **research** (universities and laboratories), **public support** (e.g. government grant providers and regional development agencies), **professional support** (e.g. management consultants, legal firms and

accountants), **finance** (e.g. business angels and venture capitalists), **industry** (entrepreneurs, and small and large firms), personal support (family and friends) and **support organisations** (incubators and accelerators). Besides the varying degree of interaction between these actors and the entrepreneur, there are also interrelations between these actors. Depending on the nature of these actor interrelations, their support initiatives within the ecosystem can either be symbiotic or redundant.

Although the framework conditions (level 1) are important and some internationally comparable statistics are available to describe it, most of the time the focus is on level 2, i.e. the description of actors and their interactions. We propose a two-pronged approach for this analysis:

- The **identification of the actors and their direct interactions** with each other through, for example, co-publications, cooperation in research projects, patent holders, employees who were previously in academia, funding for companies, financing from business angels and VC.
- **Thematic description of the actors and the close relationships** between them. These can be made visible using natural language processing methods. The NLP approach makes the various data compatible because it allows the thematic focal points for each sub-area to be recorded and compared with the focal points in other areas. This reveals different orientations and deficits. For example, it is possible to find out what the scientific foundations of the startups in Innsbruck and Vienna are, analyze in detail the topics the startups are working on, identify the correlation between scientific and startup topics, and determine the thematic focus of funding institutions, business angels, and venture capitalists.

Assuming that the description of the interaction and cooperation patterns as well as the contents within an ecosystem are possible in this way, allows to compare ecosystems based on these parameters.

The analysis of the alt protein ecosystem focuses on the startups, the scientific production of knowledge that forms the knowledge base for many startups, support by public agencies and research programmes, the investments venture capitalists (VCs) and the role of consumers. While there is a short section on the inflow of venture capital into the FoodTech sector which focuses on alternative protein production the impact of VCs of seen through the companies they invest in. These startups that aim at transforming the sector will be part of the mapping exercise. Consumer behaviour is assessed by a very brief description of the European market in the past years.

The central part of this analysis is a mapping exercise that uses a new approach to position academic research, startups and support activities in the same plane. The approach and the outcome will be presented in the next chapter followed by a short section on consumer demand and VC investment. In the final section conclusions will be presented.

3.1 Method and Data to Map the Alternative Protein Ecosystem

For the mapping of the alternative protein ecosystem language vectors are going to be used for a cluster analysis. Language vector/embeddings represent text that is transformed by an LLM into a high dimensional vector. Abstracts, project or company descriptions are used for this exercise.

The resulting vectors represent the meaning of the text and can be interpreted as coordinates in the high dimensional language space that is explored and cartographed by large language models (LLMs). Using text vectors allows to map publications, projects and companies with respect to each other in this high dimensional space. This high dimensional space can then be broken down to a 2-dimensional representation of the ecosystem that is being studied.

For the analysis of the alt protein ecosystem, a number of databases offer relevant insight on the system and its subaggregates. Most noteworthy are startup/company, publications, research grant and patent databases. As we tried to represent as many segments of the alt protein ecosystem we included the following datasets:

- OpenAlex is an open source repository of scholarly output – mostly peer reviewed scientific papers but not exclusively. Overall, OpenAlex hosts about 250 million publications.
- EU framework projects as included in cordis database. This is a full list of projects and publications done under the auspices of the European framework programmes.
- Austrian industrial innovation project and science-economy collaborations supported by Österreichische Forschungsförderungsgesellschaft mbH (FFG, Austrian Research Promotion Agency) scraped from the online project repository. The projects online are a subset of unknown share of the overall projects of this institution.
- Scientific projects financed by the Austrian Science Fund (FWF) downloaded from the website. This is a complete sample of all projects since 1994.
- Alternative protein startups as collected by Good Food Institute (GFI) and downloaded from its website.
- European Research Council (ERC) projects as provided by this institution. This includes all supported projects.
- Austria Wirtschaftsservice (aws – Austrian Promotional Bank) funded industrial industrial innovation projects scraped from the online project repository. This is only a fraction of all projects by this institution.

These datasets represent a fairly complete picture for Austria and Europe not including the activities of member states (see Table 1). For the other countries only the startups and scientific work represent the activities in this space.

Given that OpenAlex has more than 250 million publications, a 2-step procedure was used to select scientific publications that are related to the alt protein ecosystem. In the first step we identified a list of topics that are related to research on food innovation and alternative proteins including plant-base, precision fermentation and cultivated meat approaches. The list was completed with support from topical experts and is included in Annex 1. The 402,668 publications for the topics in the final selection were downloaded. In the second step we identified with semantic search and 8 search terms plus the combination of all search terms a subset of about 66,000 publications. The same approach was used for all other datasets except the alternative protein startup database of GFI which was included in its entirety.

The final sample consisted of almost 71,000 observations of which about 93% were scientific publications from OpenAlex. About 3% of observations are startups and EU framework projects while the ERC and FFG stand for about 0.2%, FWF for 0.1% and aws for 0.03%. The sample therefore is dominated by scientific literature.

Table 1: Sources and composition of the sample

Source	Number of observations	Number of observations in the sample	In % of observations	Share in % of sample
openalex	402,668	66,107	16.42	93.13
startup	2,330	2,330	100	3.28
cordis	93,586	2,133	2.28	3.0
erc	16,283	167	1.03	0.24
FFG	10,782	161	1.49	0.23
FWF	19,500	66	0.34	0.09
aws	1,095	19	1.74	0.03
TOTAL	546,244	70,983	13.0	100.0

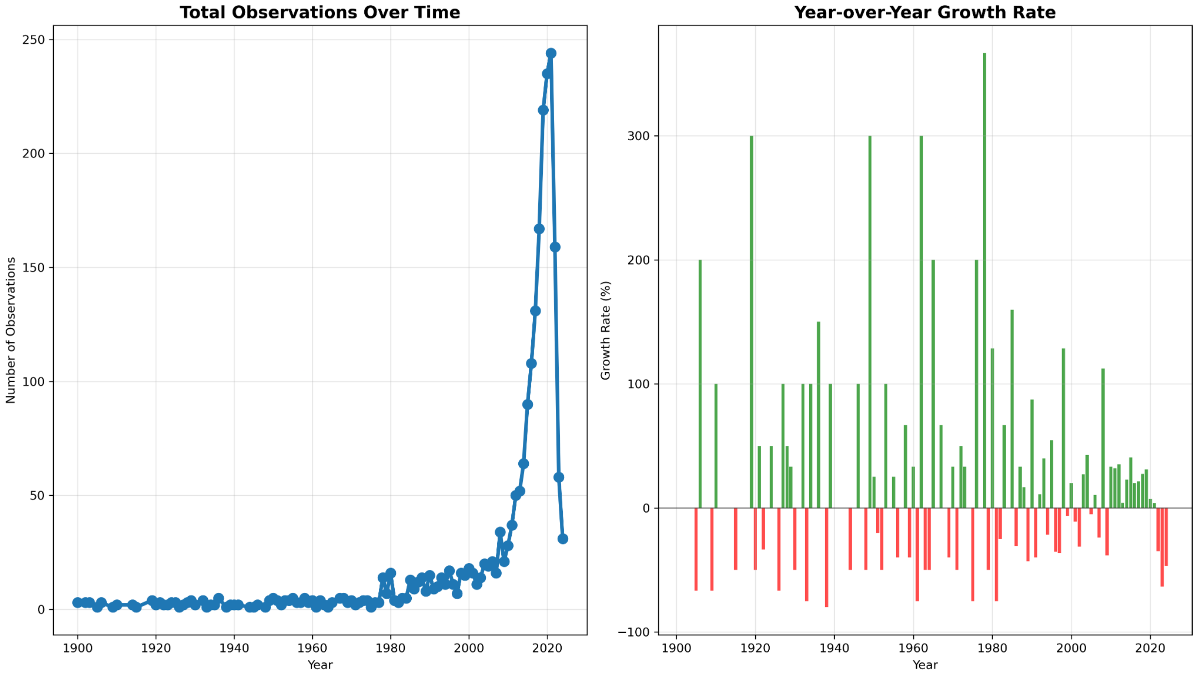
The share of projects that ends up in the final dataset is already a first indication how important the food innovation topic is for the institution. 16.4% of the OpenAlex extract were selected for the final sample. This might be considered low given that we already preselected publications that were on topics associated with food innovations. The outcome depends on the set level for similarity which was 0.4. Choosing a lower similarity score for the selection would have increased the number of OpenAlex publications in the final sample and vice versa. About 2.3% of cordis projects are on food innovation topics as defined here. This is higher than for the other institutions which show a score between 0.34% (FWF) and 1.74% (aws). As we had only a subset of projects for FFG and aws, the share of food innovation projects among all projects that are supported by these institutions may be much higher or lower.

3.1.1 GFI Company Database Analysis

Overall there are 2,330 observations in the GFI database downloaded on October 20th 2024. The companies included are startups and established companies in the food and biotechnology space. Ordered by the date of establishment, a persistent increase in the number of companies is discernible after the year 2000 and particularly in the years since 2008. As the GFI database contains mostly investor-backed companies, this reflects to a significant amount the preferences of investors who were willing to invest in particular segments of the market at particular times.

This trend holds until 2020 and a decline in the number of startups in the years afterwards. The strong decline is mostly due to an underrepresentation of startups in the years after 2020 – i.e. not all startups were visible to those collecting the data which likely includes the year 2021 – and a decline in the number of startups for various reasons (to be discussed in the venture capital section. There is no way to disentangle those two effects.

Figure 3: Evolution of GFI database by year of company establishment



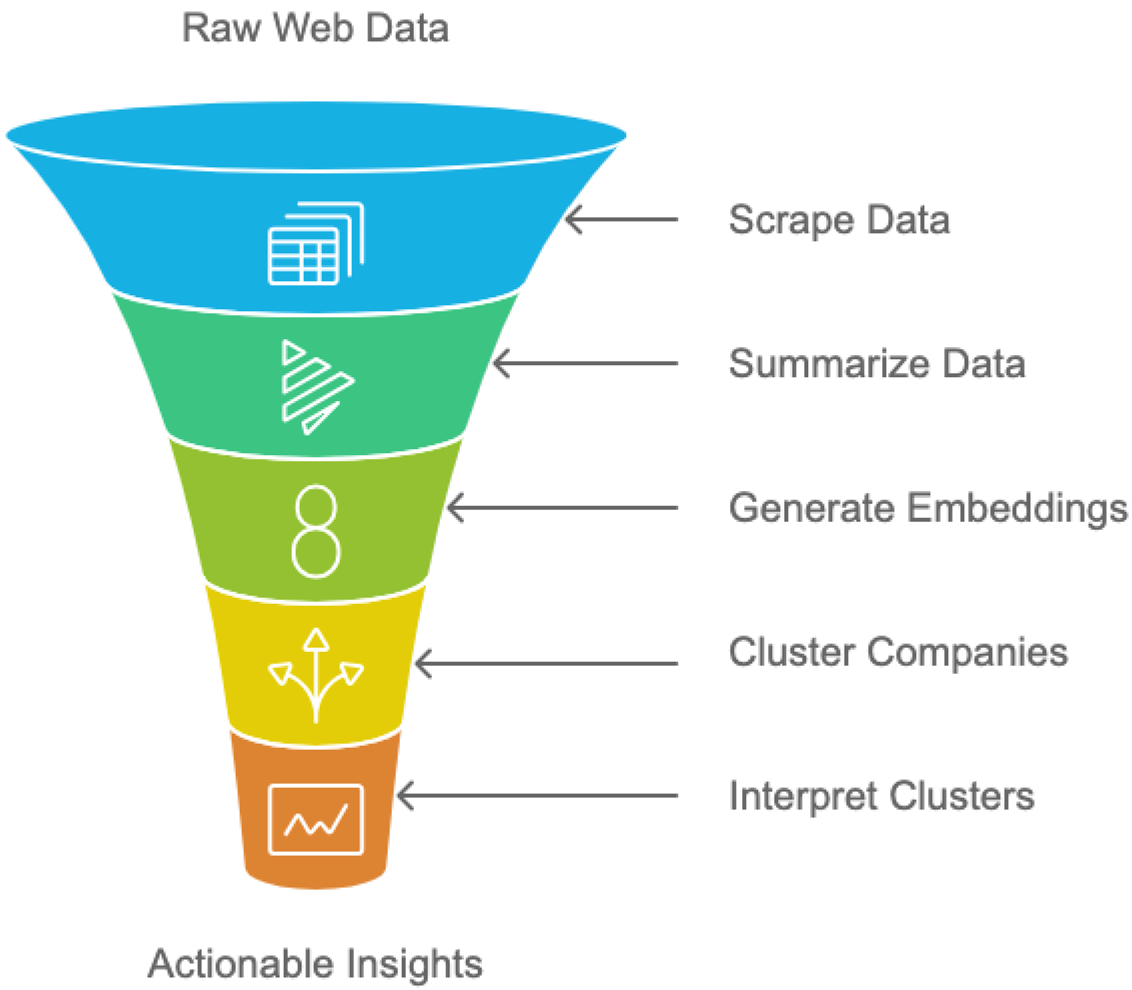
Looking at the foundation years of the companies since 1900 hundred, shows roughly 3 phases: Up to 1980 the pattern is erratic which is mostly due to the small number of newly established companies that strongly fluctuates from year to year. There is a slight increase in the number of companies founded that are now populating the alt protein space from 1980 onwards but the growth rate are still erratic. Only from 2008 onwards a strong and persistent growth of alt protein companies is discernible which comes to an end in 2021/2022. In this period 1,708 companies — or about three quarters of all companies in the database — were established, the majority of which were founded after 2008.

The companies positioned here are a mixture of startups and established companies — so-called incumbents — who have also entered the alternative protein market, or have always been located in it. The oldest company now producing plant-based alternatives was founded in 1834. Around 100 companies were founded before the mid-1970s (left-hand side of Figure 3).

3.1.2 Mapping startup ecosystems

While the transformation of text into language vectors is straightforward, the "harvesting" of appropriate texts is not. Mapping startups needed a description of company activities which was not available in the GFI database. The internet address of the companies in the GFI database was used to have an AI write a summary of the company's activities based on the scraped content of the startpage of their internet presence (see Figure 4). The other dataset used all provide either an abstract or a project description that was used for creating embeddings.

Figure 4: Workflow for the embedding based clustering



The outcome of the cluster analysis is used to colour UMAP based mappings of the observations. UMAP transforms high dimensional vectors into 2-dimensional representations. This approach is first applied to the alternative protein companies to see how this industry is structured and secondly to the larger sample that is dominated by academic research in this area.

3.1.3 Mapping Alternative Protein Companies

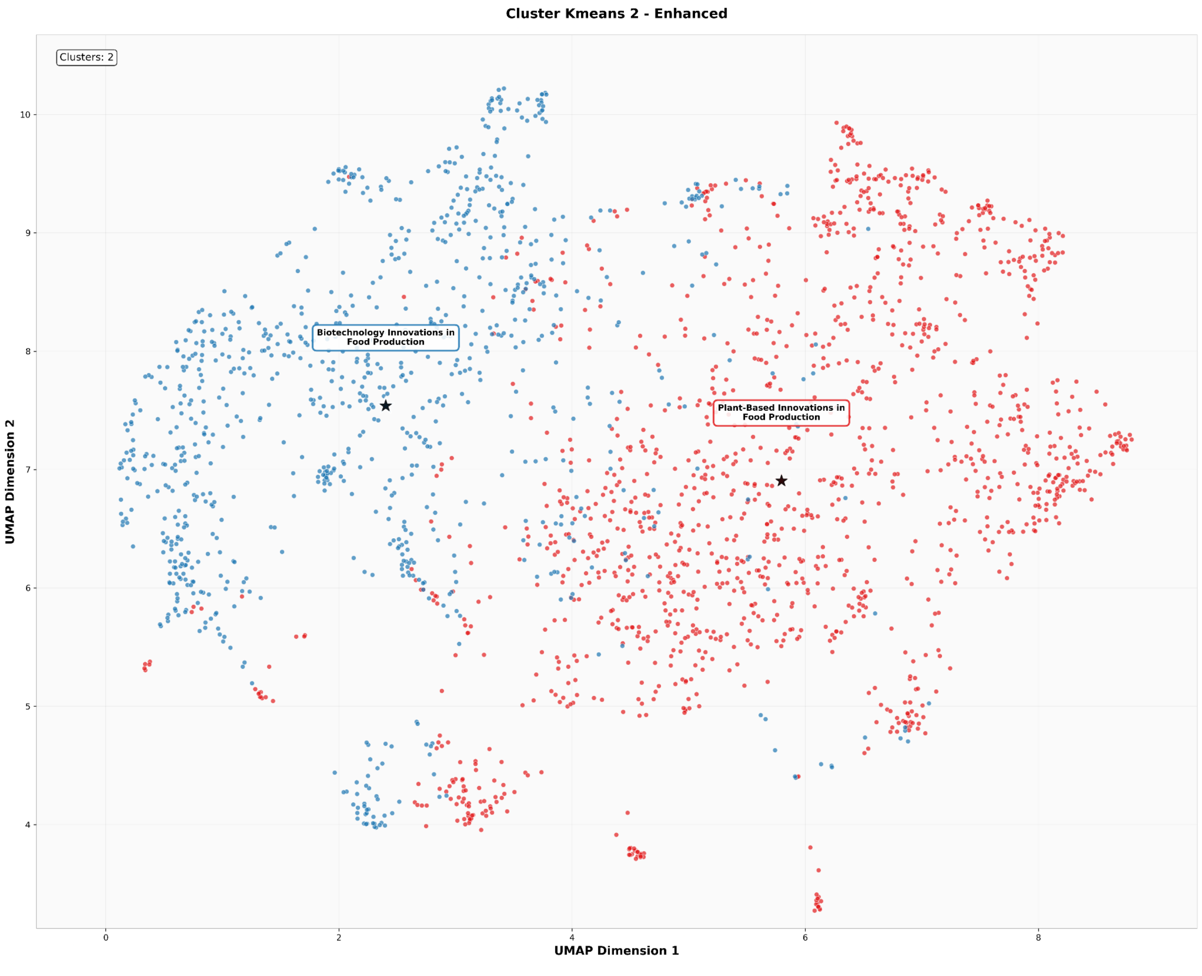
For the mapping of the industry a short summary of the company activities was produced based on the content of the public webpage. A screening of the accessibility of webpages indicated that 233 were offline. Contents for creating a summary were available for 1,973 companies. 74 webpages could not be scraped for a number of reasons: some companies did not allow the content to be scraped while others only had a presence on LinkedIn, Facebook or Instagram which was also not scraped.

