Food and Feed for the Future

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Food and Feed for the Future

Lyon, 1 September 2023

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Foreword

The organizing committee: Jean-François Hocquette, Gilles Truan, Sonja Dominik, Joachim Huet, Valérie Heuzé

Agri-food systems must evolve towards a pattern of sustainability and resilience to ensure food security and nutrition for all. The status quo is not an option. Major transformations in agricultural systems and natural resource management will be required to ensure a safe and healthy future for all people and the entire planet. The growing protein demand of the growing global population can only be sustainably addressed by diversifying the protein offering.

During this workshop, invited speakers and delegates presented and discussed challenges and opportunities for protein production from animals, plant-based sources, and novel protein sources (insects, yeast, microalgae, cellular agriculture, etc.) and how they contribute to sustainable food systems.

Different options were discussed to address the problem: they can focus on new technologies such as microbial production to produce more food or they can consider more sustainable land-based food systems.

Therefore, this workshop addressed the following questions:

- How will the global need for protein be met combining ethical and sustainable agriculture with microbial bioproduction?
- Can microbial bioproduction be considered safe, resilient and non-competitive with land farming?
- What are the modern nutritional approaches to healthy production of animal and human diets in a resource-and carbon-constrained world?
- What are the socio-economic issues of future sustainable agricultural systems?
- How to address the ethical/societal acceptance challenge of food and feed microbial/tissue bioproduction?

This workshop targeted all stakeholders who aim at understanding and forecasting the future of feed and food whether they are potential actors of change or have to deal with the constraints and opportunities generated by such changes with the responsibility of feeding increasing human populations with lower impact on the resources: namely farmers and farmers organisations (syndicates, cooperatives, associations), feed and feed additives manufacturers and retailers and their representatives, research institutions and programmes at national, transnational, and global levels; academy including students, experts, consultants and extension services, policy makers, consumers and lobbying bodies involved in the feed or the food sector at national, EU and international levels.

Thanks to all speakers and participants for their valuable contributions. Please, find here enclosed main texts of presentations by invited speakers, who have either published their work previously (in this case, references are indicated) or have recently submitted a review paper related to their presentation to the scientific journal “animal”. Abstracts in these proceedings correspond to posters presented by other authors.

Opening address

H.E. Gillian Bird

Australia's Ambassador to France

Thank you very much. I'm really delighted to be here at the opening of this workshop. I met a number of you at the wonderful dinner last night but before I begin, can I please thank Jean-François Hocquette for his introduction and the invitation to speak to you today. Let me also acknowledge the other workshop chairs Mr. Gilles Truan and Mr. Alexander Wezel and I'd very much like to welcome warmly my Australian colleagues from CSIRO, Dr Andy Sheppard, Dr Arti Tobin and Dr Brad Ridoutt who you'll be hearing from later. Let me also thank the other members of the organizing committee from AFZ, INRAE and ISARA and this event's co-sponsor, the OECD Co-operative Research Programme: Sustainable Agricultural and Food Systems (CRP).

Food and Feed for the Future is such a great title for an important and timely topic. How we can make our food supply more sustainable and more resilient? As outlined in the program, this touches on a range of global challenges including food security, climate change, and socioeconomic issues as well as agriculture and food tech approaches in response. These topics are among the priorities Australia and France have identified to build an even closer bilateral relationship. In July of last year. President Emmanuel Macron invited the then newly elected prime minister Anthony Albanese to visit. That was within five weeks of him having been elected and they reconfirmed their commitment to a stronger bilateral relationship and launched a roadmap to do so.

There are three pillars to that roadmap. The first is defence and security, the second is resilience and climate action, and the third is education and culture. Food security, sustainability, and climate change and indeed our broader scientific collaboration all have their place across all three pillars and this roadmap is currently being negotiated and should be launched by the end of this year.

Another event that we can look forward to is the joint Science and Innovation meeting between Australia and France which will provide an opportunity for more in-depth discussions and exchanges between policy makers and practitioners in the areas of science and innovation. The last joint meeting was held in Canberra, Australia in 2019, and we are working with our French host to arrange the next meeting. Fortunately we do not have to wait for these important events to move ahead with bilateral science collaboration. It is taking place unabated as shown by this event. Indeed, our key workshop organizers INRAE and CSIRO are fortunately long-standing partners. An INRAE delegation visited Australia earlier this year and I understand that joint linkage calls between CSIRO and INRAE are working well. Projects have already been funded this year in the areas of agriculture and there is a strong commitment from both organizations to do more.

I also understand that CSIRO and INRAE are keen to explore opportunities to create an international associated lab around soil carbon sequestration within the Pacific Islands, pioneered by our next speaker Andy Sheppard. This builds on the ongoing work of CSIRO's European laboratory which has been based in Montpellier for 57 years, managing collaboration in pest and weed management with EU-based scientists and agencies. Other priority areas for CSIRO in its collaboration with France include space, quantum, and clean energy.

Since my arrival in Paris in late 2022, I have seen many more examples of such productive exchanges in the field of science and innovation, and I will just list a few of the highlights. In April 2021, the Australia-France roadmap for innovation and science collaboration was signed. That year, CNRS opened an office in Melbourne for Asia and Oceania and this followed CNRS's launch of the CROSSING international research laboratory in South Australia with its focus on artificial intelligence and autonomous systems. In late 2021, we saw the establishment of the French hub of AFRAN, the Australian-French Association for Research and Innovation which aims to promote cooperation between French and Australian researchers, R&D managers, industry players, innovators, and policy makers.

The embassy is proud to be represented on its board together with our workshop chair Jean-François Hocquette. I'm sure many of you are members but if you are not I encourage you to sign up for free on the AFRAN website and you will find in your folder a flyer with more information, so please do so. Finally in August of last year I hosted the launch of AUFRANDE, the Australian-France network of doctoral excellence, which is a 15 million euro doctoral training Network led by RMIT with European Commission financial support.

In conclusion, let me just note that these collaborations and events such as today's Food and Feed for the Future show that our researcher to researcher collaborations are strong and comprehensive, that they cover a range of issues in sectors including agriculture, energy, climate change, and space, to name just a few. They show the incredible results that Australian and French scientists can achieve together. They are absolutely vital to enhance our bilateral collaboration and they help address global challenges we are faced with together.

So thank you very much for this invitation to speak to you today and I wish you all a very productive discussion. Thank you!

H.E. Gillian Bird
Australia's Ambassador to France

Invited talks

Jean-François Hocquette, INRAE, AFZ

Irène Tolleret, European Food Forum

What is sustainability of food and feed?

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In 2015, the 17 United Nations Sustainable Development Goals (SDGs) were unanimously adopted by 193 Member States. They provide a reference framework for sustainability in all sectors, including our food systems. In 2018, FAO proposed 4 priority areas for the livestock sector, as a simplified framework based on the SDGs (FAO, 2018): 1/ food security and nutrition; 2/ livelihoods and economic growth; 3/ public health and animal health including animal welfare and finally; 4/ natural resources management and climate.

This paper proposes a perspective on the sustainability of food and feed using these 4 areas as a framework, with a particular focus on food security and nutrition and on natural resources management and climate, and reviewing recent advances in sustainability assessments.

Food security and nutrition

The demand for food products is expected to increase by 2050, regardless of the type of product or the development scenario envisaged (FAO, 2018). For example, if current trends continue ("business as usual" scenario), the demand for fish is estimated to increase by +35% and that for cereals by +54% while demand for meat, dairy and fish should increase by +52%, +40% and +39% respectively. On the other hand, with a scenario favouring the sustainability of food (due to best practices, public policies and changes in consumer behaviour), demand would increase from +25% for eggs, +29% for meat, +40% for dairy and +48% for fruits and vegetables. We will need more food in the future.