The cluster analysis for the alternative protein startups dataset was done for 2, 30 and 100 clusters. The content of the clusters was interpreted by the openAI gpt-5-nano model. In the most aggregated 2-cluster solution startups are either part of the “Biotechnology Innovations in Food Production” or the “Plant-Based Innovations in Food Production” cluster. 1,395 companies are in the plant-based cluster while 935 are in the biotechnology cluster. The cluster content is described as follows:

- Cluster 0: Plant-Based Innovations in Food Production – This research cluster focuses on the burgeoning field of plant-based food innovations, highlighting various companies and products that cater to health-conscious consumers and sustainability advocates. Emphasizing technology-driven approaches, these companies develop alternatives to traditional meat and dairy products, aiming to enhance taste, nutrition, and environmental sustainability.

- Cluster 1: Biotechnology Innovations in Food Production – This research cluster focuses on the intersection of biotechnology and food production, emphasizing sustainable practices, alternative proteins, and advanced processing technologies. It encompasses a wide range of applications, including plant-based and cell-based food products, fermentation processes, and innovative ingredient solutions aimed at enhancing nutritional value and environmental sustainability.

Figure 5: 2-Cluster solution for alternative protein companies



The first noteworthy observation is that some companies in both clusters of the alternative protein space – plant-based and biotechnology-based – have been around for decades (see Figure 6). Both groups showed a massive increase of companies after 2008 particularly. The increase was started by plant-based companies while biotechnology-based startups followed with some delay. This is reflected in the growth rates of companies between the 2009-2015 and 2016-2022 subperiods in which the number of plant-based companies increased by about 220% while biotechnology-based startups almost quadrupled (+380%, see Figure 7).

Figure 6: Evolution of companies in the 2-Cluster Solution

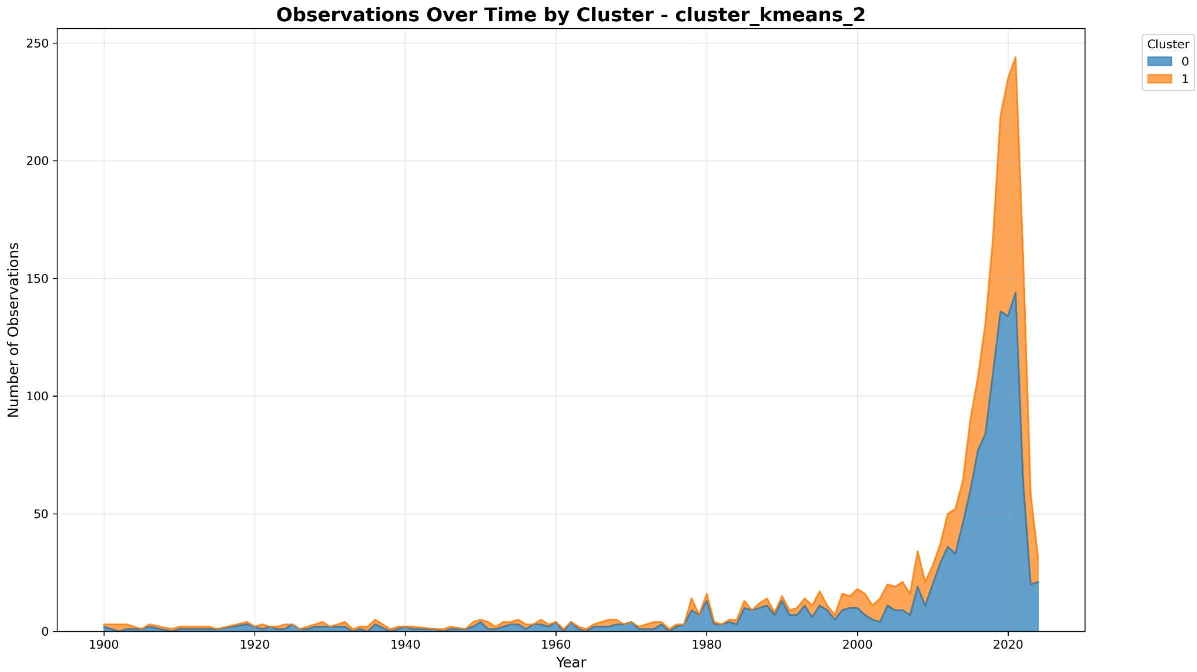
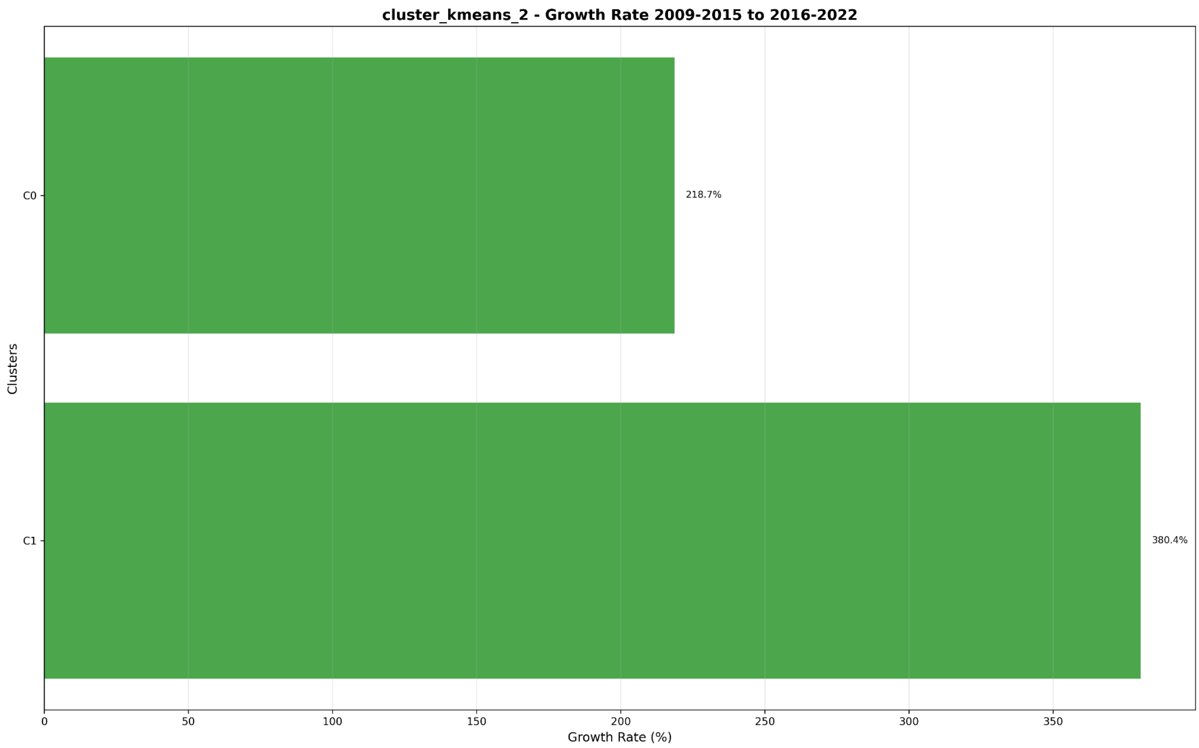


Figure 7: Growth rate of startups in the 2-Cluster Solution



The composition of the sector is much more disaggregated in the k-means 30-cluster solution (see Figure 8). While the topics of the 30-cluster solution largely follow the boundaries of the 2-cluster solution, they are usually not completely downward or upward compatible. Some of the cluster heading seems quite specific – like Plant-Based Food Innovations in Japan or Plant-Based Jackfruit Innovations – others seem largely focussed around the same topics but in different clusters. There are at least 5 sectors which vary the sustainable plant-based food innovation topic. Closer inspection is needed to identify the differentiating factors in these cluster separations though they inhabit spaces close to each other.

Figure 8: 30-Cluster solution (k-means) for alternative protein companies

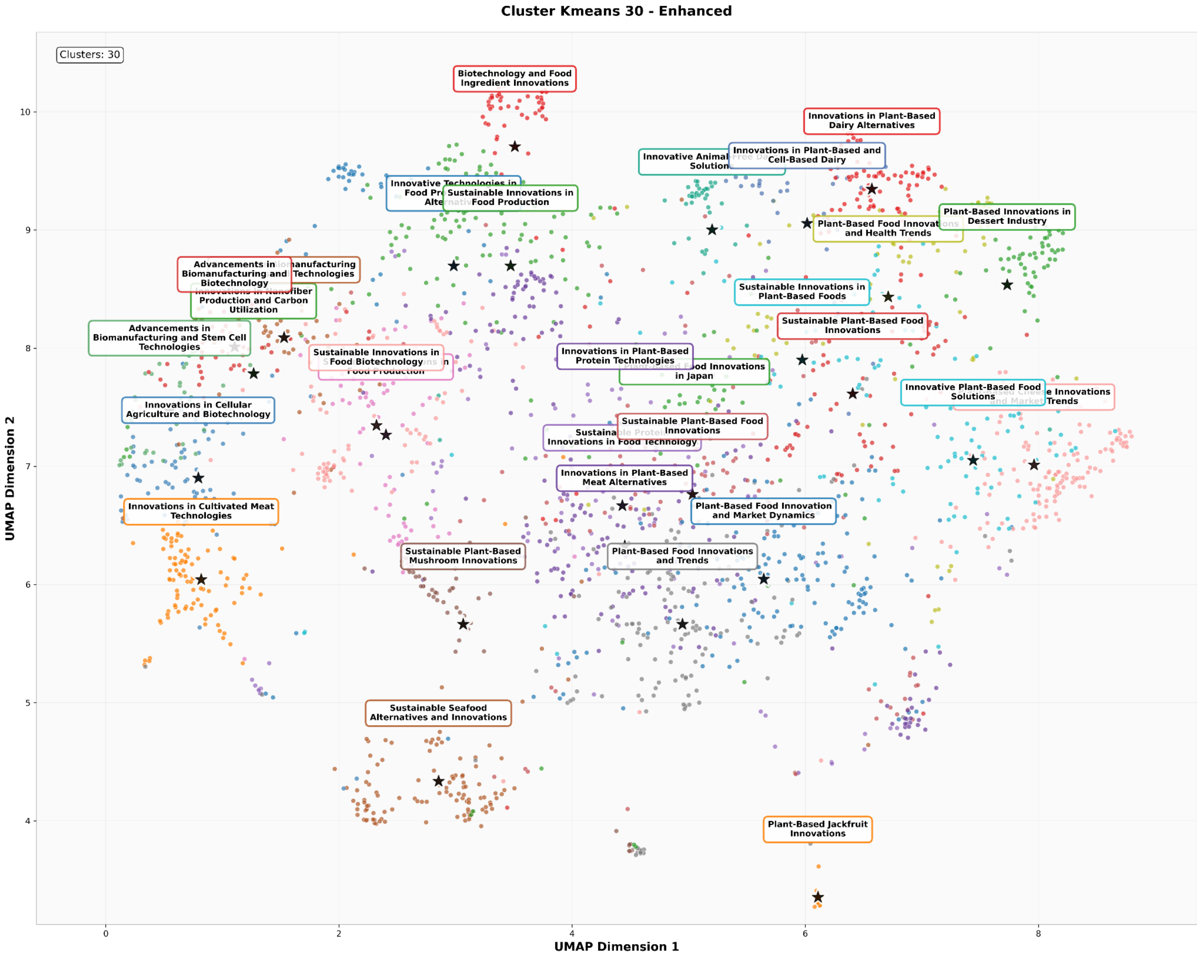


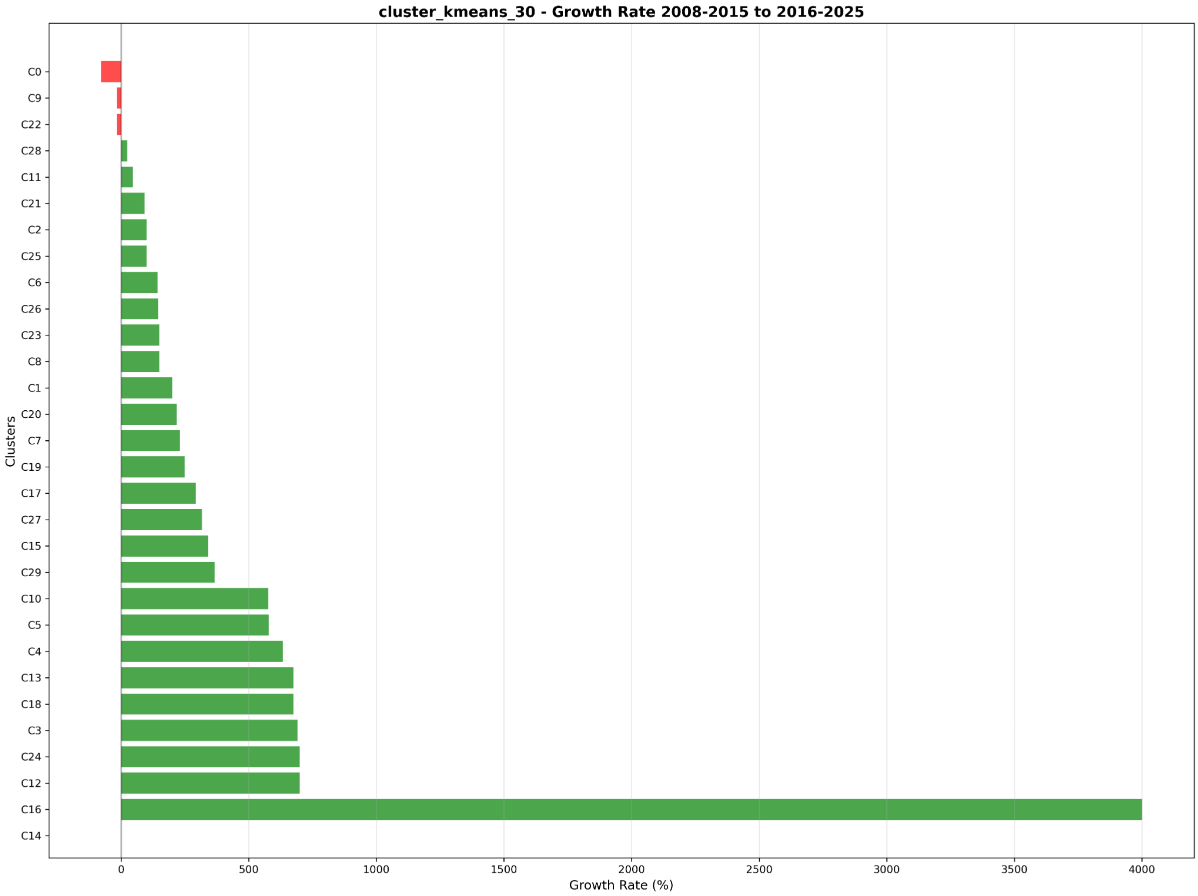
Table 2: 30-Cluster solution (k-means) headers and cluster growth rank

Cluster ID	Heading	Cluster size	Sample size	Growth rank
14	Mycelium-Based Alternative Protein Foods	51	17	1
16	Animal-free Dairy: Fermentation and Molecular Farming	42	14	2
4	Engineered Plant-Based and Fermented Meats	113	39	3
12	Precision Fermentation and Upcycled Ingredients	84	29	4
24	Functional Plant-Based Protein Ingredients	93	32	5
3	Commercializing Cellular Agriculture for Diverse Meats	98	34	6
18	Next-Gen Dairy: Plant and Cell-Cultured Milks	36	12	7
5	Marine-Focused Alternative Protein Technologies	114	39	8
10	Alternative Protein and Food-Tech Ecosystem	119	41	9
13	Inputs and Scale-Up for Cultivated Meat	74	25	10
29	Industrial Biomanufacturing Platforms and Informatics	50	17	11
27	Plant-Based Dairy, Fats, and Upcycling	54	18	12
15	Plant-Based Meat and Convenience Foods	156	54	13
17	Plant-Based Protein & Ingredient Technologies	102	35	14
7	Culinary-Driven Plant-Based Dairy Alternatives	58	20	15
19	Engineered Cell Microenvironments and Bioprocess Control	42	14	16
20	Barista-Grade Plantmilk Formulation and Supply Chains	92	32	17
26	Fermentation and Algal-Based Sustainable Ingredients	85	29	18
1	Industrial Food-Tech and Protein Processing Ecosystem	53	18	19
6	Cultured Plant-Based Cheese Alternatives	142	49	20
23	Jackfruit-Based Plant Meat Alternatives	14	4	21
25	Industrial Fermentation for Sustainable Biomanufacturing	51	17	22
8	Soy-Centric Plant-Based Food Innovation	26	9	23
2	Scale-Up Platform Technologies: Electrospun Nanofibers and CO_2 Valorization	7	2	24
21	Plant-Based Alternative Protein Ecosystem	151	52	25
11	Plant-based Dairy Alternatives and Functional Foods	91	31	26
28	Plant-Based Frozen Desserts & Upcycling	63	22	27
22	Food Ingredients, Processing and Co-Manufacturing Networks	141	49	28
9	Functional Plant-Based Ingredients and Supply Chains	79	27	29
0	Industrial Plant-Protein and Ingredient Networks	49	17	30

The cluster growth which is a simple comparison of the number of companies in a particular cluster between the 2008-2015 and 2016-2024 period brings a mixture of plant-based and biotechnology companies at the top and at the bottom (see Figure 9).

The strongest increase was observed in cluster 14 Sustainable Plant-Based Mushroom Innovations where the first companies started only in the 2016-2024 period. Therefore no growth rate could be computed. Cluster 16 Innovative Animal-Free Dairy Solutions grew by about 4,000% and is now populated by 42 companies. The following 8 clusters had impressive growth rates ob around 500%. The only clusters with slightly negative growth in the number of companies are cluster 0 Biotechnology and Food Ingredient Innovations, cluster 9 Sustainable Plant-Based Food Innovations and cluster 22 Sustainable Innovations in Food Production.

Figure 9: Ranking of Cluster Growth between 2008-2015 and 2016-2024



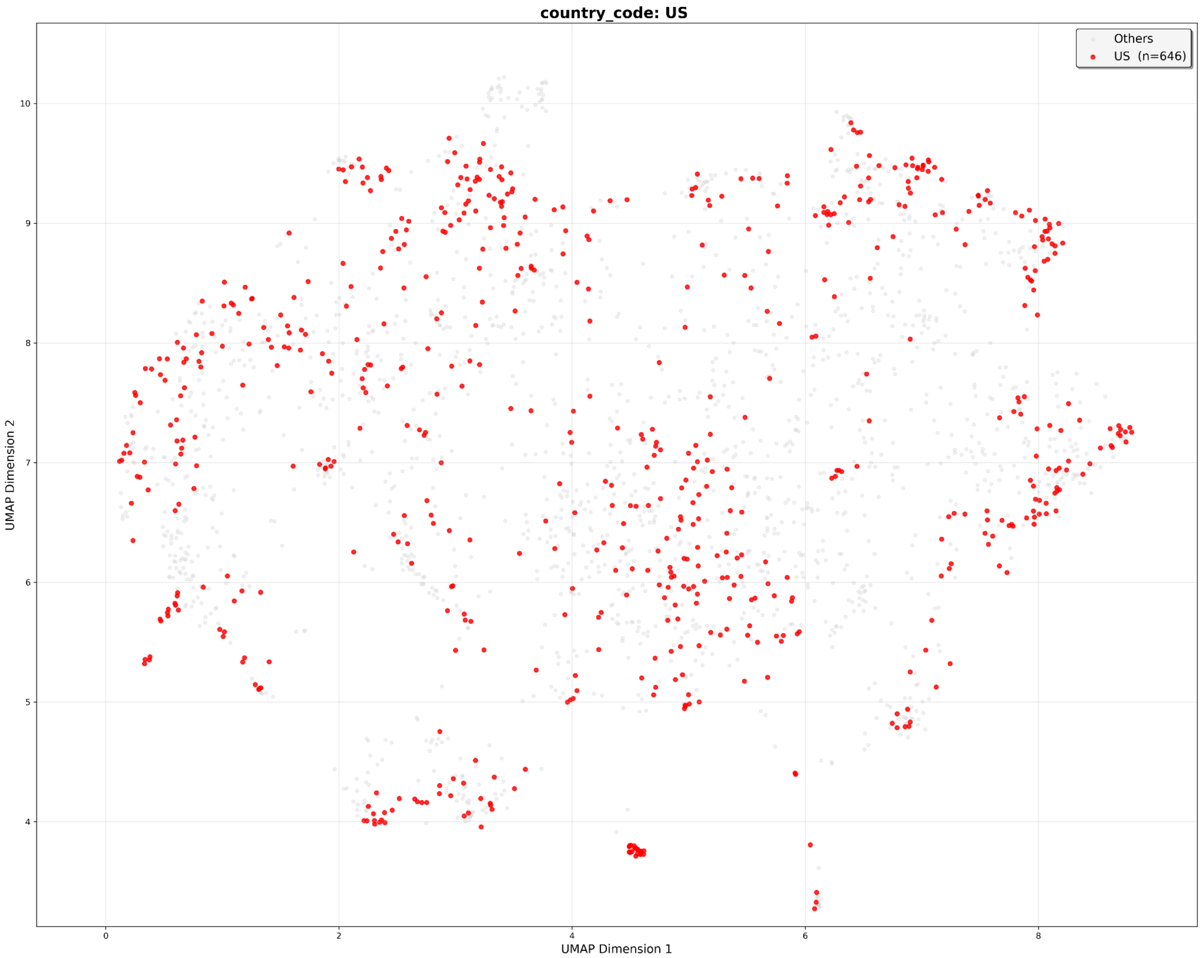
The geographical distribution of companies is an indication who are the first movers in this industry. Remembering the fact that no company database is complete, this is a tentative assessment of the evolution of the industry's demography. In the 2008-2015 period, the alternative protein space was dominated by US and European companies. The latter outperformed the US in terms of new entrants and had a 34% share in the 2015-2022 period while US companies stood for 29%. Still, both regions grew at a smaller pace than companies in the Asia Pacific region region (+436%) and in Africa and the Middle East (+394%, see Table 3).

Table 3: Geographical distribution of alternative protein companies

Region	Count 2008-2015	Count 2015-2022	Share 2008-2015 (%)	Share 2015-2022 (%)	Growth Rate (%)	Growth Ratio
Europe	116	455	30.9	34.3	292.2	3.92
U.S. and Canada	153	384	40.7	29.0	151.0	2.51
Asia Pacific	50	268	13.3	20.2	436.0	5.36
Africa/Middle East	16	79	4.3	6.0	393.8	4.94
Latin America	31	65	8.2	4.9	109.7	2.1
Unknown	4	45	1.1	3.4	1025.0	11.25
Australia/New Zealand	6	29	1.6	2.2	383.3	4.83

From a European perspective, this is one of the few emerging markets where Europe is in a leading position and where European companies are active across the whole spectrum of this industry (see Figure 10).

Figure 10: European Companies in the Alternative Protein Space



3.1.4 Mapping the Complete Alternative Protein Ecosystem

The full dataset comprises more than 70,000 observations. The fact that about 93% of observations are academic publications is an indication of the amount of research done and knowledge generated in academic research around the alternative protein field. The dataset and the results are therefore dominated by this category and show which topics are dominant in academic research. Information on the activities of alternative companies and supporting agencies allows to see where these actors decide to anchor their efforts.

For the full dataset 2-, 3-, 27- and 97-cluster solutions were implemented. Here, the focus is on the 3- and 27-cluster solution (see Figure 11and Figure 12). Both cluster solutions for the full dataset integrate startup companies, scientific publications, and EU-funded research projects, providing a comprehensive view of the alternative protein knowledge ecosystem.

The 3-cluster solution (see Table 4) divided observations in Alternative Proteins, Processing, and Safety (cluster 0), Microbial Fermentation for Circular Bioeconomy (cluster 1) and Alternative Proteins, Food Tech, and Systemic Sustainability (cluster 2). The cluster interpretations are based on 500 observations which obviously may be insufficient to see the details and distinctions particularly between these large cluster. This holds particularly for cluster 0 and 2 whose headings are almost identical.

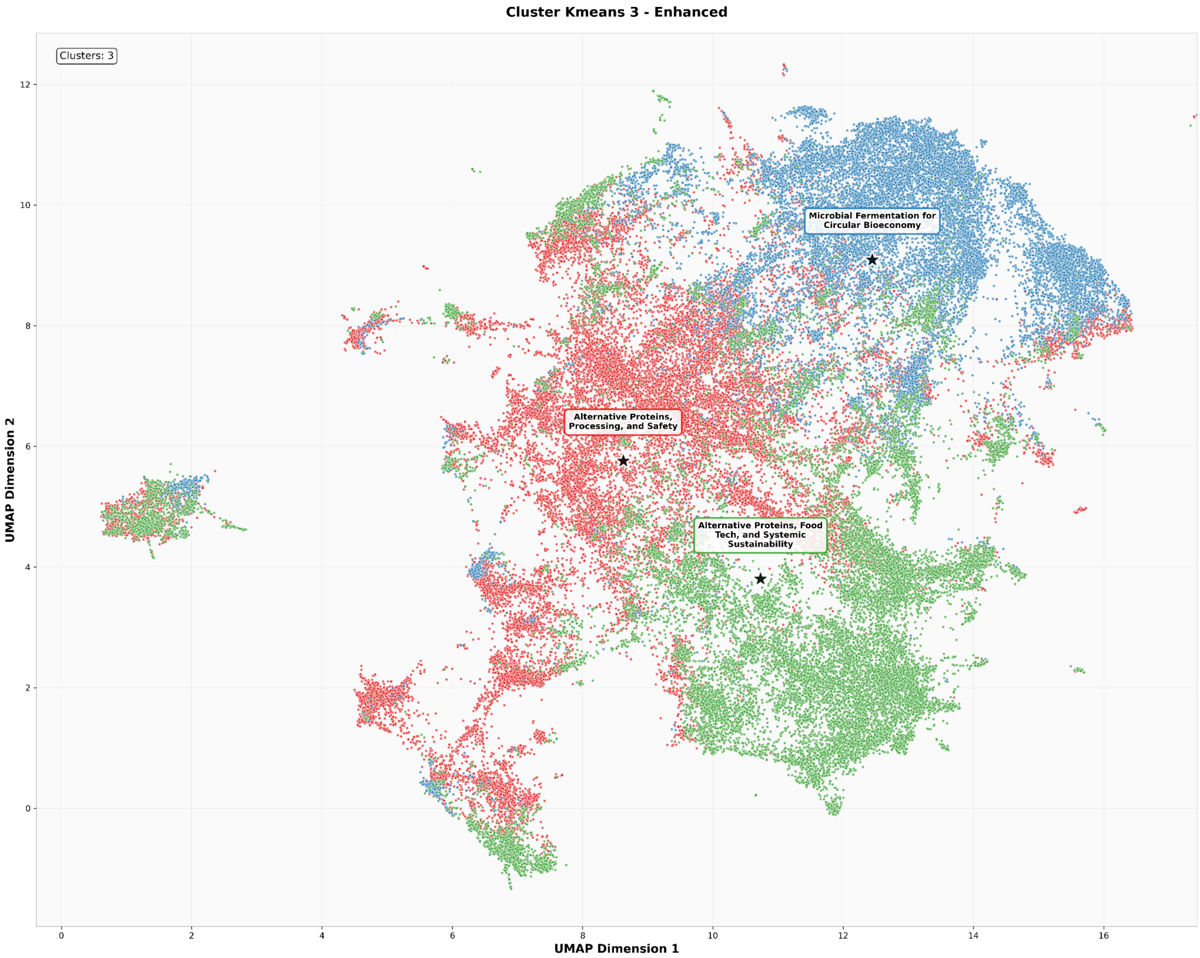
The number of observations have increased by about 57% between the 2014-2019 and 2020-2025 period. Observations have grown in all 3 clusters but most noteworthy in cluster 0 which is also the largest (see Table 4)

Table 4: 3-Cluster Solution for Full Dataset (k-means)

Cluster ID	Heading	Cluster size	Growth in % (2012.2019/2020-2025)
0	Alternative Proteins, Processing, and Safety	28,826	91.2
1	Microbial Fermentation for Circular Bioeconomy	18,659	40.6
2	Alternative Proteins, Food Tech, and Systemic Sustainability	23,498	35.8

Interestingly, companies and research publications populate distinctly different spaces in the mapping exercise. This emphasises the different nature of their activities or purposes which is not surprising. On the map of the complete alternative protein ecosystem, companies are isolated from the main bulk of observations on the left hand side of the mappings. Still the research and innovation topics on which companies have been working are related to academic research – an issue that will be further explored for the 27-cluster solution. For the 3-cluster solutions it is sufficient to note that topicwise the activities of companies do not form a separate cluster but present themselves as a mixture of the 3 identified cluster topics.

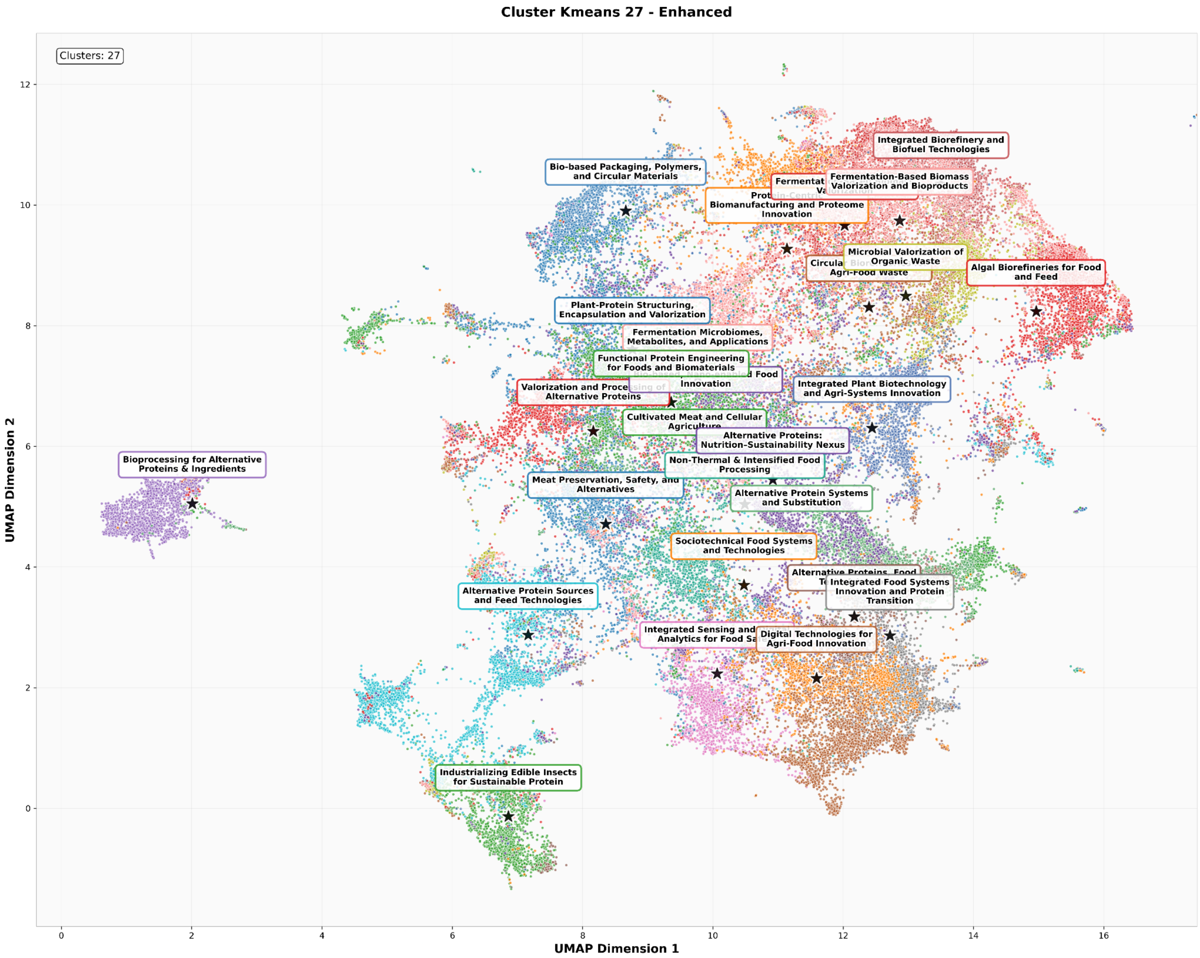
Figure 11: 27-Cluster Solution for Full Dataset (k-means)



The 27-cluster solution is far more detailed with more reliable interpretations of cluster contents (see Figure 12). At this level of disaggregation, companies form their own cluster (Bioprocessing for alternative proteins and ingredients). Here are some examples:

- Advancements in Cultivated Meat and Cellular Agriculture (Cluster 8, n=1486), which shows the fastest growth rate, indicating intensifying research interest and is being positioned in the center of the mapping
- The industrializing Edible Insects for Sustainable Protein cluster (Cluster 2, n=2097) which is somewhat apart to south of the main bulk of observations
- Protein-Centric Biomanufacturing and Proteome Innovation (Cluster 3, n=2684) is in the north of the mapping being part of the biotechnology-based clusters
- Bioprocessing for Alternative Proteins & Ingredients (Cluster 10, n=2384) on the left hand side and isolated from the densely populated center

Figure 12: 27-Cluster Solution for Full Dataset (k-means)



Given that companies work to some extent on the same topics as do academic researchers but with a different focus (i.e. commercialising products and services that might be based on academic research), it is not obvious who is in the lead. Please note that the time intervals for the calculation of topic growth rates are different in the company and the full sample clustering: The company data peters out around 2022 while scientific research data starts in 2014 and covers the most recent publications until November of 2025.

Overall, the increase in the number of publications over time reflects a larger trend in the academic world that is fuelled by intensified support for science in most regions. Particularly China and other Asian countries have increased their academic output over the past decade. The growth pattern across the cluster topics may hold some information which fields have received particular interest (and resources) over the recent past.

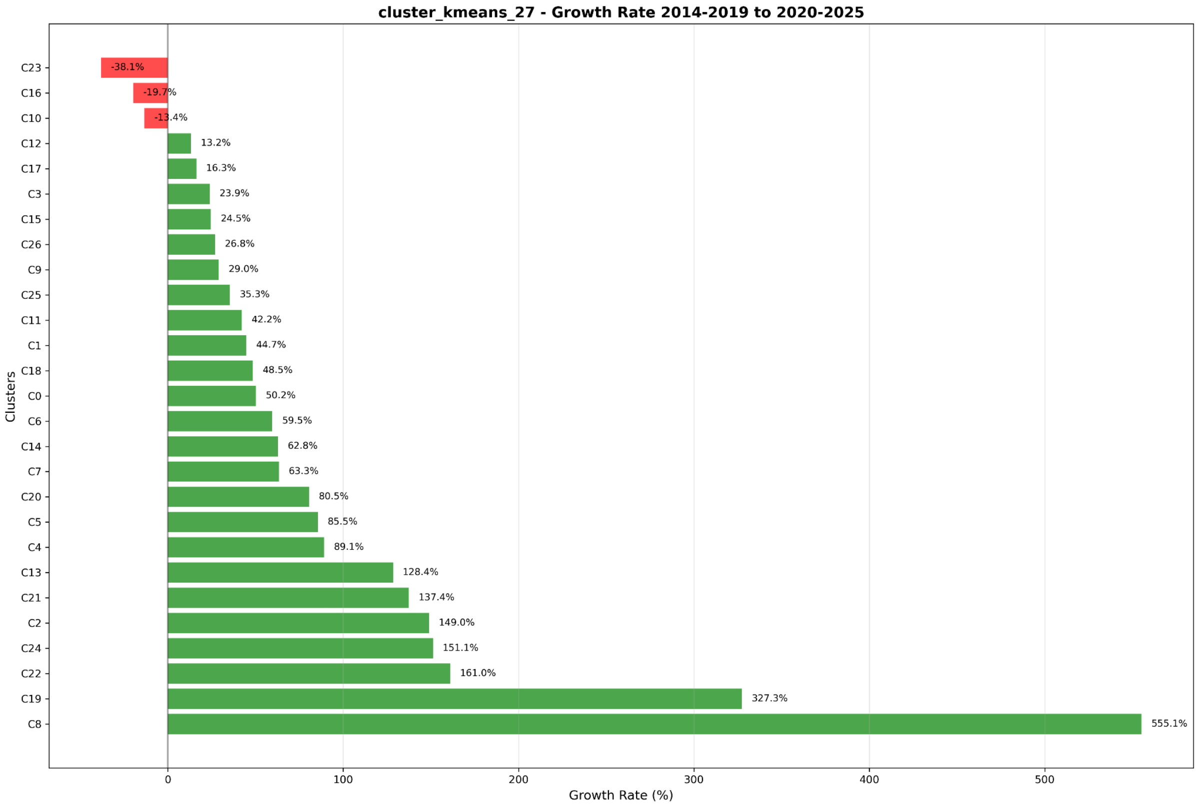
The clusters focussing on Advancements in Cultivated Meat Technology (cluster 8), Sustainable Alternatives in Meat Consumption (cluster 19), Plant-Based Protein Innovations and Applications (cluster 22), Alternative Proteins: Sustainability and Health (cluster 24), Sustainable Protein Alternatives: Insect Farming (cluster 2) and Innovations in Plant-Based Protein Applications (cluster 6) occupy the 6 fasted growing spots in the full sample. Traditional topics like biofuel production, food safety and quality, sustainable innovations in food production, innovative technologies in food processing and innovative food cultures and technologies are at the end of the growth distribution.

Interestingly, the topics that dominated startup activities throughout the 2010s have been gaining traction in academic research in the 2020 to 2025 period – exactly the time frame in which startups have been struggling after the COVID-19 induced boom years (i.e. 2020/2021). This somewhat suggests both that academic efforts are motivated and may follow start-up activities and that these topics still hold "technological opportunities" that have yet to be discovered. Consequently, academic research may now and in the future provide more impetus for companies that have been struggling in scaling precision fermentation or cultivated meat production.