This is even more important that, at present, the number of people who suffer from hunger remains high, around 735 million people, especially in South Asia and Sub-Saharan Africa. This figure, which has been on the rise again since 2015, is unacceptable and shows that the achievement of SDG 2 Zero Hunger by 2030 is very uncertain. The prevalence of hunger is also increasing.

Hunger is a major form of malnutrition, but there are two other forms: nutritional deficiencies and overconsumption of food which results in overweight and obesity. All three forms of malnutrition coexist in the world, within the same countries and even sometimes within the same households. Various indicators are used to monitor these forms of malnutrition: stunting, overweight, birth weight, obesity, etc. These indicators, some of which showing an

Anne Mottet, IFAD

improvement, are however behind schedule to reach the SDG targets set for 2030, with the exception of breast-feeding of infants.

Access to different food groups is a very important driver of food security. In low-income countries (LIC), roots and tubers represent more than half of the food supply in kcal (FAOSTAT, 2023). High-Income Countries (HIC) have a more diversified supply of foods of plant or animal origin. However, availability and access are only two of the four pillars of food security. Consideration should also be given to usage and stability over time. Animal products can contribute to reducing the nutritional deficit of the most vulnerable populations. There is indeed a negative correlation between the percentage of stunted children and meat consumption by countries (Adesogan et al., 2020). In other words, in countries where severe stunting is observed, there is at the same time low meat consumption (generally less than 30 kg carcass weight equivalent per year and per inhabitant). Conversely, in countries characterized by higher meat consumption, the rate of stunting is low.

A key component of eradicating hunger and other forms of malnutrition is reducing food loss and waste (FLW) in our food systems. In LIC, FLW varies 19% of production in dairy to 38% in fruits and vegetables, which is similar to HIC and Middle-Income Countries (MIC) where they range between 12% in dairy to 37% in fruits and vegetables (Spang et al., 2019). However, FLW happen at different stages of the value chains. In LIC, it's mostly happening at production and processing/distribution stages, and only very marginally at consumer level. While in HMIC, the share of consumer in FLW can reach up to 50% in dairy for example. Reducing food loss and waste requires therefore different approaches in different countries and value chains. It would also contribute to environmental sustainability and reducing the use of natural resources. It can be achieved by using best practices at production stage, especially recycling of biomass for feed production and improved animal health, but also by improving storage and transport of foods and increasing consumer awareness. Adequate policies can support these improvements and include labelling, regulations and standards for recycling waste as feed, packaging regulations, public procurements etc.

Food/feed competition and paradigm shift for livestock

Competition between human food and animal feed is a key aspect of sustainability and is quite debated in the press, both scientific and general. Grains represent 14% of the food consumed by farm animals, which represents about a third of the world production of cereals, therefore in direct competition with human food. But a large majority of feed consumed by farm animals is not edible for humans such as grass, straw, bran, oilcake, etc. (Mottet et al., 2017).

Feed efficiency of livestock is expressed in kg of dry matter (DM) or protein consumed by the animals per kg of dry matter or protein produced. Monogastrics and ruminants each produce the about same amount of protein (38,246 and 36,355 Mt/year respectively, according to Mottet et al., 2017). One kg of ruminant protein requires 133 kg of DM against 30 kg of DM only for monogastrics, suggesting an apparent lower efficiency of ruminants. However, it takes only 6 kg of human edible DM to produce one kg of ruminant protein against 16 for monogastrics, suggesting on the contrary an apparent better efficiency of ruminants. Considering meat only, it takes 2.8 kg of edible DM to produce one kg of ruminant meat protein compared to 3.2 for monogastrics. The ratio of edible plant protein per kg of animal protein is below 1 for ruminants (0.6 on average worldwide) against 2 for monogastrics. This means that ruminants are a net contribution to global protein availability. This is especially true for pasture-based livestock systems.

About 2.5 billion ha are needed to feed livestock (Mottet et al., 2017). Out of this total, 77% are grasslands and pastures, two thirds of which cannot be converted to croplands and can therefore only be used for grazing animals. Benoit and Mottet (2023) propose that, in a context of rising energy and grain prices, livestock's sustainability requires a paradigm shift. This means moving away from high opportunity-cost feed and give priority to (i) crop residues, cover crops and coproducts from food processing activities and waste and (ii) forages from areas unfit for mechanization, with heterogeneous feed values in time and space, that can only be harvested by grazing. It also means redistributing animals in territories and avoids competition with arable land and resources that have a "harvestable" energy content, for example for biogas production. Priority should be given to feed resources that have low spatial concentration, with difficult or costly mechanical harvesting, and to leading animals to the resource, by practicing transhumance.

Improving circularity for better natural resources management and climate outcomes

Beal et al. (2023) consider 5 key components of environmental and natural resources sustainability: climate change, land-use, biodiversity, water and soils. They argue that better circularity in livestock can improve environmental sustainability of food systems.

Currently, humans harvest about 25% of total biomass produced on Earth each year. Annual feed intake of livestock represent about 20% of global human appropriation of biomass, or 6 billion tonnes of DM/year (Mottet et al., 2017). On the other hand, manure could cover more than 80% of N and P requirements but supplies only about 12% of the gross N input for cropping. Therefore, there is room for better recycling of biomass in feed and of manure for fertilisation or fuel.

A case study in the EU showed that feeding only leftovers to livestock can supply 31 g protein/(cap*d) (van Hal, 2019). This would require optimal distribution of leftovers over livestock systems and an adaptation in livestock productivity to the nutrient density of the leftover resources used as feed. Another case study in China showed that using more low-opportunity-cost feed (45–90 Mt) could save 25–32% of cropland area without impacting livestock productivity. This could also save one third of water used for feed crops irrigation, synthetic fertilizer and greenhouse gas emissions (Fang et al., 2023).

Alternative protein foods

The future of food and feed also lies outside of the traditional food systems that include farming or land-based activities. Cellular food, or sometimes called "lab-grown" or synthetic, could also be part of our future food systems. They represent a promising option for nutrition with low amounts of natural resources and their sustainability is a topic for research. It is a sector that has received large amounts of private investments in the USA and in Europe, but that has little relevance for small-scale farmers or enterprises, especially in LMIC. While market studies indicate that the sector could reach a significant share, currently, there is no large scale production of cell-based meat or milk and only a few countries have granted market authorisation. Cell culture technology still needs to be optimized and the impacts on nutrition better understood. While the number of animals can be considerably reduced by producing cell-based meat, the technology still requires bovine serum as a growth media. Environmentally, virtually no land is required, but energy requirements are high to maintain constant temperature and GHG emissions may actually be higher than those of beef farming according to recent studies (Risner et al., 2023).

Plant-based substitutes are an existing dynamic market, mostly in HIC. They represent about 2.5% of the meat market shares and 15% of the dairy market in the US. While the nutritional impact of plant-based meat substitutes is questioned due to their high-processed nature and high content of sodium in particular, soy milk substitutes have a good nutritional profile, of higher quality that other plant-based milk substitutes. However, both markets have been on the decline recently and large emblematic companies have made significant loss.

Insects are part of our present food systems, and could gain in importance in the future. Global mass production of edible insects for both food and animal feed was estimated at 10,000 tonnes in 2020, most of which is used in animal feed. However, the impacts of mass insect production on food/feed safety and on biodiversity are still mostly unknown.