Table 5: 27-Cluster Solution for Full Dataset (k-means)

Cluster ID	Heading	Sluster size	Growth rank
8	Cultivated Meat and Cellular Agriculture	1486	1
19	Alternative Protein Systems and Substitution	2049	2
22	Functional Protein Engineering for Foods and Biomaterials	3204	3
24	Alternative Proteins: Nutrition–Sustainability Nexus	2762	4
2	Industrializing Edible Insects for Sustainable Protein	2097	5
21	Plant-Protein Structuring, Encapsulation and Valorization	2904	6
13	Bio-based Packaging, Polymers, and Circular Materials	1769	7
4	Bio-based, Nano-enabled Food Innovation	2956	8
5	Circular Biorefineries for Agri-Food Waste	2037	9
20	Algal Biorefineries for Food and Feed	2845	10
7	Alternative Protein Sources and Feed Technologies	4618	11
14	Alternative Proteins, Food Tech, Adoption	2362	12
6	Fermentation Microbiomes, Metabolites, and Applications	3152	13
0	Valorization and Processing of Alternative Proteins	3259	14
18	Integrated Plant Biotechnology and Agri-Systems Innovation	2313	15
1	Meat Preservation, Safety, and Alternatives	2895	16
11	Microbial Valorization of Organic Waste	2027	17
25	Digital Technologies for Agri-Food Innovation	2550	18
9	Fermentation-Based Biomass Valorization	3602	19
26	Fermentation-Based Biomass Valorization and Bioproducts	2712	20
15	Integrated Food Systems Innovation and Protein Transition	2979	21
3	Protein-Centric Biomanufacturing and Proteome Innovation	2684	22
17	Integrated Biorefinery and Biofuel Technologies	2348	23
12	Integrated Sensing and Digital Analytics for Food Safety	1984	24
10	Bioprocessing for Alternative Proteins & Ingredients	2384	25
16	Non-Thermal & Intensified Food Processing	2445	26
23	Sociotechnical Food Systems and Technologies	2560	27

Figure 13: Ranking of Cluster Growth between 2014-2019 and 2020-2025



The categorical and regional mapping visualizations reveal the geographic distribution and thematic concentration of alternative protein activities globally. The analysis demonstrates significant regional variation in the development of these fields. While Europe had with almost 23% the largest share of publications in this field in the 2014-2019 period, research grew much faster in Asia in the 2020-2025 period (see Table 6). While the European share was slightly reduced to 21.6%, the Asian share grew to 28.2%. This signals – as already mentioned – an overall trend of increased scientific output particularly from Asian countries but also growing attention and funding for research that impacts knowledge production in the alternative protein space and most certainly is a precursor of industrial activities.

Table 6: Geographical distribution of alternative protein activities

	2014-2019	2020-2025	Total	Growth (%)	Share P1 (%)	Share P2 (%)
Asia	5,318	12,089	17,407	127.3	19.6	28.2
EU27	6,211	9,258	15,469	49.1	22.8	21.6
North America	3,234	3,634	6,868	12.4	11.9	8.5
UK	7,35	869	1,604	18.2	2.7	2.0
Other	12,436	17,953	30,389	44.4	45.7	41.8
TOTAL	27,199	42,934	70,133	57.9	100.0	100.0

China leads in scientific publication output growth which indicates strong institutional backing (see Table 7, Figure 14 shows in which areas China focuses research). The same holds for South Korea. Europe, with Germany as the primary hub, shows balanced development across research, startups, and EU-funded projects, with particular strengths in fermentation technologies. In the US research on alternative proteins grows but at a much lower rate than in all the other countries.

Table 7: Geographical distribution of alternative protein activities (countries)

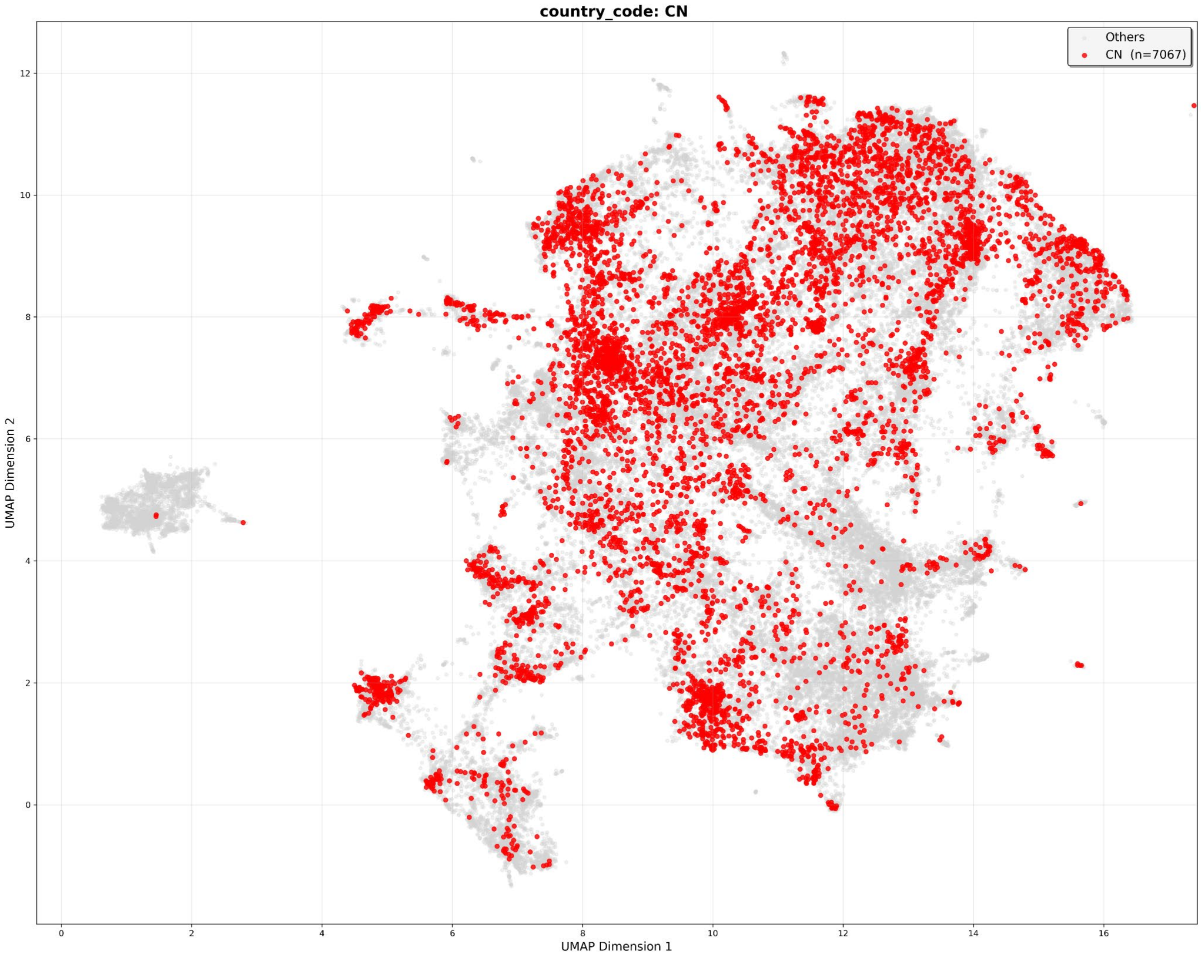
	2014-2019	2020-2025	Total	Growth (%)	Share P1 (%)	Share P2 (%)
China (CN)	1,838	5,228	7,066	184.4	21.9	37.6
United States (US)	2,621	2,806	5,427	7.1	31.2	20.2
Italy (IT)	816	1,264	2,080	54.9	9.7	9.1
Spain (ES)	625	1,033	1,658	65.3	7.4	7.4
United Kingdom (GB)	735	869	1,604	18.2	8.8	6.3
Germany (DE)	652	919	1,571	41.0	7.8	6.6
South Korea (KR)	387	891	1,278	130.2	4.6	6.4
France (FR)	416	522	938	25.5	5.0	3.8
Japan (JP)	303	365	668	20.5	3.6	2.6
TOTAL	8,393	13,897	22,290	65.6	100.0	100.0

The increase in research on cultivated meat and cellular agriculture (cluster 8) – to name just one example – was most pronounced in Asia. This can be interpreted as a leading indicator for increased industrial activities that are based on strategic industrial policy. This is visibly the case for South Korea which integrated the alternative protein sector into its economic development strategy (see the brief note in the Annex 5).

Table 8: Geographical distribution of observations in cluster 8: Cultivated Meat and Cellular Agriculture

Region	2014-2019	2020-2025	Total	Growth in %	Share 2014-2019	Share 2020-2025
Asia	24	392	416	1,533.3	12.2	30.4
EU27	25	171	196	584.0	12.8	13.3
North America	33	166	199	403.0	16.8	12.9
Other	114	560	674	391.2	58.2	43.3
TOTAL	196	1,289	1,485	557.7	100	100

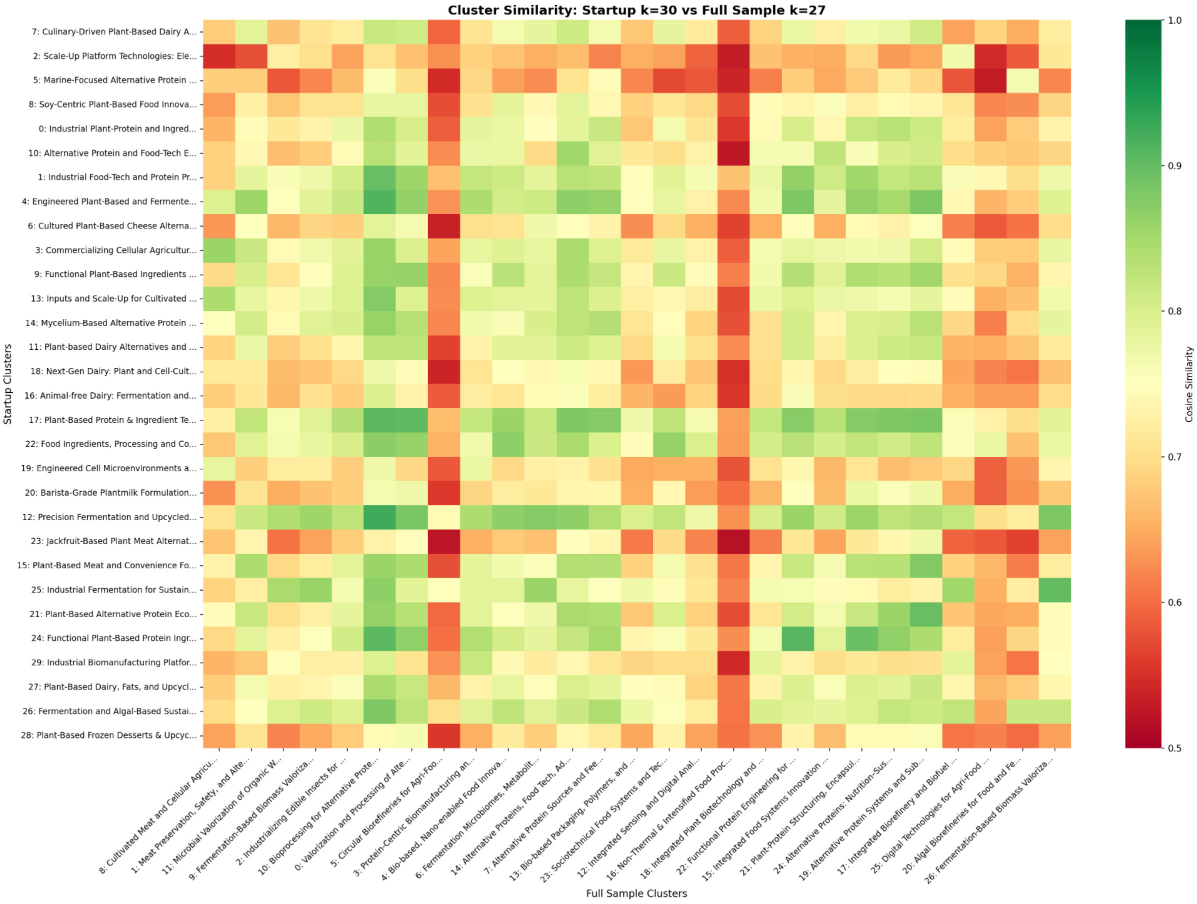
Figure 14: Chinese activities in the alternative protein space



One of the intricate problems of industrial policy is to create academic complimenting research and support structures that allow companies to catch-up or move ahead vis a vis leading competitors. The analytic approach developed here allows a first glance on the relationship between company activities, academic research and – eventually – support structures in the different fields. The heatmap in Figure 15 is based on the cosine similarities between company clusters and those for the complete alternative protein space. Areas in red stand for lower correlations while those in green indicate high correlation in cells that represent a specific combination of a company and alternative protein cluster. Please note that the correlations across all cells are fairly high.

At the alternative protein ecosystem level some clusters are correlated with a small number of industrial clusters only and are represented by mostly red vertical lines. Particularly cluster 5 (Circular Biorefineries for Agri-Food Waste), 16 (Non-Thermal & Intensified Food Processing), and to a lesser extend 25 (Digital Technologies for Agri-Food Innovation) as well as 20 (Algal Biorefineries for Food and Feed). This phenomena can also be observed at the industrial cluster level, i.e. horizontal lines that are mostly red. Cluster 2 (Scale-Up Platform Technologies: Electrospun Nanofibers and CO_2 Valorization), 5 (Marine-Focused Alternative Protein Technologies), and 28 (Plant-Based Frozen Desserts & Upcycling) are in this category. It must be noted that this line of interpretation has to be further elaborated. Still the correlations are indications where to further drill down in order to uncover the nature of the relationship between industrial and academic research activities.

Figure 15: Correlations between company clusters and cluster for the complete ecosystem



3.2 Consumer Markets and Venture Capital Investment

3.2.1 Consumer Market Trends

There are few comprehensive assessments of market growth for alternative protein products available for the general public. Nielsen IQ saw the European market for alternative protein around € 5.8 billion in 2022. The market for these products grew by 21% between 2020 and 2022. Between 2021 and 2022, growth rates were somewhat lower at 6%.

The most important segment is plant-based alternatives for milk, which account for around 28% of sales. Meat alternatives generate around 35% of sales, followed by yoghurt (9%), spreads, ready meals, ice cream, cheese, cream, desserts and fish/seafood, each with less than 5% market share.

The rapid growth in this period is to some extent due to the COVID-19 crisis which raised interest for meat alternatives. Based on some national data growth rates seem to be less exponential in the following year (see Leo, 2025).

Overall, consumer demand seems a stable pillar in the alternative protein ecosystem.

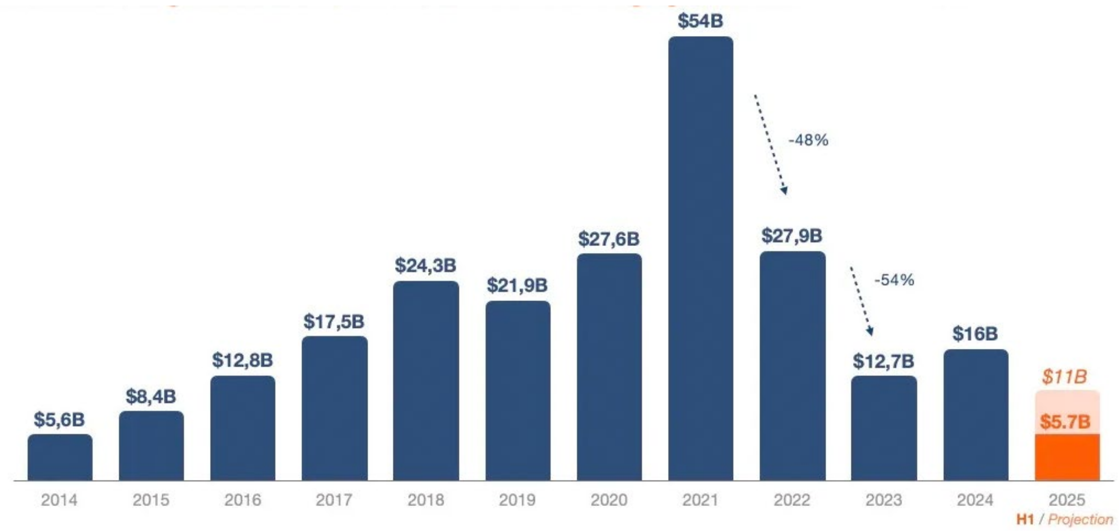
3.2.2 Investment Trends

The alternative protein sector experienced a remarkable venture capital cycle over the past decade. As shown in Figure 16, total FoodTech investment peaked at $ 54 billion in 2021, representing the apex of the sector's funding enthusiasm. The subsequent correction proved swift: investment fell 48% to $ 27.9 billion in 2022, declined further by 54% to $ 12.7 billion in 2023, before showing modest recovery to $ 16 billion in 2024. For 2025, first-half data suggests continued decline with projections around $ 11 billion for the full year (see DigitalFoodLab, 2025).

This investment trajectory reflects broader macroeconomic conditions, particularly the shift from the low-interest-rate environment of 2020-2021 to rising rates that fundamentally altered venture capital economics. For alternative protein companies, many of which require extended development timelines and substantial capital expenditure before reaching profitability, the changed environment proved particularly challenging. The negative post COVID-19 trend was intensified by the AI boom which has been the main attraction for venture capital in recent years.

The geographic distribution of investment has shifted notably (2024 + H1 2025). North America continues to lead with $ 10 billion in cumulative investment for 2024 and the first half of 2025, benefiting from deep venture capital markets and concentrated expertise in the San Francisco Bay Area. Europe follows with $ 4 billion, with growing investment in precision fermentation and sustainable food technologies. Asia has attracted $ 6.5 billion. Latin America ($ 0.4 billion), the Middle East ($ 0.5 billion), Africa ($ 0.2 billion), and Oceania ($ 0.2 billion) represent smaller but growing markets (see Figure 17, DigitalFoodLab, 2025).