Other alternative sources of protein, both for food and for feed, include microalgae, like spirulina, that represent a constant market of about 20,000 tonnes per year but still come at a high cost compared to traditional protein sources, mycoproteins, yeast proteins and extraction from co-products like potatoes and green leaves from the crop industry.

Progress in metrics and methods for assessments

The metrics used to report the impact of producing our food, for example GHG emissions, can also influence decision makers. To compare different foods, emissions are often expressed in g of CO_2 per 100 grams of product, which places animal products among the highest emitters. This does not account for the nutritional density of food, which is generally higher in animal products: 100g of meat or cheese provide more essential nutrients than 100g of rice or potatoes. A recent study by Katz-Rosene et al. (2023) shows that relating GHG emissions to nutritional density in priority micronutrients (six micronutrients commonly lacking globally: iron, zinc, folate, calcium, vitamin A, and vitamin B12) can lead to a different hierarchy of foods. Admittedly, beef remains highly emitting, but with an order of magnitude close to rice or cassava, while other animal products (such as cheese, milk and eggs) are becoming more balanced according to this indicator combining environmental and nutritional aspects. They also conclude that “environmental footprints vary significantly, with considerable ranges between the least and most impactful variants within each food type, and across different ecological indicators.” Assessment of agri-food sustainability need to include variations of nutritional and environmental performance between regions within and between commodities, and to better interpret trade-offs that come with food substitutions.

Approaches like agroecology can help limit these trade-offs. The FAO Tool for Agroecology Performance Evaluation is a multicriteria tool designed to assess the different dimensions of sustainability. Results indicate that the presence of livestock on farm can contribute to increase the overall agroecological score of farms (Mottet et al., 2022). The diversity of livestock on farm also seem to be linked with higher scores of resilience and recycling.

Investing in small-scale livestock for better food and feed sustainability

The International Fund for Agricultural Development (IFAD) is a specialized agency of the United Nations, dedicated to eradicating poverty and hunger in developing countries. It works in remote rural areas of the world to help countries achieve the SDGs. Through low-interest loans and grants, IFAD develops and finances projects that enable rural poor people to overcome poverty themselves and improve their food security and nutrition.

15% of all ongoing IFAD projects have a livestock component. Livestock investments are distributed across all regions, with a higher-than-average budget and number of projects in the Near East and North Africa region, and in West and Central Africa and East and Southern Africa to a lesser extent. The relative share of the livestock portfolio is however still not matching the share of the sector in agricultural GDP (between 20 and 40% in most LMIC).

An analysis of 99 IFAD Value Chain (VC) projects approved between 2016-2020 indicates that although crop VCs are the main focus for all regions, livestock comes second, with a share of VC support ranging from 33% to 45% depending on the region.

Investing in small-scale livestock and pastoralism is essential to improve the sustainability of our food systems. The growth of the sector has so far benefited large scale and industrial systems, while small holders have rather been excluded. In the absence of multilateral and bilateral investments by funding institutions like IFAD, uncontrolled livestock growth may lead to further environmental degradation and inequity in food systems. The impact assessment of 96 IFAD projects between 2019 and 2021 (total of US$ 7.1 billion) showed that they benefited about 112 million people. Income gains were particularly large in countries with livestock projects and higher market access increases most in livestock projects too (IFAD, 2023).

Conclusions

The sustainability of food and feed are strongly linked and one cannot be achieved without the other. Eradicate hunger and nutrient deficiency requires reducing FLW, improving productivity in LMIC and better access to markets for small producers. This needs to happen within strict environmental boundaries, especially regarding climate change, biodiversity and land. Better circularity can help reduce food-feed competition, by recycling crop-residues, by-products and agrifood waste into animal feed to replace high-opportunity-cost feed such as cereals.

To report on the sustainability of different foods and production systems and better inform decision makers and consumers, single metrics need to be overcome. Approaches like agroecology and multicriteria tools can help avoid tradeoffs between environment, economic and social dimensions of sustainability.

More investments in small-scale livestock and pastoralism are key to improve the sustainability of food and feed systems, focusing on improvements in production systems, better access to market and efficient value chains.

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Perspectives on future protein production

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Abstract

As the world's population increases to 9.7 billion by 2050, traditional protein alone will not be able to meet the growing demand for food. Diversification of the protein production is needed. Traditional proteins will need to focus on sustainable production and entire carcase utilisation, while plant proteins need to focus on targeted breeding and processing technologies to create high protein, functional ingredients from legumes that can be incorporated into healthy sustainable products including plant-based meat alternatives. Novel sources of protein from technologies such as precision and biomass fermentation have potential to add to total protein production delivering complementary proteins, however this area needs investment in infrastructure for scale-up and regulatory approval for use in human food products. This paper discusses the challenges and opportunities for production of protein-rich foods from animals, plant and novel sources from an Australian food industry perspective, however the learnings are applicable globally.

Introduction

As the global population reached 8 billion in November 2022 and is projected to hit 9.7 billion by 2050, it is predicted that we would require approximately 70% more food to what we produce currently. At the same time, we will have 55% less agricultural land per capita to produce that food (Colgrave et al., 2021).

Currently there is also lack of diversity in our global supply chain. Seventy five percent of the food comes from 5 animal and 12 plant species, with rice, maize and wheat making up nearly 60% of the calories in the human diet. This lack of diversity makes the food supply chain vulnerable to weather, pests and diseases but it also presents an opportunity to consider other nutrient rich foods that can be incorporated into our diets (Colgrave et al., 2021).

Consumer preferences in foods are dynamic and changes over time. A 2019 report by Food Frontier (Lawrence and King, 2019) highlighted the changing consumer patterns in Australia. They reported that one in three consumers were consciously reducing their meat consumption while 10% were entirely meat free (vegan or vegetarian). Most of these changes in the dietary patterns were based on concerns around the environmental impact, animal welfare, and health and well-being.

Proteins are vital for our health (Colgrave et al., 2021) as they are the building blocks of life. Therefore, we are faced with the challenge to produce food at a greater scale while reducing the environmental impact compared to today. Hence, we need to derive more food and food protein from traditional sources (meat, dairy, eggs, seafood, crops) in addition to protein from emerging but complementary sources (yeast, fungi, algae, insects). CSIRO's Future Protein Mission (FPM) is addressing this challenge. Missions in CSIRO (Commonwealth Scientific and Industrial Research Organisation) are large-scale scientific and collaborative research initiatives aimed at accelerating the pace and scale at which the nation can solve a challenge, while building an ecosystem across the country, to unlock a better future.

The aim of the FPM is to seize the opportunity created by the world's growing demand for high quality protein by supporting new Australian industries through science, innovation and technology. The three main pillars or work packages for the FPM are:

- Plant protein for new markets
- Animal protein production
- Novel protein production systems

In March 2022, CSIRO published a National Protein Roadmap (CSIRO Futures, 2022), which was developed through wide consultation with the Australian food industry. It identified that through targeted investment in science and innovation, we could catalyse $AUD 13 billion in additional growth of Australia's protein sector by 2030 and create nearly 10,000 jobs.

In June 2023, CSIRO published another roadmap called "Reshaping Australian Food Systems" (CSIRO Futures, 2023), again through industry wide consultation to identify how to transform our food systems including how the $AUD 13 billion growth will be implemented. This roadmap identified the following five key areas aligned with the Sustainability Development Goals:

- Enabling equitable access to healthy and sustainable diets
- Minimising waste and improving circularity
- Facilitating Australia's transition to net zero emissions
- Aligning resilience with socioeconomic and environmental sustainability
- Increasing value and productivity

These roadmaps have been used as a blueprint to guide CSIRO's investments in science, technology and infrastructure initiatives. Although these foresights and investments are from an Australian perspective, we believe that the learnings and the developments have the potential to be applied globally, to increase the production of traditional and complementary protein. This paper discusses case studies on the research and investment that CSIRO's FPM have made to grow the Australian protein industry by $AUD 10 billion by 2030, while addressing the environmental, nutritional and consumer needs.

Animal Proteins

The aim of the animal protein work package is to protect and grow the traditional protein industries, with sustainability as a focus. Red meat is often under scrutiny from a sustainability perspective, due to the environmental impact of greenhouse gases. Consumers will continue to consume traditional proteins, and as the middle class in Asia increase from >50% to 60% of the population (Colgrave et al., 2021), their demand for animal-based proteins will increase. As traditional proteins are a mature industry, the potential growth will come from through innovations that enhance production efficiency and sustainability. We are addressing this through sustainable feeds as well as adding value to co- and by-products to maximise the value from the entire animal. In the aquaculture space, the FPM is investing in creating new industries based on white flesh fish (WFF) as Australia imports about 100,000 tonnes of WFF per annum. We are looking at incorporating these proteins in the diet of our aging populations as animals-based proteins are nutritionally complete and more bioavailable.

Research from CSIRO, along with James Cook University and Meat and Livestock Australia (MLA) showed that when *Asparagopsis* seaweed is added to dry feed for ruminant animals, it can reduce methane emissions by more than 80% in controlled conditions. A decade of scientific research has shown that *Asparagopsis* is safe for ruminant animals and that it has no impact on the eating quality of the meat. In 2020, FutureFeed was established as a start-up by CSIRO to commercialise this ingredient. To date, nine FutureFeed licensees around the world have begun cultivating and processing *Asparagopsis* seaweed for use in livestock feed. FutureFeed is focused on scaling the *Asparagopsis* industry in order to increase the supply of this highly sought-after product, and it is continuing to seek partnerships and licensees throughout the value chain (growers, aggregators, processors and distributors). The science so far has been based in beef feedlot and dairy settings, where feed intake is easy to control. However, there is a more recent R&D focus from various organisations, including some FutureFeed licensees, on grazing applications. Therefore, the use of *Asparagopsis* in ruminant feed has great potential to address environmental sustainability in the agricultural industry through methane emission reduction.

In the last two years, together with Meat and Livestock Australia (MLA), CSIRO has developed a novel process to add value to lower value cuts of meat by producing a hydrolysed beef protein powder that is high in protein (>80%), shelf stable, completely soluble, allergen free, high in micronutrients – which can be used as a protein ingredient in products that needs protein enhancement e.g. protein ball, bars, shakes, drinks for the elderly etc. Over 70% of Australian red meat production is exported as a commodity based on its fat content. The majority of this meat is manufacturing grade meat, which is considered lower value meat compared to whole muscle primals used for steaks, sold for making burgers. This research brings meat into a space where it does not generally exist – i.e., in a shelf stable powder format. Meat generally requires chilled or frozen storage to maintain its safety and shelf-life. By delivering meat in a dry, shelf stable format, it increases its versatility and can be exported to regions of the world where cold chains are limited or non-existent, and additionally a need for nutrient-rich food. So far, the research has been based on lower value meats which are sold as a commodity, however we believe that we could use by-products from the abattoir as raw materials as well. Adding value to the potential by-product streams and upcycling them to high value ingredients, addresses sustainability through maximising both productivity and value creation from an animal.

FPM and CSIRO are also investing in growing a sustainable a white flesh fish (WFF) industry. Australia is a net importer of white flesh fish, importing over 100,000T of WFF every year (Colgrave et al., 2021). We are addressing this using two very different approaches. Firstly, we are trying to develop a new white flesh industry using *Trachinotus anak*. This fish has been identified as an excellent candidate to grow value and increase diversity of white flesh fish development in northern Australia while reducing reliance on imported product. *Trachinotus anak* is native to Australia but has been cultured around the world. It thrives in captivity and is robust in environmental variables. Our aquaculture team in CSIRO have been successful in controlled spawning of this fish in captivity, with easy larval culture and no cannibalism. This fish has fast growth rates, high fillet yields, good flesh quality and taste. The team are also building an entire fish welfare model around it, which could be applicable to other fish species too.

The second approach which is a newer research area for CSIRO is aquaponics, where we are focussing on circular economy principles to grow both low trophic fish and high value crops. To date we have successfully grown jade perch with lettuce and herbs as crops. We are currently in the process of building infrastructure to scale this research and grow higher value crops. Although aquaponics can revolutionise the way we produce and consume plant and aquatic animals, it does have its own challenges. Therefore, further research is needed to determine the cost effectiveness of the technology and the potential green credentials and social license.

Plant Proteins

The aim of the plant protein work package is to transform grains and legumes into high protein ingredients which can be made into high value products – underpinned by nutrition and sustainability.

From an Australian perspective, the plant-based industry is dominated by production volume, by wheat, barley, and canola, while globally, majority of plant-based meat alternatives are made from soy protein, which has generated a major demand for soy protein. Therefore, there is a great opportunity to convert legumes into value added ingredients, especially for Southeast Asia, due to short supply chains and high value growing market.

Future research in the plant protein area focuses on production and processing of target legumes that are important to Australia such as lupin and chickpeas. Currently, these legumes are largely bred, priced, and sold for their size shape and colour. The FPM aims to translate the learnings from other crops such as soybeans where targeted breeding has successfully increased protein content. Future research will focus on selecting for consumer-driven or food manufacturer-driven functionalities, e.g., low beany flavour. Increasing protein and improving functionality and sensory attributes of Australian based legumes could provide alternative protein ingredients for plant-based meat alternatives and baked goods.

Nationally, the development of these novel plant-based protein ingredients is so far being hindered by a lack of large-scale manufacturing processing capability to convert grains into plant-based ingredients and then into desirable end products. The cost of processing and the use of additives to extract the proteins can lead to the perception of these protein-based foods being complex and overprocessed. One of the processes currently under consideration is dry fractionation, which addresses the concerns around sustainable protein extraction.

Extrusion technology is generally used to texturize the plant proteins to give them a fibrous texture which makes them suitable for inclusion in plant-based meat products, including formed products like sausages and burgers. Again, larger scale manufacturing process and know-how to create the desired texturized protein products still requires further research and investment. CSIRO has extraction, separation, drying and extrusion capability and have helped various plant-based companies to value add their commodity raw materials and to develop new protein-based products. For example, CSIRO assisted an Australian company to scale their wet protein fractionation process for fava beans, resulting in production of concentrates with 85% protein. Similarly, we assisted another Australian based company to produce lupin concentrates with up to 75% protein by assisting scaling up their protein extraction process and characterising the techno-functionality of their protein concentrate.

We used a venture model and created v2food, a start-up from CSIRO, in response to the strong consumer demand for high-quality plant-based convenient products. CSIRO assisted them in developing an innovative process to make plant-based meat alternatives products within 9 months and has continued to support them with science and technology and develop great tasting products that consumers are seeking. These examples illustrate how legumes and oilseeds can be processed into ingredients for plant-based meat alternatives. However, the future growth in the plant protein area requires targeted breeding of new legumes to not only increase their protein content but to address quality attributes that cannot be solved by processing but that will drive consumer adoption. This will include minimal processing, clean label products, food that addresses specific nutritional concerns and food that tastes good.