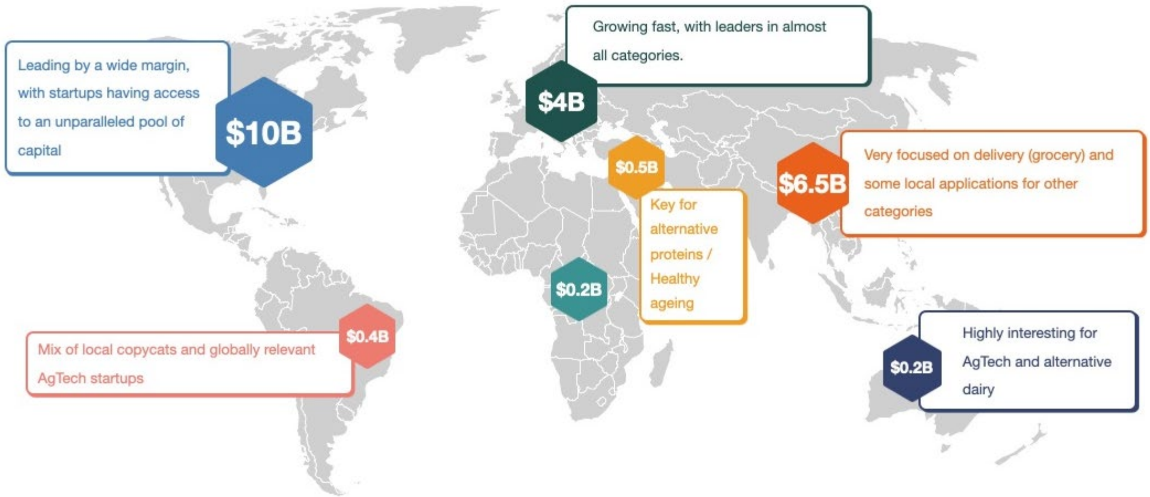
Figure 16: Global FoodTech investments



Source: DigitalFoodLab, 2025

The investment decline has produced significant casualties among alternative protein companies. Several high-profile firms have ceased operations or entered insolvency, while others have undertaken substantial restructuring. However, the contraction has also driven strategic evolution: corporate partnerships have emerged as an alternative pathway to scale, with established food companies increasingly engaging with alternative protein startups for commercialization and scale-up support rather than pure financial investment.

Figure 17: Global FoodTech investments 2024-2025



Source: DigitalFoodLab

4 Conclusions

This paper examined the alternative protein sector through the lens of disruptive innovation theory. The ecosystem mapping covered startups, research institutions, investors, and incumbents. The analysis reveals a sector at a critical inflection point where the initial promise of rapid disruption has collided with the realities of technological scaling, consumer acceptance, a pandemic and financial sustainability.

Disruption Theory Applied

The theoretical framework drawing on Schumpeter's creative destruction and Christensen's innovator's dilemma provides context for understanding current challenges. Alternative proteins exhibit classic patterns of disruptive innovation: initial technological inferiority followed by improvement trajectories governed by Wright's Law and S-curve dynamics. However, the technologies behind alternative protein products are different in nature and at different development levels. While the majority of consumers have only access to plant-based alternatives to animal products, precision fermentation is on the verge of scaling production lines. Cultivated meat, that is available in small quantities in some markets, still has some way ahead before wide mass market availability can be provided. Additionally, the food system transformation involves deeply embedded cultural, sensory, and nutritional dimensions that resist purely technological solutions.

The "sailing ship effect" – where incumbents invest heavily in existing technologies to pre-empt disruption – is evident to some extent in the food industry. This manifests through lobbying for labelling restrictions, funding of counter-narratives, and strategic acquisitions of startups. The latter may also be a sign that part of the industry is embracing the “protein revolution”. The Vegetarian Butcher was bought by Unilever, Quorn by Monde Nissin, Sweet Earth by Nestlé, and Lightlife by Maple Leaf. These acquisitions simultaneously hedge bets while potentially slowing the pace of disruption by integrating ventures into traditional corporate structures. There are presently no signs that the latter option is being applied.

The 2024-2025 Reckoning

The alternative protein sector has experienced a dramatic correction with respect to the availability of venture funds. From a peak of $ 54 billion in 2021, FoodTech investment has collapsed to approximately $ 11 billion projected for 2025 – a decline of nearly 80% (DigitalFoodLab, 2025). This contraction has produced significant casualties across all three technological approaches.

Believer Meat has ceased operations. Beyond Meat experienced a torrid year with its stock price declining by more than 95% from its all-time high. Miyoko's Creamery entered insolvency and was auctioned to the highest bidder (Watson, 2025) are just two examples of well-known companies struggling in a difficult environment. The industry has failed to articulate compelling arguments to motivate funders to continue providing capital. Structural problems that plagued early-stage development remain unresolved.

Cultivated meat faces particularly acute challenges. The three best-funded companies have demonstrated extremely challenging economics. One has already collapsed. This occurred before any meaningful progress on scaling production. Experts expect that 70-90% of companies in this space are unlikely to survive (AgFunder, 2023). Still, this remains within the norms of the venture capital industry, which offsets these losses through extraordinary returns from a handful of successful companies.

Is Venture Capital the Right Model?

Given that the time horizon for scaling precision fermentation and cultivated meat product tends to be longer than initially assumed raises some questions about whether venture capital represents the appropriate financing mechanism for alternative protein development. The VC model is optimised for software and digital business models with near-zero marginal costs and rapid scaling potential. This may be fundamentally misaligned with the capital-intensive, long-development-cycle characteristics of food technology.

Cultivated meat companies require substantial investment in bioreactor infrastructure, face uncertain regulatory pathways, and confront scaling challenges that may take decades rather than years to resolve. The typical VC fund structure with its 7-10 year investment horizons at most may be incompatible with food system transformation. The AI boom has exacerbated this mismatch by redirecting venture capital toward this sector promising faster returns.

Some companies have responded by pivoting to biopharma temporarily, where higher value per unit and established regulatory pathways provide more immediate revenue opportunities. While this may ensure survival, it represents a retreat from the sector's original mission.

Shifting Regional Dynamics

The ecosystem mapping reveals significant shifts in geographic distribution. While Europe held the largest share of scientific publications in 2014-2019 at nearly 23%, the subsequent period saw Asia accelerate dramatically. China's research output grew by 184% between the two periods, while US research grew by only 7% (see Table 7). South Korea increased its share from 4.6% to 6.4% while including alternative proteins in its national economic development plans.

This signals a potential rebalancing of innovation capacity. The next generation of industry leaders may emerge from outside traditional North American and European centres. For European policymakers concerned with food system resilience and technological sovereignty, these trends warrant attention.

Looking Forward

Market developments still positive

The industry is in a sobering phase after the end of the hype cycle around 2021. Such phases are the rule and not the exception for newly developing industries where the dominant design of products has not yet emerged. Consequently, the emergence of second-generation players that have learned from the failures of pioneers is the most noteworthy development. These companies enter with more realistic expectations, more developed supporting infrastructure, and lessons about the gap between technological possibility and commercial viability.

The animal-free dairy space shows more promising near-term economics. Perfect Day is approaching commercial scale production in India with a pivot toward premium offerings including breast milk proteins. This shift toward premium positioning rather than mass-market competition may represent a more sustainable path for precision fermentation companies.

AI is increasingly applied to protein discovery and product development. Fungi-based approaches continue to advance with scaling challenges that may prove more tractable than cultivated animal cells. Again, the ecosystem is more developed than five years ago – infrastructure, knowledge base, and supply chains have matured even as prominent companies failed.

Policy Implications

The environmental and health imperatives for food system transformation remain compelling. Animal agriculture contributes 56-58% of food-related GHG emissions while using 80% of agricultural land for only 37% of protein and 18% of calories (Poore & Nemecek, 2018). These underlying drivers have not diminished.

A substantial body of research now quantifies the externalised costs of global food systems — the environmental, health, and social damages not reflected in market prices. While methodologies and scope vary, these studies converge on a striking conclusion: the hidden costs of food production and consumption are of a similar magnitude to, or exceed, the market value of the food system itself. Conservative estimates place global food system externalities at $10-12 trillion annually (FAO, 2023; FAO, 2024; Ruggeri Laderchi et al., 2024), with some analyses reaching $15-20 trillion when broader impacts are included (Hendriks et al., 2023). This represents approximately 10-12% of global GDP (FAO, 2023; Ruggeri Laderchi et al., 2024) — a burden comparable to the world's largest economies.

The huge externalities of the food sector demand that governments act as regulators with the intention to reduce the external damage to a level that is within the limits of the planets. Supporting the alternative protein industry seems to be a no-brainer in this respect yet far from what can be observed. The major line of support for alternative protein companies came from venture capitalists while most governments provide neither systematic nor adequate support.

The options for governments to support innovations in the alternative protein sector go well beyond the stimulation of academic research and more financial support for companies. Reforming dietary guidelines (see Annex 3) and applying them to procurement policies (see Annex 2) could boost demand and can be administered at different governance layers are a direct lever to boost demand (see Leo, 2025; Mayerhofer et al., 2022; Annex 3) which is crucial for this group of products. A more innovation-friendly regulation should create a predictable environment for alternative protein companies and is one of cornerstones needed for the market introduction of precision fermentation and cultivated meat products.

This is particularly the case for Europe with a less developed risk capital market while having the largest number of companies in the alternative protein database of the Good Food Institute. The alternative protein sector seems to be one of the few areas where Europe is still in a leading position. Rapidly increasing research on alternative proteins in Asia – particularly in China and South Korea – is an indication that the next wave of competitors may come out of this region. Developing a sound support strategy and a more permissive and faster regulatory system would be a far more adequate strategy for Europe rather than tightening product labelling regulations for alternative protein products.

Consequently, alternative proteins should be a priority for industrial policy—particularly in Europe. The currently favourable position of European alternative protein companies will erode without adequate support mechanisms and a faster, more accommodating regulatory framework. Failing to act means losing industrial capacity that could help address a problem that will only grow more pressing in the years to come. Climate change will simply not be solved without reining in the damage caused by the food sector.

Shifting towards diets with reduced animal product consumption is clearly the way forward. This can be achieved either by replacing animal products with plants or with alternative proteins. Developing the alternative protein sector should form part of a broader strategy to reduce overconsumption of animal products, even if the primary emphasis remains on plant-based substitution.

Given the potential of alternative proteins to reduce food system externalities, the limited policy support is surprising. Few other sectors generate such substantial external costs, yet few decision makers seem prepared to introduce measures that would decrease environmental pollution, biodiversity loss, climate change, premature deaths, and morbidity. This reluctance may stem from overestimating public resistance to regulations based on actual external costs — such as meat taxes (see Tanase, 2025) — or from fears that supporting alternative proteins implies expectations of personal dietary change ("have one schnitzel less"). Some policy makers, however, have reached the sober conclusion that alternative proteins simply represent a market opportunity to be exploited. Those unmoved by any of these arguments should at minimum aim to increase the share of plants in diets (see Annexes 3 and 4). For policy makers who find none of these approaches acceptable, the challenge lies in identifying alternative pathways to reduce the food sector's negative externalities. Doing nothing is not an option.

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Annex 1: List of alternative protein topics used to find publications on OpenAlex

Insect Utilization and Effects
Protein Structure and Dynamics
Food and Agricultural Sciences
Advanced Proteomics Techniques and Applications
Agriculture Sustainability and Environmental Impact
Food composition and properties
Proteins in Food Systems
Algal biology and biofuel production
Mass Spectrometry Techniques and Applications
Transgenic Plants and Applications
Fungal and yeast genetics research
Probiotics and Fermented Foods
Diet and metabolism studies
Protein purification and stability
Protein Degradation and Inhibitors
Food Allergy and Anaphylaxis Research
Fungal Biology and Applications
Muscle metabolism and nutrition
Food Industry and Aquatic Biology
Tissue Engineering and Regenerative Medicine
Collagen: Extraction and Characterization
Botanical Research and Chemistry
Infant Nutrition and Health
Protease and Inhibitor Mechanisms
Food composition and properties
Food and Agricultural Sciences
Consumer Attitudes and Food Labeling
Nutritional Studies and Diet

Insect Utilization and Effects
Protein Structure and Dynamics
Food and Agricultural Sciences
Advanced Proteomics Techniques and Applications
Agriculture Sustainability and Environmental Impact
Food composition and properties
Proteins in Food Systems
Culinary Culture and Tourism
Organic Food and Agriculture
Probiotics and Fermented Foods
Food Waste Reduction and Sustainability (Meat Analogues aus Nebenströmen!)
Public Health and Nutrition
Agriculture Sustainability and Environmental Impact
Proteins in Food Systems
Nutrition, Health and Food Behavior
Agriculture, Land Use, Rural Development
Food Chemistry and Fat Analysis
Management and Optimization Techniques
Plant and animal studies
Fermentation and Sensory Analysis
Urban Agriculture and Sustainability
Innovation and Socioeconomic Development
Business, Innovation, and Economy
Agricultural Economics and Policy
Agricultural Development and Policies
Fungal Biology and Applications
Economics of Agriculture and Food Markets
Agricultural and Food Sciences
Agricultural and Food Production Studies
Agricultural Development and Management

Insect Utilization and Effects
Protein Structure and Dynamics
Food and Agricultural Sciences
Advanced Proteomics Techniques and Applications
Agriculture Sustainability and Environmental Impact
Food composition and properties
Proteins in Food Systems
Agriculture and Agroindustry Studies
Agriculture and Biological Studies
Membrane Separation Technologies
Nutrition and Health in Aging
Land Use and Ecosystem Services
Biosensors and Analytical Detection
Diet, Metabolism, and Disease
Sustainable Supply Chain Management
Health and Lifestyle Studies
Economic and Business Development Strategies
Food Science and Nutritional Studies
Additive Manufacturing and 3D Printing Technologies
Human Health and Disease
Environmental Sustainability in Business
Consumer Retail Behavior Studies
Phosphorus and nutrient management
Entrepreneurship Studies and Influences
Plant Physiology and Cultivation Studies
precision fermentation
cultured meat
cell-based meat
lab grown meat

Annex 2: Grobschätzung der Treibhausgasemissionen der Gemeinschaftsverpflegung im Rahmen des Wiener Gesundheitsverbunds

Peter Kotzan – Hannes Leo

Ausgangslage

Die Treibhausgasemissionen des Ernährungsbereichs wurden bisher kaum thematisiert, wenn es darum ging, die gesetzten Klimaziele zu erreichen, um die Erwärmung des globalen Klimas auf rund 1,5° Celsius zu begrenzen. Dies ändert sich gerade. Nicht unbedingt, weil es neue wissenschaftliche Einsichten gibt, sondern weil die schon gut erforschten Zusammenhänge zwischen dem Ernährungssektor, der Erderwärmung, dem Biodiversitätsverlust, den Wasser-/Boden- und Ressourcenverbrauchs zunehmend ins Blickfeld rücken.

Konkret werden rund ⅓ der Treibhausgasemissionen durch die Ernährung bedingt, deutlich mehr als die Hälfte davon aus der Produktion von tierischen Lebensmitteln. In Österreich gehen mehr als 70% der Treibhausgasemissionen der konsumierten Lebensmittel auf tierische Produkte zurück (Frey & Bruckner, 2021). Letztere beanspruchen rund 80% der landwirtschaftlichen Flächen für die Futterproduktion oder als Weideflächen. sind für die massiven Biodiversitätsverluste verantwortlich, hohen Wasserverbrauch und Umweltbelastung. Ebenso unbestritten sind negative Gesundheitswirkungen, die sich aus einem hohen Konsum von tierischen Produkten ergeben (siehe dazu Poore & Nemecek, 2018; Springmann et al., 2016; Sun, 2022; The Lancet Commission, 2019).

Es ist mittlerweile offensichtlich, dass man weder die Klimakrise noch das Artensterben ohne Veränderungen des Ernährungssystems lösen kann, auch weil aufstrebende Länder mit zunehmendem Wohlstand westliche Ernährungsgewohnheiten übernehmen. Allein aus diesem Umstand werden die Emissionen des Ernährungssektors um weitere 50% bis zum Jahr 2050 ansteigen. Im Umkehrschluss gibt es wenige Bereiche, bei denen mit Veränderungen so viele positive Effekte verbunden sind.

Die Expert:innen der “Lancet Commission” haben den Versuch unternommen, eine Diät zu entwickeln, die sowohl eine immer noch wachsende Weltbevölkerung gesund ernährt und gleichzeitig die Grenzen des Planeten respektiert. Die daraus resultierende “Eat Lancet Planetary Health Diet” weicht deutlich vom beobachteten Ernährungsverhalten ab und empfiehlt – im Einklang mit vielen anderen wissenschaftlichen Arbeiten – eine deutliche Reduzierung des Konsums tierischer Produkte. Veränderung heißt jedenfalls, dass der tierische Anteil reduziert wird – maximal 15 kg, wenn es nach der “Lancet Commission” geht. Diese Reduzierung bewirkt einen direkten Rückgang der Treibhausgasemissionen, weil pflanzliche Produkte deutlich weniger CO_2-Emissionen verursachen, die negativen Wirkungen auf die Biodiversität gehen zurück, Boden wird frei und Karbonsenken können durch Aufforstung und Renaturierung geschaffen werden, die Krankheitsanfälligkeit geht zurück und die Lebenserwartung steigt.

Dass bei so vielen positiven Effekten, die man mit der Reduktion von tierischen Produkten erzielen kann, nicht schon aktiv an einer Veränderung des Ernährungsverhaltens gearbeitet wird, soll hier nicht weiter thematisiert werden. Wenn allerdings über potenzielle Maßnahmen nachgedacht wird, dann wird die Gemeinschaftsverpflegung häufig als möglicher Ansatzpunkt genannt (siehe beispielsweise Mayerhofer et al., 2022). Zum einen ist sie oft im Einflussbereich der öffentlichen Hand; zum anderen kann argumentiert werden, dass man gerade in Schulen, Krankenhäusern, Altersheim etc. auf besonders gesunde und ausgewogene Ernährung achten soll. Ebenso kann argumentiert werden, dass die öffentliche Hand nicht nur von den Bürger:innen und Unternehmen Anstrengungen zum Schutz des Klimas verlangen soll, sondern mit gutem Beispiel vorangehen sollte.

Das Ernährungsverhalten zu verändern ist allerdings keine simple Intervention, sondern ein komplexer Prozess, bei dem viele Stakeholder einbezogen werden müssen. In einem Krankenhaus sind es Ärzt:innen, Diätolog:innen, Patient:innen, Köch:innen und Mitarbeiter:innen in der Verwaltung etc., die hier mitmachen sollten. Veränderungen müssen also gut vorbereitet und partizipativ gestaltet werden, um die Erfolgswahrscheinlichkeit zu erhöhen.

Derzeit gibt es wenig Veränderungsdruck in Österreich. Die durch die Politik vorgegebenen Rahmenbedingungen sind noch keineswegs auf einen “Change Prozess” ausgerichtet, sondern eher auf eine Fortsetzung des status quo. Es wird gerne über Regionalität und den Anteil von Bio-Produkten gesprochen, Treibhausgasemissionen kommen in der Diskussion selten vor; dass man diese für einzelne Institutionen berechnen kann, wird sogar in Abrede gestellt.

Zumeist sind die vorhandenen Empfehlungen sehr einfach gehalten, im Ansatz richtig (“Pflanzenanteil erhöhen”) aber wenig handlungsleitend. Einrichtungen, die den Veränderungsbedarf und die positiven Wirkungen auf Gesundheit, Klima, Biodiversität etc. erkannt haben, sind noch weitgehend auf sich gestellt.