Novel Proteins

The aim of the novel proteins work package is to support the development of new industries that upcycle no to low value waste streams into high value protein ingredients, i.e., repurposing agricultural or food waste using precision or biomass fermentation or for insect production. Precision fermentation uses both genetic engineering (synthetic biology) (Colgrave et al., 2021) to synthesise compounds that would otherwise be too expensive or complicated to harvest. Recent advances in terms of cost and throughput of reading and writing DNA, as well as more precise genome engineering tools have opened opportunities for the food industry to produce specific high-value ingredients or compounds to cater for food products for the non-animal-based ingredient market.

This segment has seen record investment from venture capital companies, including two start-ups from CSIRO. Eden Brew is using precision fermentation to make casein proteins in order to make milk micelles from yeast while Nourish Ingredients uses a similar technology to produce animal lipid alternatives that enhance the sensory experience of plant-based meat mimetics. There are several other start-ups being incubated in this space. One of the biggest challenges is the lack of infrastructure to operate at scale. Therefore, urgent investment is required for larger scale fermentation and downstream processing, as well as techno-economic analysis to determine the cost effectiveness of the precision fermentation technology. Another factor to consider is the regulatory approval of these novel ingredients.

Biomass fermentation has been around since 1985. Quorn, which is mycoprotein or single cell protein derived from *Fusarium venenatum*, using biomass fermentation, has been available commercially since 1985. This mycoprotein was grown on glucose and added vitamins and minerals. The new opportunity in biomass fermentation is to derive mycoproteins from food waste rather than refined sugars. The FPM is investigating biomass fermentation as means to upcycle different waste streams to produce food and feed. Australia produces about $20 billion (DCCEEW, 2020) of food waste each year. This includes agricultural, processing, food service and household wastes. FPM is using biomass fermentation as means to upcycle these waste streams as the agri-food biomass can be used as the raw material in the process. Agri-food biomass is subjected to thermal and physical process to reduce or eliminate the initial bacterial load and then treated with enzymes to convert lignocellulose material such as wheat, rice bran or brewers spent grain (BSG) into fermentable sugars, which are then subjected to microbial fermentation to increase the protein content of the biomass and remove undesired compounds. Recent research at CSIRO using BSG, showed that the biomass fermentation resulted in increasing the protein content from 15 – 44%. This protein can then be used as raw material for food and feed. Protein from biomass fermentation is currently being trialled in as an ingredient in aquafeeds at CSIRO.

Another emerging area in novel protein production is molecular farming. In molecular farming a plant is genetically modified to produce an ingredient, similar to precision fermentation. For example, CSIRO has successfully developed a genetically modified canola variety that is high in nutritional long-chain omega 3 lipids (Petrie et al., 2020). Although molecular farming is sometimes compared to precision fermentation, the timelines to modify a crop are longer, but the yields can be higher compared to precision fermentation due to the scale of growing plants. Hence, in recent times molecular farming is attracting interest from industry, including venture capital funding.

Conclusions

In conclusion, science, technology and innovation will play a crucial role in enhancing future protein production. Innovations that unlock different protein sources will allow the consumer to make informed decisions and select the food they prefer from sensory, nutritional and sustainability perspectives. There are many opportunities in animal and complementary protein areas, however adoption and scale-up will continue to remain a challenge. National and global protein ecosystems would need to be created which brings together various stakeholders such as governments, researchers, and industry to work collaboratively to build a more sustainable food system.

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Microbial biotech for feed and food for the future

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Overall context

Micro-organisms are powerful upgraders. They can grow at doubling times of a few hours. They convert organics to cell protein and valuable metabolites at rates in the range of 10-100 g dry matter per litre volume and per day. They thereby can achieve yields and food conversion factors which surpass those of higher organisms with a factor 5-10. It is now well established that microbes are optimal when allowed to operate in cooperation which each other, that is as diversified and constantly adapting microbiomes. The rumen represents such an eco-system fermentation. Yet, as of today when converting cellulose, its efficiency is still limited (of the order of 5-25%) and moreover, in terms

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of the climate change, the rumen produces the undesirable methane gas. In terms of sustainability of the planet, R&D should focus on a route by which ligno-cellulosic plant fibers can be fermented to valuable commodities by means of top-performing microbiomes, preferably also fixing nitrogen from air. Such perspective needs a new mindset among scientists, consumers and particular also the regulators. Indeed, the latter tend in the EU to be restrictive towards fermentations which optimally use the power of naturally evolving microbial mixed cultures (De Vrieze et al., 2010). In the presentation, our experiences in the past with respect to upgrading of secondary resources by fermentation are evaluated and the current potentials in the context of the EU Green Deal are presented. A biorefinery using plant derived cellulosic input materials and making use of microbiomes which are genetically and ecologically optimally engineered, holds potential to extend largely the feed and food supply of the planet and decrease significantly the negative impact of the latter on global warming by using less fossil fuel based fertilizer and producing less greenhouse gases (Piercy et al., 2022).

Open versus closed bio-conversions

Mixed culture microbiology, also called spontaneous fermentation, or 'terroir fermentation', is used worldwide to prepare beer, wine, kombucha, choucroute,... All these upgrading processes proceed, – provided care and craftsmanship –, with good results. The alternative process line is the so-called precision fermentation. In sterile reactor systems, well defined species are cultivated. They generate in a determined way a set of valuable end products. Very often, the precision fermentations are a factor 10 more expensive in capex and opex than the spontaneous fermentations. Moreover, the defined species most often only convert part of the input substrates; thus a major amount of waste products are generated.

Focus on nitrogen

The key component of proteinaceous feed an food, i.e. nitrogen deserves particular attention (Matassa et al., 2015). Producing mineral fertilizers from dinitrogen present in air, requires lots of energy. Actually, one kg of reactive fertilizer nitrogen corresponds to 2 L of fossil fuel equivalent and some 2-4% of all fossil fuel use goes to the production of industrial fertilizer. A major problem is that, when applied to crops, only some 40% is effective; the larger part is lost by run-off, leaching, unwanted processes… Even more problematic is the fact that only a fraction of this harvested crop nitrogen ends up on our plate as food. To close the cycle, the nitrogen going through the body ends up in wastes (waste waters) which to be cleaned up demand once again energy. Finally, in the bioconversion of nitrogen, a particularly process train is always lurking i.e. the oxidation of the reduced nitrogen to nitrite and nitrate by nitrification and the subsequent denitrification of the these nitrogenous species. These conversions bring about that several percent of the nitrogen ends up as nitrous oxide. The latter is a very powerful greenhouse gas. Roughly, in our biosphere the use and cycling of nitrogen is thus responsible for some 10% of all global warming. Food production accounts for some 35% of all greenhouse gases and meat production represents at least one third of that.

Microbial biotech in bonus and malus

Over the past decades, various studies have demonstrated that microbes can ferment crop plant material, at rates of several gram to even 100's of gram per litre reactor volume per day, to valuable commodities such as organic acids, methane; when operated aerobically, microbial single cell protein can be produced. Aerobic organotrophic conversions are characterized by unmatched conversion efficiencies: 1 kg sugar can yield 0.4 kg yeast dry matter of some 2.0 kg yeast wet biomass. Cattle, pigs, poultry, fish have Feed Conversion Factors of the order of 4-8; for dairy the FCF is in the order of 8-13. For insects it is also quite high in the order of 10. Micro-organisms have FCF values which are a factor 10 smaller and better. A key advantage of working with microbiomes is that they are based on cooperative partners which have the capacity to interact, communicate and constantly evolve so that all nutrients and energy delivered to them is optimally used and generation of leftovers is minimal. Yet, the weaknesses of microbial upgrading are evident. Single-cell products are of lower value: they do not have the textural functionality often needed to prepare food products. Microbial cells (bacteria are of the order of 1 μm; yeast -fungi-algae have dimensions of 5 μm) are difficult to harvest (e.g. they need centrifugal forces) and they are particularly hard to process (dewatering, drying,...). Most of all, microbial biomass is subject to very stringent regulatory measures. At present, the EFSA (European Food Safety Authority), although accepting that products such as mushrooms, choucroutes, cheeses based on raw milk,… are part of the quality of our life, considers all newly developed single and mixed culture ferments as 'novel foods'. This means that in order to receive acceptance and be allowed to be commercialized, these new development products have a dossier to be completed which requires years of testing and evaluation and costs millions of €. Moreover, the fact that microbiome-based foods need to be permanently guaranteed in terms of constancy of composition of the microbiome makes that this line of development in the current EU regulation is virtually blocked. In order to achieve the sustainability targets of 2030, we need the effective use of the upgrading power of microbiome-based associations and thus we have to hope that the EU regulators will become more open to recent insights in terms of fermentation with and quality control of microbiomes. Of course, the resources thus produced should be healthy but clever concepts such as the monitoring for the absence of 'unwanted' rDNA should suffice to provide quality assurance.

Bacterial resp. yeast / fungal /algal protein

A first and foremost aspect is that bacteria are quite small (1 µm) and require special technology to harvest (flocculation, centrifugation, drying). Yeast, fungi and algae have larger cell sizes (5 µm or more) and can be processed easier. They also have a configuration which is more apt to the implementation of important feed and food functionalities. For conventional, well-established types of micro-organisms, grown in pure culture under strict axenic conditions, the end products are currently widely implemented as feed or food. Indeed, the 'conventional' production of yeast (mainly *Saccharomyces*), fungal (mainly *Aspergillus* as in Quorn) and algal (mainly *Spirulina*) biomass for feed and food is the road to further scale up. These products certainly are produced at high quality and will substantiate the so-called 'protein shift ' of the next decades.

In the attendance of more innovation and sustainability supportive governmental policies, several industries are waiting to construct large scale industrial units to produce novel types of microbial protein from non-conventional low cost resources such as methane, hydrogen and starch (Unibio, Calysta, Solar Foods,…). Production prices are projected to be of the order of some 1500-2500 € per ton dry matter and thus in the range of that of top quality fish meal. Clearly, the roads for providing new and environmental friendly microbial biotech products to the feed and food chains are on the drawing board.

The EU Green Deal

At present a mere 16% of the Haber Bosch fertilizer nitrogen is effectively ending up as food. The EU has clearly stipulated that the enormous losses should be decreased. As a matter of fact, in the Netherlands and in Flanders, nitrogen emission reduction has become a core aspect of governmental policies and is a constant element of debate. The EU favours the concept of grassland-based biorefinery. Indeed grasslands inhibit the nitrification process and thus decreases losses of nitrate and the formation of the deleterious green house gas nitrous oxide. By mowing the grass and subjecting it in the factory to various processes, top quality feed and food can be produced, as well as materials, and the residues can be converted to biogas. This biorefinery concept also opens the possibility to reconsider the role of the ruminant as pivotal user of plant-based cellulosic materials. It seems reasonable that microbial biotech could aim at the creation of a system that takes low cost plant-based cellulosic materials (straw, hay,…) and generate from such carbohydrate fibers higher value feeds and foods with good efficiency. A special remark in that context is that micro-organisms have the capacity to fix nitrogen from air and thus the fossil fuel-based nitrogen dependency can be decreased. Moreover, we can genetically engineer them in a safe way to bring forward effectively various kinds of valuable commodities.

The powers of education and communication

Several decades were needed before it became generally accepted that climate change was due to human activities. The concept that we need at large scale to use microbiomes to reach the Sustainable Development Goals is fortunately gaining momentum. Indeed microbiomes are highly effective and can adequately be managed and controlled. The impact of the production of microbial protein in reactors has been calculated to represent a saving of 6% of all land surface currently under crop production; this is the total amount of land today used for agriculture by China. The public is generally illiterate about these potentials and the way forward is teaching, communication with the public and setting up interactive ‘sand box’ citizen science demonstrations. In the EU, there has over the past decades been a veritable mismatch between the regulator and the innovator. Concepts such as genetic modification and use of microbiomes have been branded as ‘dangerous’; we must reverse this mismatch to positive thinking in order to create better, more divers and particularly more environmentally sustainable feed and food for the future.

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Cultured meat production: insights from a tissue engineering perspective

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It has been claimed that clean meat would eliminate the need for animal farming and slaughter. Additionally, replacing animals as a food source by clean meat is touted as holding environmental benefits. Although certainly worthy causes, several scientific issues with this approach have been previously discussed, but appear to have been forgotten in the rush to commercialize a product. We briefly discuss the outstanding issues that will need to be addressed before market success and we note where claims in the public media differ substantially from data published in the peer-reviewed scientific literature (Thorrez and Vandenburgh, 2019).

There has been a significant increase in the number of scientific articles related to cultured meat, which is in line with the current interest from the scientific community and consumers, but mainly from investors, food industry, and regulatory bodies. Despite the billions of dollars being invested, there are significant technical, ethical, regulatory, and commercial challenges to getting these products widely available in the market (Wood et al., 2023).

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Cultured meat aspires to be biologically equivalent to traditional meat (Fraeye et al., 2020). If cultured meat is to be consumed, sensorial (texture, color, flavor) and nutritional characteristics are of utmost importance. We compare cultured meat to traditional meat from a tissue engineering and meat technological point of view, focusing on several molecular, technological and sensorial attributes. We outline the challenges and future steps to be taken for cultured meat to mimic traditional meat as closely as possible (Fraeye et al., 2020).

Certain companies in the rapidly expanding cultured meat space claim that cultured meat is exactly the same in taste, flavour and nutrition as traditional meat, but without the need for animal slaughter, and bringing benefits for human health and the environment (Olenic and Thorrez, 2023). It is important to point out that cultured meat is still in the early phases of development and, in many cases, the claims are based on assumptions rather than facts. We outline several knowledge gaps, mainly based on technical issues, with repercussions related to the possible benefits as well as economic and regulatory challenges. Cultured meat production still faces several hurdles including the omission of animal-derived components and economic viability. A lack of transparent production methods limits the evaluation of product characteristics and environmental impact. Detailed production procedures are not available, making it impossible to corroborate the many claims related to their product characteristics and sustainability (Wood et al., 2023, Olenic and Thorrez, 2023).

Current products are not identical to the products they aim to replace. There is still considerable dissimilarity at the level of sensory, nutritional, and textural properties, while important quality-generating steps in the conversion of muscle into conventional meat are missing (Wood et al., 2023, Fraeye et al., 2020).

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Food safety aspects of cell-based food: global perspective

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Introduction

Cell-based food production involves culturing cells isolated from animals. Various food end products can be developed using muscle and fat tissues from cattle, pigs, poultry, fish, shrimp, crabs, lobsters or even kangaroos. As the global demand for proteins grows, many in the food sector are looking into opportunities to expand the scope of diverse sources of proteins that can be both environmentally sustainable and nutritionally sound. The commercial landscape for cell-based food is fast expanding with various companies developing assorted products around the world. Many food safety authorities are working, often in tandem, to identify and address the potential food safety implications so that appropriate

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regulatory frameworks can be set up to protect consumers. The Food and Agriculture Organization of the United Nations (FAO), together with the competent authorities engages many other stakeholders, including researchers who study the food safety issues of cell-based food, cell-based food developers and producers, and non-governmental organizations to collaborate in this space to advance our collective knowledge.