Ein wesentlicher Unsicherheitsfaktor bei Reformbemühungen in der Gemeinschaftsverpflegung ist die karge Datenlage. Beispielsweise gibt es zu den Treibhausgaseffekten weder fundierte Schätzungen, die eine Abschätzung des Potentials von Veränderungen zuließen, noch gibt es Benchmarks für einzelne Institutionen. Weil es gut möglich ist, dass sich die THG-Emissionen beispielsweise von Krankenhäusern deutlich unterscheiden, bleibt unklar, ob man zu den Vorreitern gehört oder im Mittelfeld herumdümpelt.

Dieser Beitrag soll dazu beitragen, die Diskussionen mit Informationen anzureichern, Fragestellungen zu definieren und mögliche Veränderungen zu skizzieren. Dazu werden die Treibhausgasemissionen des Wiener Gesundheitsverbunds grob geschätzt, der Beitrag von verschiedenen Nahrungsmitteln herausgearbeitet und Potentiale aufgezeigt. Er wird ausdrücklich darauf hingewiesen, dass dies eine erste Grobschätzung ist, die verfeinert werden muss, um tragfähige Schlüsse zuzulassen. Die Grobschätzung ermöglicht es jedoch eine erste Positionsbestimmung vorzunehmen, Alternativen zu rechnen und so erste Eindrücke zu gewinnen, was in diesem Bereich möglich ist.

Vorgangsweise

Die Treibhausgasemissionen werden top -down – ausgehend von 93 Warengruppen, die vom Wiener Gesundheitsverbund für die Darstellung der Warenströme verwendet werden – berechnet. Die Emissionfaktoren stammen aus zwei Quellen: der Aufstellung des ökologischen Fußabdrucks von Lebensmitteln in Deutschalnd (Reinhardt et al., 2020) und den Werten aus der online LCA-Datenbank LiveLCA.com, die eine Sammlung Life Cycle Analysen (LCA) ist.

Die in den Datenbanken zu Emissionsfaktoren verwendeten Kategorien decken sich nicht immer vollständig mit den internen Warengruppen des Gesundheitsverbunds. In diesem Fall wurden beide Datenbanken verwendet, um möglichst passende Näherungen zu finden. Natürlich wäre in diesem Fall auch der Rückgriff auf detaillierte LCA -Datenbanken möglich. Darauf wurde aber aufgrund der explorativen Natur dieser Berechnungen vorerst verzichtet. Im Endergebnis gibt es für jede Warenkategorie jeweils einen Emissionswert aus den zwei genannten Quellen. Die jeweiligen Warengruppen wurden dann Klassifikationen zugeordnet (z.B. tierisch – pflanzlich) und ausgewertet.

Die Zahl der geschlachteten Tiere für die Bereitstellung der Verpflegung im Wiener Gesundheitsverbund wurde ebenfalls berechnet. Dazu gab es ein Mapping zwischen den verwendeten Fleischtypen und dem, was ein Tier in der jeweiligen Kategorie im Durchschnitt liefert. Mit diesem

Zugang kann berechnet werden, wie viele Tiere geschlachtet werden mussten und wie viel Prozent der Tiere jeweils genutzt wurden.

Ergebnisse

Treibhausgasemissionen

Der Wiener Gesundheitsverbund verarbeitet pro Jahr rund 4 .000 Tonnen Lebensmittel. Rund 40% davon sind tierischen Ursprungs, die restlichen 60% sind pflanzenbasiert. Die daraus resultierenden Treibhausgasemissionen liegen zwischen 8 .000 und 11 .000 Tonnen. Der niedrigere Wert beruht auf den Emissionsfaktoren aus der Studie zum Fußabdruck von Lebensmitteln in Deutschland; der höhere wird mit Emissionsfaktoren aus der online LCA -Datenbank LiveLCA berechnet.

Übersicht A2 - 1: Warenstruktur und Fußabdruck

	kg	in %	Fußabdruck Deutschland	in %	LiveLCA	in %
Tierische Lebensmittel	**1.607.108**	**39,1**	**6.002.705**	**71,9**	**7.791.035**	**70,6**
Pflanzliche Lebensmittel	2.505.918	**60,9**	2.342.182	**28,1**	3.237.762	**29,4**
Gesamt	**4.113.026**	**100,0**	**8.344.887**	**100,0**	**11.028.797**	**100,0**

Der Unterschied zwischen diesen zwei Berechnungen ist beachtlich. Die Schätzung basierend auf den LiveLCA-Werten ist rund ⅓ höher als jener aus der Studie zum Fußabdruck von Lebensmitteln in Deutschland. Wenig Unterschiede gibt es hingegen bei der Zuordnung auf pflanzliche und tierische Lebensmittel: Beide Berechnungen ordnen rund 70% der Treibhausgasemissionen den tierischen Bestandteilen zu (siehe Übersicht A2 - 1). Die doch beachtliche Abweichung deutet auf einen Niveauunterschied zwischen den zwei Quellen für die Emissionswerte hin, obwohl das Verhältnis der Emissionsfaktoren für tierische und pflanzliche Lebensmittel sehr ähnlich ist. Frey & Bruckner (2021) kommen bei der Analyse der THG-Emissionen für Gesamtösterreich ebenfalls zur Einsicht, dass mehr als 70% durch die tierischen Ernährungsbestandteile verursacht werden. Insofern repliziert der Gesundheitsverbund gesamtösterreichische Strukturen.

Übersicht A2 - 2: Emissionen pro kg für tierische und pflanzliche Lebensmittel

	Fußabdruck Deutschland	LiveLCA	% Abweichung
Tierische Lebensmittel	3,7	4,8	30%
Pflanzliche Lebensmittel	0,9	1,3	44%
Emissionsreduktionsfaktor	4,0	3,8	5%

Die Niveauunterschiede werden deutlich, wenn man die Emissionen pro kg analysiert. Der Emissionswert pro kg tierischer Lebensmittel liegt zwischen 3,7 und 4,8 kg. Bei pflanzlichen Lebensmitteln liegt dieser Wert zwischen 0,9 und 1,3 kg (siehe Übersicht A2 - 2). Die Unterschiede bei den Emissionsfaktoren zwischen den zwei Datenquellen sind also bei tierischen Lebensmitteln mit 30% etwas niedriger als bei pflanzlichen Produkten (40%).

Aus den Emissionen pro kg kann ein Emissionsreduktionsfaktor berechnet werden (siehe dazu Gismondi &Leo, 2023). Bei diesem sind die Emissionen von pflanzlichen Lebensmitteln der Richtwert und es wird gemessen, wie viel Treibhausgase eingespart werden können, wenn man tierische Lebensmittel durch pflanzliche Alternativen ersetzt. Dies ist natürlich – vor allem auf dieser hochaggregierten Ebene – eine Vereinfachung, weil unterstellt wird, dass 1 kg der pflanzlichen

Alternative den gleichen Ernährungsbeitrag leistet wie 1kg des tierischen Lebensmittels[1]. Dennoch hilft diese Vereinfachung, um einen wesentlichen Umstand deutlich zu machen: Wenn man tierische Produkte durch pflanzliche Lebensmittel ersetzt, fallen die Treibhausgasemissionen auf rund ¼, (Reduktionsfaktor von knapp 4), was einer Senkung um mehr als 70% gleichkommt. Damit könnten 4.500 t (Fußabdruck Deutschland) bzw. 5.700 t (LiveLCA) Treibhausgasemissionen eingespart werden. Diese Überschlagsrechnung legt nahe, dass die Emissionen des Wiener Gesundheitsverbunds de facto halbiert werden können, wenn man alle tierischen Produkte durch pflanzliche ersetzt.

Diese Reduktionsstrategien können und sollen spezifischer gerechnet werden, wenn man beispielsweise Rindfleisch – eine Lebensmittelkategorie mit sehr hohen Emissionen pro kg (Fußabdruck Deutschland: 13,6 kg CO_2eq pro kg, LiveLCA: 29,9 kg CO_2eq pro kg) – durch eine Fleischalternative ersetzt. Stellvertretend für die Fleischalternative werden die Emissionen von Beyond Meat Burgern verwendet. In einer – nach Aussagen von Beyond Meat – peer reviewten LCA-Studie (Heller & Keoleian, 2018) belaufen sich die Emissionen des Fleischersatzprodukts auf 3,5 kg CO_2eq pro kg des Burgers. Vergleicht man diese mit den sehr unterschiedlichen Emissionswerten für Rindfleisch, dann können die Emissionen mindestens auf ¼ bis maximal 1/10 des Niveaus von Rindfleisch gedrückt werden. Das Einsparungspotential ist jedenfalls – unabhängig davon, wie hoch die tatsächlichen Emissionen des vom Wiener Gesundheitsverbunds gekauften Rindfleisch sind – sehr hoch.

Übersicht A2 - 3: Emissionsreduktionsfaktoren bei Ersatz von Rindfleisch durch Fleischersatzprodukte

	Fußabdruck Deutschland (CO_2eq pro kg)	LiveLCA (CO_2eq pro kg)	Heller & Keoleian (CO_2eq pro kg)
Rindfleisch	13,6	29,9	32,7
Beyond Meat Burger (Fleischersatzprodukte)	3,5	3,5	3,5
Emissionsreduktionsfaktor	3,9	8,5	9,3

Obwohl Rindfleisch mengenmäßig einen relativ kleinen Anteil hat, ist es für 14% (Fußabdruck Deutschland) bzw. 24% (LiveLCA) der Gesamtemissionen verantwortlich. Ein Austausch durch Fleischersatzprodukte würde folglich die Gesamtemissionen um 11% bzw. 21% reduzieren.

Geschlachtete Tiere

Aus dem Fleischverbrauch kann abgeleitet werden, wie viele Tiere dafür mindestens geschlachtet werden müssen. Diese Rechnung geht davon aus, dass zum einen nicht alle Teile im Rahmen der Verpflegung verwendet werden. Die letzte Spalte in Übersicht A2 - 4 zeigt, dass maximal die Hälfte (Schwein) und minimal ein Fünftel (Kalb) im Gesundheitsverbund verkocht werden. Für die Berechnung der Mindestanzahl der geschlachteten Tiere ist zu berücksichtigen, dass jedes Tier nur eine bestimmte Menge des gewünschten Fleisches (z.B. Schopf, Lungenbraten) liefern kann.

[1] Bei disaggregierter Betrachtung kann der Ernährungsbeitrag der pflanzlichen Alternativen höher oder niedriger sein.

Übersicht A2 - 4: Tieräquivalente des Fleischkonsums im Gesundheitsverbund

Tier	in kg	in %	Mindestanzahl Tiere	in %	Durchschnitt - liche Abnahme in %
Schwein	111.269,6	27,6	2.216.9	0,8	49,23
Rind	70.843,3	17,6	696	0,3	30,38
Jungrind	4.002,2	1,0	64	0,0	28,04
Kalb	21.597,1	5,4	582	0,2	26,51
Huhn	122.550,6	30,4	242.424	91,4	44,07
Pute	73.149,1	18,1	19.133	7,2	31,86
Insgesamt	403.411,9	100	265.115,9	100	35,02

Insgesamt müssen für die verwendeten 400.000 kg Fleisch 265.116 Tiere getötet werden. Mehr als 90% davon sind Hühner. An zweiter Stelle folgen Puten (7,2%). Die restlichen Tiere stellen nach Köpfen jeweils weniger als 1% der geschlachteten Tiere dar.

Erste Schlu ssfolgerungen

Hier wurde versucht, die Zahl der geschlachteten Tiere zu berechnen, die für die Verpflegung der Patienten des Wiener Gesundheitsverbunds notwendig sind und die mit der Ernährung zusammenhängenden Treibhausgasemissionen grob zu schätzen. Die Emissionswerte für die georderten Lebensmittel stammen aus zwei unterschiedlichen Quellen. Beide Schätzungen basieren auf den Bestellmengen für 93 verschiedene Warengruppen.

Obwohl die Berechnung der Emissionen deutlich detaillierter erfolgen könnte, erlauben diese Berechnungen doch erste Einsichten:

- Es kann festgehalten werden, dass die Ernährung der Patienten Emissionen zwischen 8.000 t und 11.000 t CO_2eq verursacht. Rund 70% dieser Emissionen gehen auf die Verwendung von tierischen Produkten zurück. Dass für Österreich insgesamt die tierischen Komponenten ebenfalls für 70% der Emissionen verantwortlich sind, deutet an, dass man hier österreichische Ernährungsgwohnheiten reproduziert (siehe Frey & Bruckner, 2021).
- Eine probate Maßnahme zur Reduzierung der Emissionen ist die Erhöhung der pflanzlichen Komponente. Ein vollständiger Ersatz von tierischen Produkten durch pflanzliche Produkte würde die Emissionen des Wiener Gesundheitsverbunds in etwa halbieren. Bei dieser Aussage gilt es zu beachten, dass kein Speiseplan unterlegt wurde, der sicherstellt, dass alle ernährungsphysiologischen Kriterien erfüllt werden, sondern lediglich die Menge der tierischen Produkte in kg durch pflanzliche ersetzt wurde.
- Wenn nur Rindfleisch durch pflanzliche Fleischalternativen ersetzt wird, sind Einsparungen – je nach Quelle der Emissionswerte – von 11% bzw. 21% der gesamten Emissionen möglich.

- Insgesamt müssen für die verwendeten 400.000kg Fleisch 265.116 Tiere getötet werden. Mehr als 90% davon sind Hühner. An zweiter Stelle folgen Puten (7,2%). Die restlichen Tiere stellen nach Köpfen jeweils weniger als 1% der geschlachteten Tiere dar. THG-Emissionsreduktionsstrategien legen nahe, dass man zuerst jene tierischen Produkte mit den höchsten Emissionen pro kg reduziert. Damit sollte insbesondere der Konsum von Rind und Lamm reduziert oder gänzlich abgeschafft werden – ein Schritt, zu dem sich die Gemeinschaftsverpflegung in Dänemark entschieden hat.

- Ein anderer Zugang wäre der Ersatz von Fleisch mit hohen Emissionen durch Fleisch mit niedrigen Emissionen. Dem steht entgegen, dass der Fleischkonsum insgesamt deutlich zu hoch und reduziert werden sollte. Nur den "Fleischmix" zu verändern, reicht daher nicht.

Diese Berechnungen sind relevant, weil der Ernährungssektor rund ⅓ der Treibhausgase produziert, der wesentlichste Faktor in der gegenwärtige Biodiversitätskrise ist, hohen Wasser-, Ressourcen- und Bodenverbrauch verursacht und – bei gegebenen Ernährungsverhalten – negative Auswirkungen auf Gesundheit und Lebenserwartung hat. Veränderungen des Ernährungsverhaltens sind daher notwendig.

Die öffentliche Hand setzt bei der Bekämpfung der Klimakrise nicht zuletzt auf die öffentliche Beschaffungspolitik, die rund 14% des BIPs in Europa ordert. Damit hätte man einen großen Hebel, um die Treibhausgasemissionen zu senken. Die öffentliche Beschaffungspolitik, soweit sie den Ernährungsbereich betrifft, negiert die möglichen Auswirkungen auf die Treibhausgasemissionen und fokussiert auf regionale Beschaffung von biologisch hergestellten Produkten. Daraus ergibt sich höchstwahrscheinlich nur ein geringer Lösungsbeitrag zur Klimakrise, weil die Transportkosten nur einen geringen Anteil an den Gesamtemissionen haben und die biologische Produktion zum Teil höhere Emissionen verursacht als die konventionelle Landwirtschaft. Es ist daher hoch an der Zeit, die Klima- und Biodiversitätskrise in Entscheidungen bei der Beschaffung von Lebensmitteln im Rahmen der Gemeinschaftsverpflegung zu integrieren, weil diese einen signifikanten Lösungsbeitrag liefern kann, der weit über die Reduktion von Treibhausgasen und die Erhaltung von Lebensraum hinausgeht.

Die Messlatte für den jährlichen Fleischkonsum, wie auch für das Ernährungsverhalten insgesamt, wird durch die Planetary Health Diet gelegt. Diese von anerkannten Expert:innen erarbeiteten Ernährungsrichtlinien sind international akzeptiert und stellen sicher, dass eine noch immer wachsende Bevölkerung gesund ernährt werden kann, ohne die Grenzen des Planeten zu sprengen. Logischerweise sollte man daher auch von Institutionen in der Gemeinschaftsverpflegung verlangen, dass sie den Empfehlungen der Planetary Health Diet folgen. Für die Verpflegung in Krankenhäusern muss berücksichtigt werden, dass die oberste Priorität auf der Gesundung der Patienten liegt und nicht in der Reduktion der negativen Umweltwirkungen der Verpflegung. In der überwiegenden Zahl der Fälle dürfte es hier aber keinen Zielkonflikt geben.

In Summe kann festgehalten werden, dass es keinen Politikbereich und keine einzelne Maßnahme gibt, bei welcher es so viele positive Wirkungen gibt wie bei der Erhöhung des pflanzlichen Anteils in der Ernährung. Vorreiternationen und Institutionen sind schon dabei, die notwendigen Interventionen umzusetzen. Dazu gehören beispielsweise der dänische Aktionsplan für pflanzenbasierte Ernährung (Ministry of Food, Agriculture and Fisheries of Denmark, 2023) oder die Veganisierung von Krankenhäusern in New York. Gerade in der Gemeinschaftsverpflegung und der öffentlichen Beschaffung, wo die öffentliche Hand praktisch "freie Hand" hat, kann man mit dem Transformationsprozess beginnen, der – wenn er richtig gemacht wird – auch gesamtgesellschaftlich mitgetragen wird und ohne große Irritationen ablaufen kann.

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Annex 3: Surprisingly tasty guidelines that might save the planet

There seems to be a huge demand for dietary guidelines if newspaper articles, the Internet or books are used as indicators but – among the huge and increasing number of diets – only the non-officials tend to be in the limelight. Official "food-based dietary guidelines" (FBDGs) actually do not make a dent in the eating behaviour of citizens.

The fact that FBDGs are not designed to quickly lose weight might explain some of the popularity difference. As science-based FBDGs aim at shaping the long-term eating patterns of citizens, almost all countries are invested in developing them. They are usually not regularly updated but only once there is sufficient new evidence that demands adaptation. Still official dietary guidelines are most of the time ignored by citizens but also policy makers. This might be about to change. Better: this ought to change as they have to be brought in line with a wider set of (public) objectives concerning the health of the population, and climate as well as environmental problems. In brief: the need to provide healthy diets to a still growing global population that respect the boundaries of the planet's biosphere is a huge challenge given the present impact of the food system.

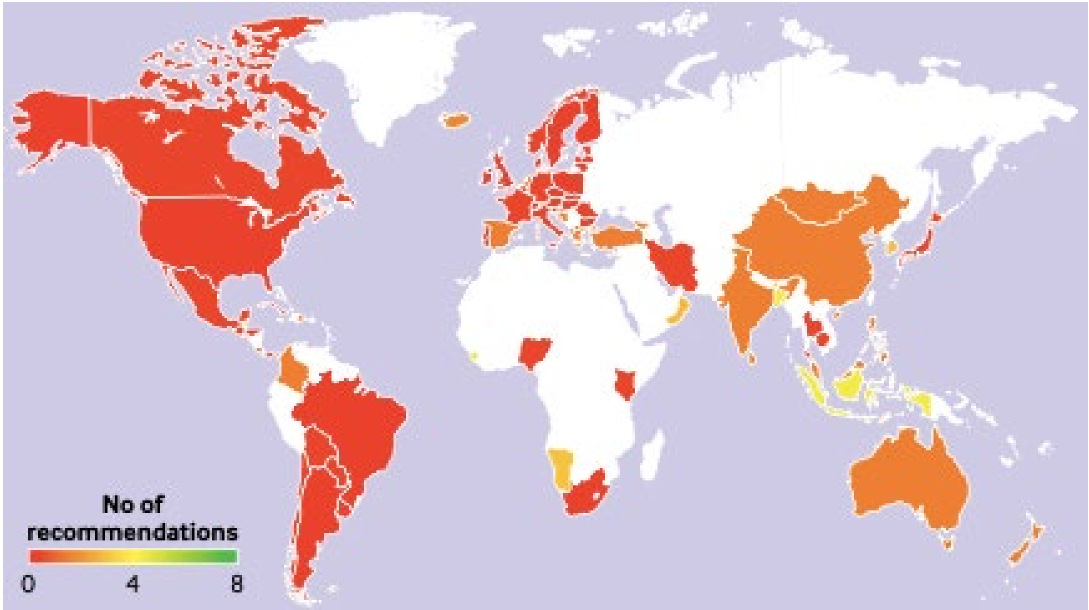
Why should FBDGis fix the climate, biodiversity loss and environmental degradation?

Dietary guidelines are increasingly expected to help mitigate the negative impact of diets on climate change, public health, loss of biodiversity, environmental pollution, land and water consumption – to name the most important areas. These demands are not unreasonable given that the food system is producing about 1/3 of global GHG emissions. Close to 60% of emissions are due to the huge consumption of animal products. Likewise animal keeping is the major driver in biodiversity loss and environmental pollution as well as non-communicable diet related diseases such as coronary heart diseases, stroke, cancer, respiratory diseases and type 2 diabetes. As animal keeping is occupying about 80% of agricultural land – both for feed production and pasture – the opportunity costs are huge as the land can not be renatured or reforested. Reforested or renatues land would be a huge carbon sink and bring the 1.5°C warming objective within reach again (see Sun et al., 2022; Pure & Nemecek, 2018). Presently, due to the increasing adoption of Western style diets in successfully catching-up countries, the GHG emissions together with the other unwanted side-effects of the food system are expected to grow massively until 2050 (Springmann et al, 2016).

Would adherence to the present FBDGs solve these problems? And, if not, what kind of diets should be recommended by FBDGs? And, is anybody up to the job yet?

Springmann et al. (2020a) compared the actual food intake in 85 countries with the hypothetical consumption pattern that should be observed if everybody would strictly follow the national dietary guidelines. The results underline the fact that nobody is very successful in convincing citizens to follow the official guidelines. Based on eight different categories of recommendations set by the respective countries, the most successful countries managed to achieve at most four of them. These countries tend to be in Asia rather than Europe (Spain, Greece, Turkey, Iceland, Portugal achieving 3 points) or the Americas.

Figure A3 - 1: Number of food based dietary guideline recommendations that were achieved in each country



Source: Springmann et al. (2020a)

Given that most of these guidelines were developed without reference to environmental issues, would following them really have a positive impact on the environment?

FBDGs should be beneficial for the health status of the population, right? Springman et al. (2020a) show that adherence to the national FBDGs would reduce premature mortality caused by diet-related non-communicable diseases by about 15% on average. This is as expected but food-related GHG emissions would also drop by 13%.

While this shows the potential impact of FBDGs, Springmann et al. (2020a) point out that these potential reductions are not in line with international agreements that were signed by these countries: the Paris Climate Agreement, the Aichi biodiversity targets related to land use, and the sustainable development goals related to water use and fertiliser application would be violated. Thus the FBDGs in place – even when fully adhered to – would not be sufficient to reduce GHG gas emissions, biodiversity loss and environmental degradation as well as avoidable diseases and premature death sufficiently thus violating agreements in place and signed by the countries. Clearly, there is no path to global sustainability without reforms in the food system – dietary guidelines being one building block in this process.

Figure A3 - 2: Percentage difference between recommended intake and current intake

Food group	Percentage difference between recommended intake and current intake								
	Average	Europe	North America	Near East	Asia and Pacific	Latin America	Africa	WHO	EAT
Legumes	166	197	90	309	128	279	240		247
Whole grains	122	119	-16	194	144	160	113	241	362
Milk	60	16	21	534	103	53	32		9
Fish	36	56	21	0	32	53	55		5
Nuts and seeds	22	56	18	1	7	132	29		428
Fruits and vegetables	18	17	62	-43	14	29	54	-8	15
• Fruits	34	16	57	-18	43	13	50	7	28
• Vegetables	9	18	67	-60	2	64	58	-17	7
Eggs	17	5	-57	9	25	45	20		-51
Sugar	-6	-15	-47	-23	23	-41	-2	9	-33
Meat	-28	-36	-48	-5	-29	-1	-19	-9	-49
• Poultry	-13	-19	-48	-3	-13	29	-18		5
• Red meat	-34	-38	-46	-8	-39	-4	-15		-68
• Processed meat	-44	-51	-50	-11	-13	-73	-46	-56	-100
Energy intake	-6	-18	-18	-8	-3	-11	7	-6	-6

Fig 2 | Percentage difference between recommendations from food based dietary guidelines (FBDGs) and current intake by food group and region. Positive values (in black) indicate greater intake in FBDGs and negative ones (in red) indicate lower intake. The comparison is based on recommended mean values. For the global FBDGs, the percentage changes between the guidelines and current intake is the average across all countries with a FBDG. WHO=World Health Organization; EAT=EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems

Source: Springmann (2020a).

What do FBDGs want us to eat?

A clear picture emerges from the comparison of differences between the present intake and that recommended by present dietary guidelines as well as the WHO and EAT-Lancet diets: All FBDGs recommend more intake of legumes, whole grains and fruits as well as less intake of animal products. The EAT-Lancet diet recommends for example a total ban on processed meat and a reduction of red meat by 68%. Overall meat consumption should be reduced by 49%. These numbers concern the global average food intake and reductions might be higher (or lower) for the different regions.

The EAT-Lancet diet was specifically developed by a group of eminent scientists to provide healthy food for a still growing world population while respecting the boundary of the biosphere, i.e. being sustainable over the long term. This diet is the only one among those analysed by Springman et al. (2020b) which accomplishes both environmental as well as health targets. The in depth analysis of the impact of different variants of the EAT-Lancet diet on health, climate and environmental goals shows that the flexitarian version that still allowed for about 15kg of meat – mostly chicken – per year just about met the set goals. The vegan diet had the best outcomes overall and a particularly positive climate impact: only 24% of the GHG allowance to stay within international agreements would be emitted.

What follows?

The research by Springmann et al. (2020b) clearly shows that most FBDGs – including those of the WHO – neither adhere to already signed international agreements nor produce optimal health outcomes nor keep the food system within planetary boundaries. There is a common driver behind the impact of the food system on climate, biodiversity loss, environmental pollution and health issues: the huge consumption of animal-based products and animals. Based on the analysis of the Lancet Commission – a group of eminent experts in the field of climate change, diets and health – about 80%

of the potential to reduce negative externalities of food systems can be realised by a reduction of the intake of animal products. Another 10% could be removed if production methods in agriculture would be changed. Only 5% – and this is somewhat surprising – if food waste would be reduced.

Previous studies have already indicated that there is a need to adjust what is being on the plate globally. Given the evidence, one would expect that policy makers around the globe have been busy in adopting the food system in their sphere of influence. Existing evidence suggests that governments are rather slow in updating their FBDGs. Klapp et al. (2022) analysed 95 dietary guidelines with regard to the provision of evidence on plant-based and vegetarian diets, plant-based alternatives to milk, dairy products or meat. Of the reviewed guidelines only 36 (37.9%) mentioned plant-based meat alternatives, 35 (36.8%) mentioned plant-based alternatives to milk, and 12 (12.6%) mentioned plant-based alternatives to dairy products. The large majority of FBDGs was classified as "uninformed" about alternatives to animal products. Also, the authors criticised the missing granularity of many guidelines. Out of 100 countries, 47 have a purely animal-based meat food group, giving meat a special status by implying that it should be an essential part of a healthy diet. Four countries (France, Italy, Germany, Switzerland) opposed a vegan diet while most countries were in "the uninformed" group, i.e. they did not have a position on vegetarian/vegan diets.

Klapp et al. (2022) used the references to plant-based alternatives to meat, milk and dairy products for developing the "Balanced Food Choice Index", which is a ranking of countries based on the inclusion of up to date dietary recommendations in their guidelines. The Netherlands were on top of the ranking, followed by Australia and Switzerland[2]. While there are 3 EU countries among the top ten (Sweden (9), Belgium (Flanders, (10)), the 3 lowest ranking EU countries occupy rank 89 (Slovakia), 76 (Austria) and 61 (France). As the ranking of EU countries spans across the whole spectrum, the potential for learning and progress is significant in Europe. The huge heterogeneity, and also some examples given by the authors, are an indicator that policy makers might be out of sync with their constituents (see e.g. Veganz, 2020; Agroberichten Buitenland, 2020,) and scientific research thus not delivering evidence-based recommendations.

Some Implications

There is obviously a huge discrepancy between official guidelines and the food intake of citizens directly questioning the authority of national policy makers in this domain. Is it that the efforts to enforce FGDBs are negligible or is it simply impossible to be heard among the "noise" produced by the food industry and media or are FBDGs often so outdated that they are hardly relevant anymore?

There is, of course, no straightforward answer to these questions but various layers on which eating behaviour could be influenced:

1. It is the task of the public sector to actually address the challenges created by the present structures in the food system and dietary habits. The way forward are system innovations rather than punctual interventions that bring the food sector onto a sustainable path. Ideally this change process is guided by a strategy and implemented in a participatory way.
2. While many citizens are already adopting eating habits that are healthy, climate friendly and non pollutant, many are not aware of the problems and challenges caused by the food system and are largely guided by inherited, traditional and cultural norms/experiences as well as influenced by communications of the food industry. FBDGs are the basis for educating citizens – both young and older – thus laying the foundation for biosphere-friendly and healthy eating.

[2] These are 10 highest ranked countries: 1. Netherlands, 2. Australia, 3. Switzerland 4. Qatar, 5. New Zealand, 6. United Kingdom, 7. China (Hong Kong, 8. USA, 9. Sweden, 10. Belgium (Flemish).

Of course, they have to be easily understood and applied and – equally important – up to date and up to the job. None of this holds for most guidelines as was clearly demonstrated by the research of Springmann et al. (2020) and Klapp et al. (2022). Many guidelines are so outdated that most citizens may have a better understanding of diets which are beneficial for both climate and health than the recommendations themselves. The climate dimension is clearly missing in many guidelines.

3. Given that most FBDGs are not up to date and are ignoring the impacts on the biosphere, the quickest way forward is to build on the EAT-Lancet guidelines which are evidence based and meet all relevant criteria. Flexitarian, pescetarian, vegetarian and vegan variants are available. The task at hand is to "localise" them by somehow "translating" global guidelines into locally understood dietary guidelines/recommendations.

4. FBDGs are to be taken seriously by the public sector as well and resources must be allocated to actually achieve the targets. If this is not done – which seems to be the status quo – then this exercise is meaningless. If taken seriously, the public sector has channels to directly implement them. One is communal feeding in schools, hospitals, retiree homes, the military, etc. where updated DBFGs can be applied immediately (see Mayrhofer et al., 2022).

5. Dietary changes may be faced by all forms of resistance if they are not elaborated in a participatory way. There are examples in various countries where top down changes in the offering of canteens (e.g. one vegetarian day per week) have led to massive resistance. The way forward are participatory processes that give a say to all stakeholders in the change process. This helps to find solutions for more plant based offerings that improve health and reduce the impact on the biosphere.

6. The framing of the food system change process is hugely important. Many discussions focus on food you have to do without rather than on the discovery of new equally tasty or tastier food. Helping citizens to explore the large food cosmos might be one of the most important and rewarding tasks in this process. When successful, the so far neglected options might be the better options overall.

The outcome of such an inclusive, properly framed process might be totally different than expected. The Swedish mission-oriented process to change school food is a nice example for this. The video illustrates how Vinnova went about changing school food by involving everybody in the process, not least pupils. They went on an organised discovery process screening alternatives to the food actually offered in school canteens. Obviously, there is a lot of "new" food to discover that helps to translate FBDGs which might be marked by some as "totally frugal" into both tasty/ier and better alternatives for health and the environment. The change process creates win/win situations in areas that are heavily disputed in other environments. Fact-based, inclusive, participatory and hands-on approaches work in developing alternatives to traditional offering and are a vital tool in making change happen. Fortunately, there is a handbook on the mission-oriented (Hill et al., 2022) approach cultivated by Vinnova which is also highly recommended for those that are about to venture into changing "the system".

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Annex 4: No way to deal with GHG emissions of fresh food because of contradictory life cycle assessment data?

Riccardo Gismondi – Hannes Leo

Life Cycles Assessment (LCA) tries to evaluate the environmental impact of products, processes or services throughout its entire life cycle, accounting for the input raw materials, energy used in extraction, production, distribution, use and disposal as well as the emission and environmental impacts during consumption and deposition. Given the complexity of production processes, methodological choices, system boundaries and the related decisions to be taken, many researchers and practitioners doubt the applicability of this method for day to day decisions (see Clune et al., 2017 for an overview).

Still, the LCA is regularly used to evaluate the impact on energy consumption, greenhouse gas emissions, water consumption, biodiversity and disposal. The alternative, focussing on subsystems – even if they come with well defined properties and boundaries – would be an even worse choice as the results would solely depend on the chosen fraction of the overall impact generating process. While arriving at the one true value for the cradle to grave impact of a product/service/process is obviously impossible, striving for it and dealing with imperfect estimates is the only meaningful alternative.

While LCA databases are already used to analyse the impact of individual food products and the food sector overall, missing or inconsistent values for fresh food are seen as a major problem for a comprehensive climate footprint labelling of the products on offer. Clune et al. (2017) somewhat closed this gap by collecting more than 500 LCA studies that contain GHG emission estimates for almost 1,700 fresh products. This is a good starting point to reflect on methodological obstacles that prevent the use of LCA derived emission data and impact scores in day to day decisions by consumers, restaurant owners, cooks or public procurement decision makers.

The CO_2-equivalents for each product diverge substantially as is argued by critics of this approach (see Figure A4 - 1a and 1b). Plant-based products emit between 0 and more than 7 kg of CO_2eq per kilo of the product. The median estimate – i.e. the estimate in the middle if all estimates are ranked according to size – is about 0.5 kg. This is distinctly different from zero but only 1/16 of the maximum estimate for plant products. The 7 kilo emitting plant is not an avocado – as you might have guessed – but greenhouse grown berries. Despite its bad reputation, avocados produce slightly more than one kilo of CO_2 per kilo if they are produced in Peru and consumed in Germany (see Figure A4 - 2; you may explore this and more estimates on the LiveLCA.com page). If eating nothing but 2.43 kg of avocados per day keeps you happy, you would just about exhaust your daily food related CO_2 budget. Formulated differently, your consumption pattern would keep you within the limits of international climate agreements even if you feed solely on the much “maligned” avocados.