Overview of the production process of cell-based food

The production processes for the various cell-based food products may be different from one another. However, having a basic understanding of the generic production process is necessary prior to help in the identification of potential food safety hazards. A simple animation video was developed by FAO to provide a generic understanding of production process of cell-based food. For a high-level understanding of the production process, four common phases have been identified namely 1) cell sourcing, 2) cell production, 3) harvesting and 4) processing.

Nomenclature issues

Prior to engage in the expert discussions on scientific issues regarding food safety of cell-based food, FAO developed an evidence-based literature synthesis on nomenclature. The result showed that while some different preferences exist among different sectors, the term "cell-based food" was found to be less confusing, conveniently overarching and generally well-accepted by consumers. However, there is no term that is 100 percent scientifically correct. In theory, any organism made of cells can be described as "cell-based", therefore, it does not automatically distinguish the technology to grow edible tissues from "cells". Also, the term "cell-based" has never been used for food, therefore some food business operators may prefer not to use the term. The terms "cultured" and "cultivated" can be confusing as they are often used in the aquaculture sector to indicate farmed fish and fisheries products. The term "cellular agriculture" can be considered too general as it may include the topic of plant cell culturing or fermentation, which can use a wide variety of methodologies and techniques. There has also been a challenge identified on the use of commodity names such as "meat", "chicken" or "fish" together within the terminologies, thus the consistent use of "food" and "food products" has been maintained for the work of FAO and the World Health Organization (WHO) so far. Appropriate nomenclature that is truthful and not misleading facilitates informed decision-making by consumers, helping them understand what they are purchasing or not purchasing. Most consumers are currently unfamiliar with cell-based food products and the processes made to use them. Regulatory authorities have the opportunity to communicate about these in advance of consumers' initial encounters with the products on a menu or in a store, increasing familiarity and avoiding surprises in the marketplace. Adoption and consistent use of consistent nomenclature across commodities / species and used by all stakeholders can help consumers better understand the products and processes and can create a common search term that may be used to find more information about them (Hallman and Hallman, 2020, 2021). While

FAO/WHO uses "cell-based food" as a working terminology and international harmonized terminologies are ideal, experts have suggested that country contexts and meanings in respective languages need to be carefully considered when determining the terminology, as it has an immediate and significant impact on regulatory actions such as labelling.

State of the art in 2022: cell-based foods around the world

In 2022, FAO and Ministry of Health of Israel hosted a stakeholder round-table meeting and a group of researchers and developers discussed ensuring the safety of cell-based foods. The report of the meeting entitled "Cell-based food: its safety and its future role" illustrated various cell-based production processes used for chicken nuggets, hamburgers, beef steak and sushi salmon, as well as some key input materials, such as scaffolds, cell lines and growth media, that in certain cases are consumed along with the cell-based food product. All the participants stated that food safety is of foremost importance. The report provides an overview of the 2022 status of the topic of cell-based food development and paved a way for conducting food safety hazard identifications for cell-based food.

Why food safety is the priority?

Currently, various cell-based food products are marketed with some claimed benefits that the products may bring, such as sustainability including environmental friendliness, improved animal welfare, and food security to name a few. However, there are only model-based assessments available and there is no certain evidence-based proof that the large-scale production of cell-based food would contribute to such benefits yet. Therefore, it is important for developers and researchers to engage in such studies to start generating the real data sets. However, before companies can invest in the large-scale production process, there are few concerns consumers may raise, and one of the most important questions is food safety, as in all the cases of the use of new technologies on food. And food safety always comes first, because if safety cannot be assured, no other discussions would matter. There is an immediate need to ensure that risk-based methods are used to assess the safety of cell-based food. In this regard, FAO developed a 20 minutes educational video "Ensuring the safety of cell-based food" that shows the various food safety measures that are typically used in producing cell-based food.

FAO/WHO expert consultation results

FAO organized an expert consultation through a formal process, in collaboration with WHO, to conduct the global hazard identification process, the first step of food safety risk assessment within the risk analysis paradigm. The results of hazard identification, together with various literature synthesis results as well as country case studies on regulatory frameworks, were compiled, and in April 2023, FAO and WHO launched a milestone publication "Food safety aspects of cell-based food".

Through the rigorous hazard identification process, experts found that many hazards have been already well-known, and they exist in the conventionally produced food. For example, microbiological contamination can occur at any stages of food production processes, including the one of cell-based food. Interestingly, most cases of microbial contamination during the cell growth and production stages inhibit cell growth. If the cells have grown and reached product expectations for harvest, then such contamination would not occur during the production process. However, it is always a possibility to have such contaminations at the post-harvest processing phase, as is the case with many other food products. Experts also found that various existing control measures and good practices, as well as Hazard identification and Critical Control Points (HACCP) systems can be applicable to ensure food safety for cell-based food. Such food safety plans would also need to focus on the materials, inputs, ingredients and equipment that can be specific to cell-based food production, referring to the use of new substance applications and the possibility of allergic reactions to them. While such inputs and materials can be new, experts have pointed out that existing preventative measures and safety assurance tools are applicable to control such hazards. The hazard identification step should be followed by 3 more steps of the formal risk assessment process, namely hazard characterization, exposure assessment and risk characterization. Currently not much exposure is reported thus there is not sufficient data to conduct exposure assessment thus a full risk assessment is not possible to be done. This is one of the reasons why experts focused on identifying hazards only.

Communication matters

While specialists clearly differentiate the concept of "hazard" and "risk", the importance of this distinction is not always commonly understood and appreciated by the media or consumers. Therefore, the list of hazards identified by the experts could be all perceived as risks, rather than controllable hazards with variance in probability and degree of threat. Transparency in communicating how regulatory decisions are being made is one of the most important pillars of a good communication strategy for competent authorities. The public must be able to ascertain that decisions are being made competently and in the interests of protecting public health. To facilitate this, regulatory authorities may consider making health and safety research and data easily accessible to interested stakeholders. Consistency in safety assessments across regulatory agencies will increase consumer confidence in food safety, so collaboration across agencies may be a useful approach. Openness is also critical to the process. Openness refers to the opportunity for engagement with all food safety stakeholders, including those affected by the risk and those potentially responsible for it. Communication is considered an integral aspect of content development, beginning with engagement of relevant stakeholders.

Factsheet for regulators

Separately from the milestone publication, FAO and WHO also published a short factsheet entitled "Nine things to know about food safety aspects of cell-based food" (FAO and WHO, 2023). The factsheet targets national food safety competent authorities and provides key elements for them to consider some useful activities, such as holding stakeholder meetings with cell-based food developers, listening to consumers to understand what they want to know, establishing and using consistent terminology, reviewing other countries' regulatory situations to identify both good practices and lessons-learned, reviewing existing national regulatory frameworks to consider potential applicability, and simulating possible hypothetical scenarios for regulatory needs and actions. For more information about relevant activities by FAO on food safety aspects of cell-based food, visit [www.fao.org/food-safety/scientific- advice/crosscutting-and-emerging-issues/cell-based-food/](www.fao.org/food-safety/scientific-advice/crosscutting-and-emerging-issues/cell-based-food/).

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Bertrand Dumont, INRAE

Applying agroecological principles to animal farming systems fosters transition towards sustainable food systems

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Agri-food systems must evolve towards greater stability and resilience, and need to stay within "safe and just Earth system boundaries" (Rockström et al., 2023). Animal production systems (APS) have received particular attention in the news and scientific media due to their negative impacts on climate change, and perceptions of what are ethically acceptable production methods. The status quo is thus not tenable. Major transformations in animal production systems, feed use and natural resource management will be required to ensure a safe and healthy future for people and the planet.