Figure A4 - 1a: Distribution of CO_2eq emissions per kilogram of plants

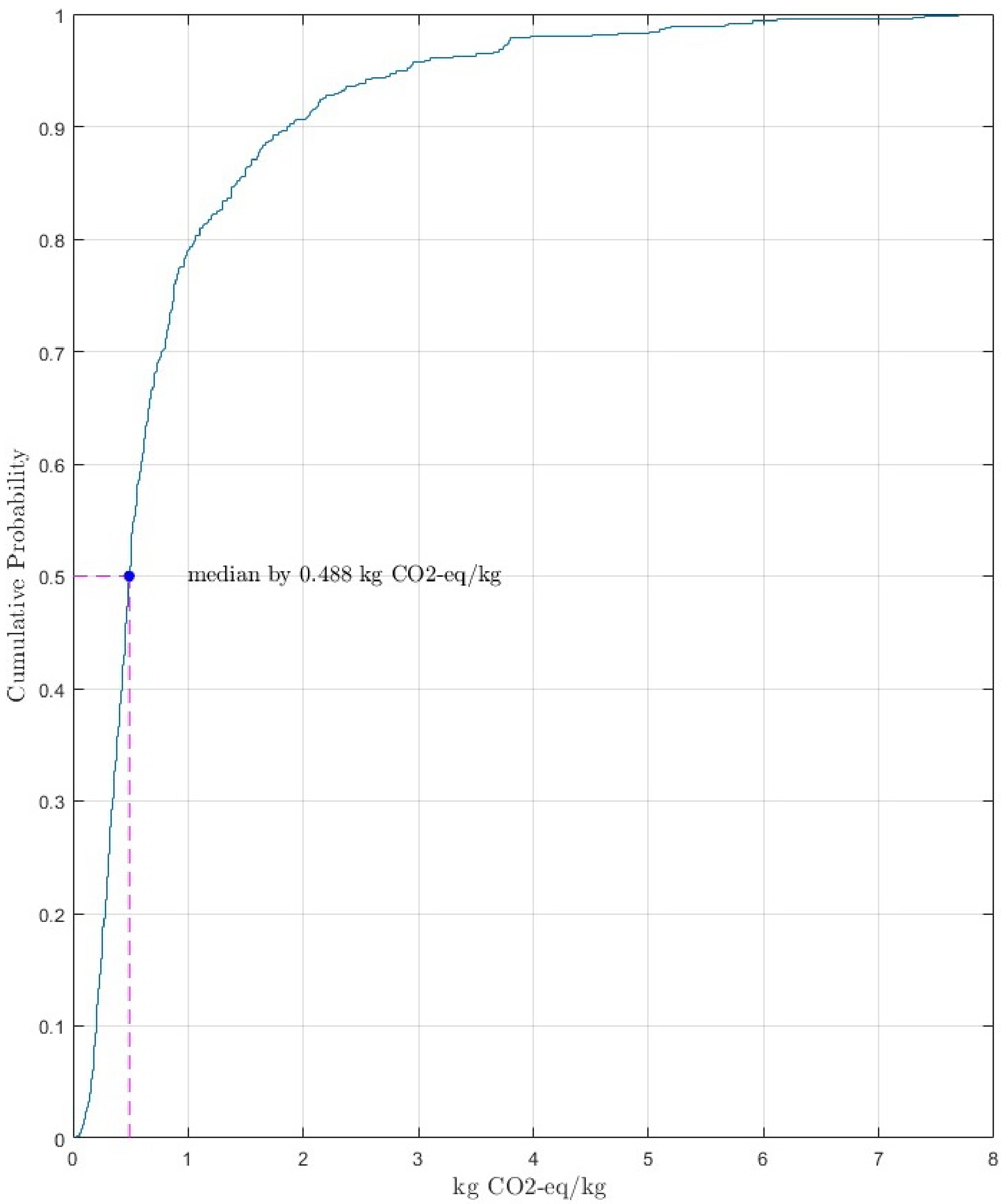
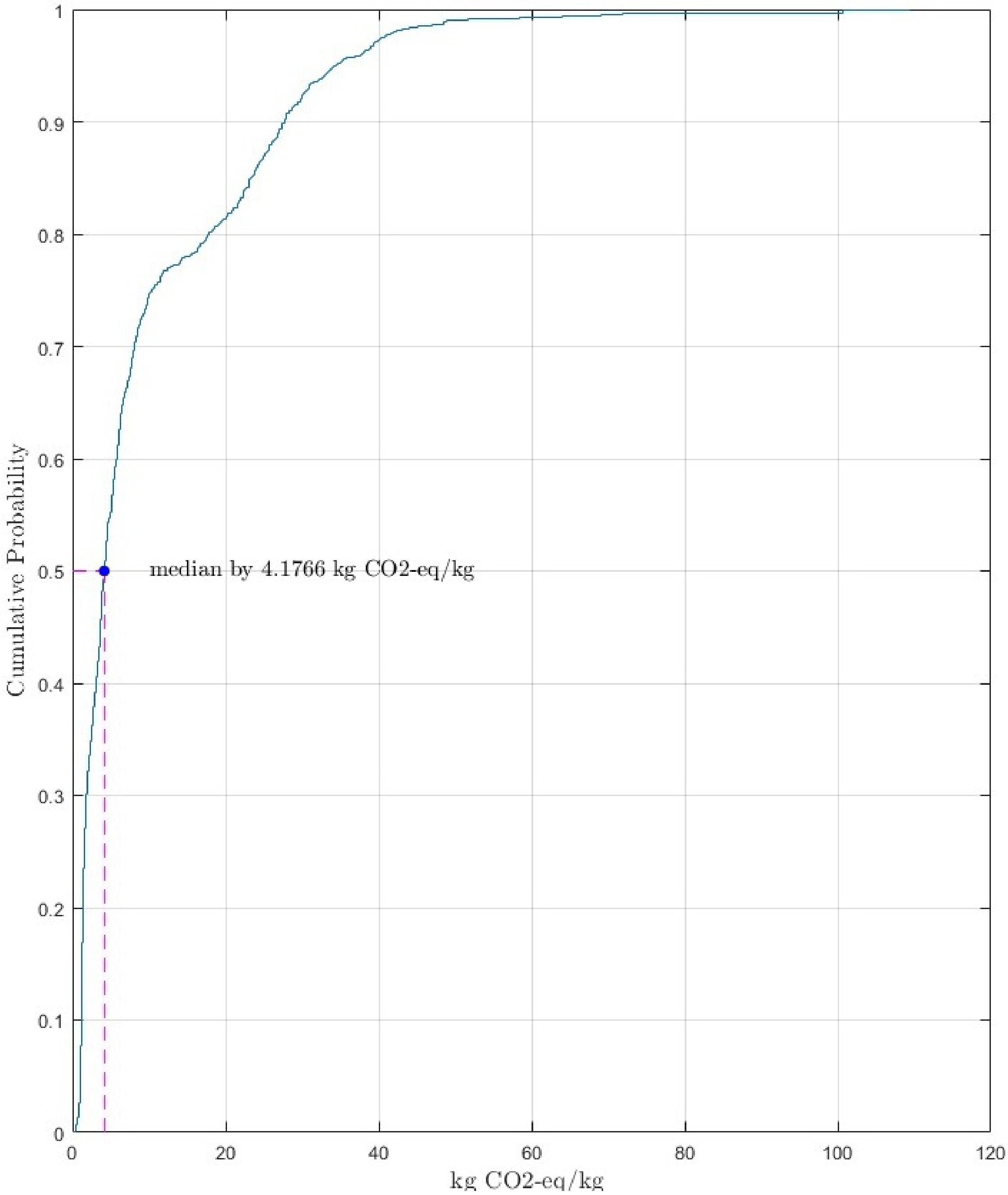
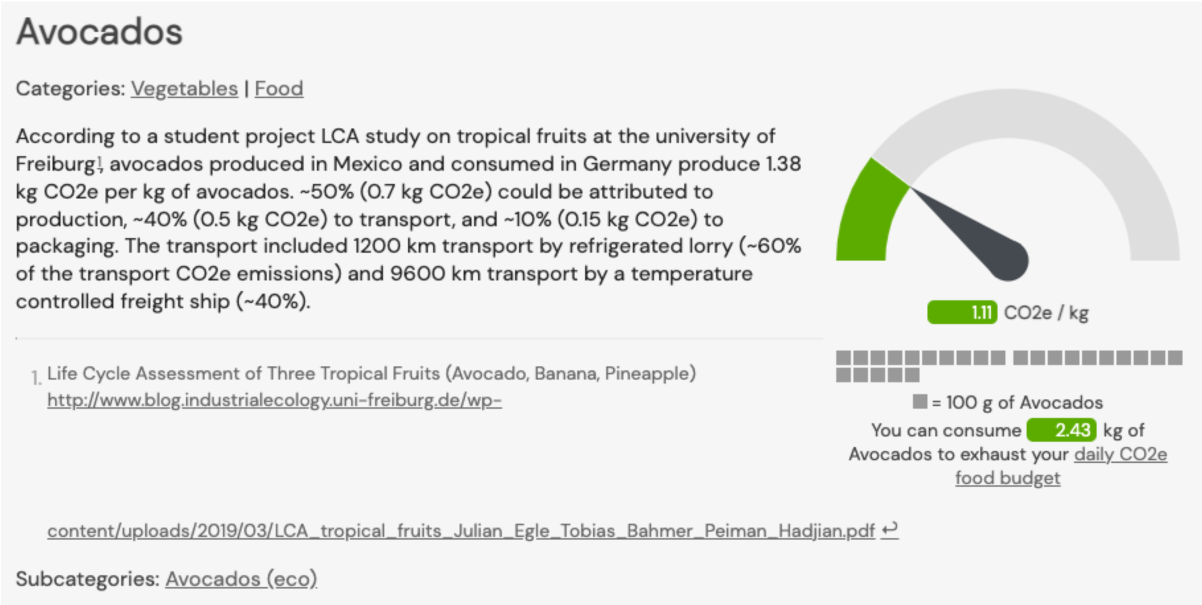


Figure A4 -1b: Distribution of CO_2eq emissions per kilogram animal-based products



Source: Own calculations based on data from Clune et al. (2017).

Figure A4 - 2: Spotlight on avocados



Source: https://livelca.com/products/avocados_a4baf62f-86f6-422e-8136-53eee0a08203

While avocados are better than their reputation – at least in terms of CO_2 emissions -, animal products are not as is visible in Figure A4 - 1b: the median emissions per kg of animal products is 4.2 kg CO_2eq in this collection of LCA studies. Based on the average CO_2 emissions of 14.24 kg per kg of meat (see livelca.com), staying within stated climate targets would demand that you eat no more than 0.19 kg meat per day without any (!) side-dishes. You would then consume about 70 kg of meat per year[3] which is not much above the European average. This causes food-based CO_2 emission of slightly less than a tonne per year. While this meat-only diet would keep your CO_2 emissions at a justifiable level, the overall impact on your health would be devastating. To avoid this outcome, the experts of the Lancet Commission (2019) developed the dietary recommendations which respect the boundaries of the planet and the need to provide healthy food for a still growing world population. In terms of meat intake this diet recommends a steep reduction to about 15 kg per year.

Anyway, if CO_2 emissions are concerned, there is a strong boundary between the plant and animal kingdom. The median CO_2 estimate for plants is 0,5 kg CO_2 emissions per kg of the product. For ruminants (e.g. beef, lamb) the median emissions are more than 26 kg of CO_2eq. Dairy, fish, poultry and non-ruminants emit far less CO_2eq per kilo than ruminants but significantly more than plants, concretely, about 3 times for dairy, 7 for poultry, 8 for fish, 12 for non-ruminants, and 52 for ruminants.

[3] This would definitely please our cats.

Table A4 - 1: CO_2 emission for different subsets of the surveyed LCA studies

Category	1st percentile	5th percentile	1st quartile	Median	3rd quartile	95th percentile	99th percentile
Dairy	0.4	0.8	1.2	1.4	1.8	9.1	13.2
Fish	0.9	1.1	2.1	3.8	6.5	14.2	32.5
Non-Ruminants	3.0	3.6	4.4	5.7	6.6	8.8	19.5
Plants	0.1	0.2	0.3	0.5	0.9	2.9	5.7
Poultry	1.3	1.8	2.7	3.6	5.0	7.6	8.6
Ruminants	10.37	15.2	21.8	26.3	33.3	48.6	100.7

Source: Own calculations based on data from Clune et al. (2017).

Still there are many tricky choices to be made when making dietary decisions. Different LCA values for the same product make it difficult to decide between different products (see Table A4 - 1). This is made obvious by an assessment of the variation within categories. Surprisingly this is largest for plants:

- The CO_2 emissions of the top 1% plants are 70 times higher than those of the bottom 1%. This huge difference is due to differences in CO_2 emission patterns across plants, the way they are produced, where they are produced, how they are transported etc. as well as methodological differences, individual decisions during the analysis, measuring errors etc. For plants, producing them in glasshouses seems to be the biggest impact factor as almost all LCA values at the high end of the distribution are for glasshouse grown plants.
- This spread is also considerable for dairy – 30. In this category, milk clusters at the lower end while butter and hard cheese are on the higher end of the distribution and therefore responsible for the large bandwidth of CO_2 emissions for dairy products.
- The spread for fish is 34. Here the way of fishing, the distances covered, the production and delivery mode (frozen vs. fresh vs. in containers) and methodological differences are partly explaining the wide variations.
- The difference between low and high emitting food is rather low within the non-ruminant (7), poultry (7) and ruminant (10) categories.

In absolute terms the differences are almost negligible in the plants category but substantial in all other categories. In the extreme, 1 kg of beef may come with a CO_2eq. of either 10 or 100 kg depending on the factors already mentioned.

Table A4 - 2: Within category and between category spread of estimates

	Within category spread		Between category spread (plant-based is default)		
Categories	**99th percentile vs 1st percentile**	**3rd quartile vs 1st quartile**	**Plant-based 1% vs 99% of…**	**Plant-based 1st quartile vs 3rd quartile of…**	**Emission reduction factor if substituted by plants***
Dairy	33	2	132	6	2
Fish	36	3	325	22	7
Non-Ruminants	7	2	195	22	7
Plants	57	3	-	-	-
Poultry	7	2	86	17	6
Ruminants	10	2	1007	111	37

$$*Emission\ Reduction\ Factor\ (ERF) = \frac{Emissions\ of\ 3rd\ quartile\ of\ category\ x}{Emissions\ of\ 3rd\ \ quartile\ of\ plants}$$, rounded

An ERF of 2 means the emissions could be halved by substitution this food category by plants.
Source: Own calculations based on data from Clune et al. (2017).

Practitioners deal with the large differences for LCA estimates by cutting off extreme values and relying on the median, average or the first and third quartile. Clune et al. (2017) demonstrate that the latter approach works well by calculating the difference between a diet based on Australian consumption patterns, an alternative diet where meats were substituted by less CO_2 emitting substitutes, and a mostly plant -based diet. They were using the 1st quartile, the median and the quartile for their calculations. If CO_2 emissions are to be reduced, the plant -based diet outperforms the other options by a wide margin[4].

Aside from restoring the applicability of LCAs in decision making even if fresh products are concerned, this points to huge between category differences. If plants (i.e. 1st percentile) are the default value, the top 99% percentile of ruminant products emit 1007 times more CO2eq per kilo. The corresponding values for fish are 325, for non-ruminants 195, dairy 132 and poultry 86. The more moderate comparison – i.e. because of dropping extreme values – is by using the CO_2 emission of the first quartile of plants and comparing it to the 3rd quartile of the other categories. Still the multiples for other categories emissions are substantial: the third quartile of ruminants emits 111 times more CO2eq than the first of plants, fish and non-ruminants score 22 multiples, poultry 17 and dairy 6. The low multiple of dairy is due to the overrepresentation of LCA studies for milk (more than 250) in this category.

Where does this discussion of CO_2 emission for fresh products leave us? Are LCA values in any way informative if dietary decisions have to be made? If not – surprisingly the conclusion at which we will arrive – then in what insights are to be taken?

1. In general, plants emit the least CO_2 per kg and should thus be the default option if the climate impact of diets is to be reduced. This rule is reinforced by the negative health and biodiversity

[4] The emissions of the plant-based diet were 2.14 (1st quartile), 2.67 (median), 3.22 (3rd quartile). The corresponding results for the original diet were 53.08/62.53/73.53 and 22.07/28.14/32.19 for the "like for like" substituted meats.

impact, the large environmental pollution, and huge water and energy consumption of animal-based products. This holds even if the lower end of the CO_2 emission distribution of animal-based products is used for the comparison and gets even stronger if animal welfare criteria are added to the calculations.

2. The differences within animal-based food categories are considerable too. Obviously, ruminants (e.g. beef, lamp, sheep) come with significantly higher CO_2 emissions than non-ruminants, poultry and fish. Prioritising the latter in the composition of the suggested 15kg annual meat intake is the obvious choice when reducing the climate impact of diets. The same holds for dairy products where butter and cheese are on the high end of the distribution while milk is on the low end. Still switching to plant-based milk can reduce CO_2 emissions further.
3. Even within product categories like milk or kiwis differences are substantial. Some of them are easily explained – glasshouse vs. open land productions - while others are more difficult to fathom. As this problem is most pressing for fresh products – and we use only LCA data for fresh products here – calculating a range between the first and third quartile is a reasonable compromise that can be used to get estimates that are sufficient to make well-informed decisions. Given that there are always methodological differences and – equally important – differences in the individual decisions taken by researchers in the assessment process, too much emphasis on analytical precision of results is counterproductive. Consequently, simple guidelines suffice.
4. The most important insight is that rather than looking at within category differences the differences between categories are key for strategies to reduce the individual or food system food print. “Veganising” strategies do cause huge reduction in GHG emissions. Replacing milk by something plant-based reduces CO_2 emissions by half; the corresponding emission reduction factor for ruminants is 37 meaning that replacing one kg of ruminant meat by 1kg of plants will reduce emissions to 1/37th of ruminants emissions. Given that there is already a large number of plant-based substitutes available, this strategy allows for huge reductions in CO_2 emissions.
5. The latter also holds for communal catering and restaurants. The shift towards plant-based diets is most important. Still, accounting for carbon emissions is important to assess if the offering is aligned with climate goals and as well as in gauging change processes. Without being able to measure the status quo as well as the change, processes will miss momentum and may regress towards “old habits”.
6. There is a substantial number of databases that provide LCA-based values for non-fresh foods not only for CO_2eq emissions but also environmental impact scores, health benefits etc. For example, Open Food Facts is an open source database that crowdsources the ingredients of food products and adds climate and environment data allowing for informed buying decisions of consumers that use their mobile app. Likewise the mobile app of Inoqo provides an assessment of the impact of food products and is also available for download.
7. While there are few efforts to bring the food system in line with climate right now, this will have to change if humanity is to avoid the breakdown of the biosphere. This is particularly obvious for public sector actors which are both the regulators of the system as well as providers of food services in schools, retiree homes, hospitals, military etc. as well as for their employees. It is often forgotten that the climate and biodiversity treaties signed are being clearly violated by the present state of the food system as well as the offering in public canteen or the public procurement decisions taken. The rule of law as well as honouring signed contracts is not a decision variable for public sector actors.

Last but not least, we were focussing only on the climate impact of food and used data for fresh products only. Making decisions in this field is, of course, more complex as the health, environment, biodiversity, water and land use etc. impacts of the food system have to be taken into account too. Furthermore, the preferential buying of regional and/or organic products are also important decision variables. Building decision systems that adequately deal with the multifaceted nature of the food system and its impact are not a trivial challenge. The considerable confusion about what to prioritise and how to deal with the transformation in agriculture that may be the result of changes on the demand side further adds to this challenge.

We think that many decisions that concern the food system were not evidence-based – to say the least – but based on traditional views, cultural preferences, influenced by lobby groups, slowed down by inert consumers, missing alternatives/substitutes and reluctant and captured regulators (see also our blog on dietary guidelines). Still – on the positive side – the root cause of most negative impacts is more than obvious: it's the overproduction and overconsumption of animal products. So while the food system is highly complex, the overall direction – reducing the intake of animal products – is hard to dispute.

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Annex 5: South Korea: Joining the alt protein bandwagon?

South Korea has only recently jumped on the alternative protein bandwagon. This move is primarily motivated by the growth potential of alternative proteins, but is also supported by discernible changes in Korean dietary habits. With younger generations' growing interest in animal welfare and sustainability, demand for plant-based products is rising significantly. Figures from the Korea Institute of Rural Economics (see Vegconomist, 2023) project that the South Korean plant-based products market will likely reach 280 billion won (€ 177 million) by 2026. For the global market, revenues of $ 17.8 billion are expected for 2025. According to the Vegan Society, 250 South Korean brands have now collectively registered almost 3,000 products with the Vegan Society Trademark.

Although Korean cuisine is heavily meat and fish-based, there are at least two approaches that form a foundation for this trend toward more plant-based foods: First, there is a large number of plant-based side dishes (banchan) that hold a prominent place in Korean cuisine. Second, there is the traditional Buddhist temple cuisine, which enjoys high esteem.

Economic policy views the upswing in alternative proteins as a longer-term trend that is manifesting globally and represents an opportunity for Korean producers. Consequently, the protein transition is being supported through:

- the development of a regulatory framework for cultivated meat. This task has been part of the national development plan in effect since 2022.
- a comprehensive strategy to promote plant-based agriculture (Vegconomist, 2023) and the introduction of alternatives to animal products. This strategy was published just 10 days after the Danish action plan for plant-based foods.
- a national plan for the development of food technologies. Within this plan, scientific institutions, companies, and public sector organizations are working together, all addressing different aspects of cultivated meat.
- the establishment of the Gyeongbuk Cell-Cultivated Foods Regulatory-Free Special Zone (RFSZ) makes it possible to overcome remaining legal hurdles in the development of cultivated meat. This is intended to support companies in developing competitive products.

These programs are supported by the Ministry of Food and Drug Safety and the Ministry of Agriculture, Food and Rural Affairs.

The economic policy measures are meeting an already flourishing business scene that spans the entire spectrum of the alternative protein sector – from plant-based to precision fermentation to cultivated meat. Established food conglomerates frequently invest in alternative protein companies.

The business-friendly environment is also attracting foreign alternative protein companies to the Korean market. These include primarily companies from Singapore, but German companies (Infinite Roots) are also attempting to escape the uncertain regulatory situation in Europe through expansion into South Korea.

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