Agroecology is among the most promising options to achieve food system sustainability. As a scientific discipline, agroecology applies ecological theory for the design and management of sustainable agroecosystems and food systems. A diversity of plant and animal species and optimization of interactions among system components are mobilized to enhance agroecosystem functions, thus pre-empting chemical inputs. From a transition perspective, agroecology works on different aspects, from input substitution as a first step to system redesign that questions production goals (e.g., creating added-value at the farm or community level rather than maximizing outputs per animal or per unit area).

Agroecology differs from other sustainable development proposals particularly due to its focus on redesign. Sustainable intensification is an efficiency-oriented sustainable development perspective that aims to produce more with less environmental impact from existing agricultural land and thus spares land for nature (Dumont et al., 2018). Agroecology, however, proposes to work with nature. While sustainable intensification goes hand in hand with the development of digital technologies, Sullivan (2023) has recently highlighted significant epistemic and structural barriers between agroecology and ag-tech that primarily aims for increased agricultural productivity. Dumont et al. (2018) argued that for digital technology to become part of the agroecological transition it is imperative that it is developed as a low cost option accessible to smallholder farmers, and that it enables them to enhance their autonomy.

Despite the recent surge in the academic literature on agroecology, APS have scarcely been considered in most agroecological thinking. The delay in the attention on agroecology in the livestock sector may be explained by the fact that in Latin America, cattle farming is often associated with problems of deforestation and land grabbing in large farms, and was thus outside agroecology's original scope.

On the basis of a study conducted by Altieri (2002), who identified the key ecological processes to be optimized in agricultural systems, Dumont et al. (2013) proposed five principles as a guideline to implement site-specific combinations of agroecological practices in APS: i) achieve integrated animal health management; ii) decrease the external inputs needed for production; iii) decrease pollution by optimizing the metabolic functioning of farming systems; iv) enhance functional diversity within livestock farming systems to strengthen their resilience; and v) preserve biological diversity by adapting management at farm and landscape scales. The application of these principles have been shown to generate environmental and economic benefits that have been quantified across a range of ruminant, pig, poultry, aquaculture, and integrated crop-livestock farms.

More recently, Wezel et al. (2020) have proposed a consolidated list of 13 generic agroecological principles as part of transition pathways to more sustainable food systems. Nine of these principles can be directly related to the five principles of Dumont et al. (2013). Additional emphasis is given to economic diversification and co-creation of knowledge. Co-creation of knowledge implies co-development of practices by involving farmers in collaborations with the scientific community and other stakeholders. It implies i) integrating farmers' values, perceptions, and practices; ii) accounting for the singularities of the local production system to be transformed; and iii) disseminating knowledge among local communities and regional stakeholders.

In this presentation, we will discuss how the agroecological principles proposed by Dumont et al. (2013) apply in five innovation hubs from the European Union's Horizon Europe project Agroecology-TRANSECT (www.agroecology-transect.net), focusing on either grassland-based production in the Massif central (France), Switzerland and Bulgaria, or the integration of plant and animal production in Andalusia (Spain) and Guadeloupe (French West Indies). In doing so, we will highlight how horizontal sharing of knowledge based on farmers', scientists' and citizens' perceptions and values, farmer-to-farmer exchange, and greater participation of NGO and social organizations in decision-making facilitate the transition towards sustainable APS.

Integrated animal health management can be seen as a three-pronged strategy. It aims to combine i) preventive approaches: use of forage mixtures with species containing condensed tannins in Switzerland; multispecies grazing to reduce strongyle load of parasites at pasture in Bulgaria and Guadeloupe; ii) curative approaches: use of herbs to replace some veterinary products in Bulgaria; and iii) early-detection approaches to select animals or groups to be treated: looking at animal eyelids in Guadeloupe. In the French Massif central, the main objective is to co-create sustainable and ethically acceptable grassland-based dairy farming systems that are responsive to citizens' concerns for animal welfare, e.g. by late separation of the calf from the dam. Coeugnet et al. (2023) have adapted the KCP design method to explore innovative solutions and build a common perspective among dairy farmers, farm advisors, NGO and citizens, which for example led them to rethink the organization of the veal calf sector.

One strength of agroecological APS lies in their self-sufficiency, which can reduce feed-food competition, pollution, and dependency on erratic market prices by maximizing the use of grass-based diets for ruminants and recycling on-farm waste. However, it also increases dependency on climatic conditions, for instance, summer droughts that can drastically reduce grassland biomass production. In the French Massif central, a grassland typology was co-created between researchers, a PDO cheese union, farm advisors and environmental NGO, and a diagnostic tool was proposed to farmers to explore management strategies adapted to the types of grasslands present on their farms. An educational game reveals the benefits provided by grassland type diversity to cope with various climatic or socio-economic hazards (Carrère et al., 2021).

Incorporating diversity into APS can increase their performance and strengthen their resilience. The innovation hubs illustrate the benefits for system resilience of preserving agrobiodiversity (e.g., local breeds in Bulgaria, Switzerland and Guadeloupe) or of incorporating more diversity in forage mixtures (Lüscher et al., 2022) or on tropical micro-farms (Selbonne et al., 2023). In Andalusia, researchers and farmers together with the local agricultural officers are exploring opportunities for local small-scale slaughter and transformation of meat and dairy at public infrastructures, including material means, training and legal coverage. Such an agrifood system perspective could allow retaining added-value within the region, with positive social and environmental outcomes.

Finally, the innovation hubs illustrate how a number of grassland management practices (extensive grazing, late mowing, avoiding grazing of some strips to enable flowering, etc.) aim to increase farm habitat value for biodiversity. In Bulgaria, a non-profit organization contributing to the ecological development and preservation of rural areas has teamed up with the Bulgarian Society for Protection of Birds to create a YouTube film capturing the benefits of High Nature Value Farming for wildlife (www.youtube.com/watch?v=C3N-nmZyR7hA). In Andalusia, diversified grazing systems including Iberian pigs, small ruminants and cattle in agro-silvo-pastoral systems are essential for wildfire prevention.

We conclude that the innovation hubs of Agroecology-TRANSECT project show how the principles of agroecology can be implemented in APS to promote agroecological transition, strengthen farm resilience, and provide environmental and social benefits at food system and landscape scales. Further insights on the potential for scaling out agroecological APS calls for analysis of lock-ins and opportunities for anchoring in contrasting socio-ecological contexts.

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Pathways to climate neutral red meat production

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The Paris Agreement (UN, 2015) is the primary global consensus for action to combat climate change. Article 2 describes the ambitious goal of limiting global mean temperature rise to 1.5°C above pre-industrial levels (well below 2°C) to significantly reduce risks and impacts. According to the IPCC, "Stabilizing the climate will require strong, rapid, and sustained reductions in greenhouse gas emissions, and reaching net zero CO_2 emissions" (IPCC, 2021). This requirement to achieve

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net zero CO_2 emissions stems from the long-term impacts of these emissions, potentially lasting for millennia. The IPCC also notes that, “Limiting other greenhouse gases and air pollutants, especially methane, could have benefits both for health and the climate” (IPCC, 2021). In comparison, methane emissions have a relatively short atmospheric lifetime, in the order of 12 years (Smith et al., 2021), meaning that a steady emissions profile over time can be consistent with climate stabilization.

The differences in GHG characteristics complicates the development of multi-gas climate action strategies. Climate metrics can be used to establish an equivalence between different types of GHG emissions, with results typically reported as CO_2-equivalent emissions. However, it is well known that there is no absolute equivalence. Each climate metric uses a different basis for comparison; for example, by estimating the relative climate impact at a certain future point in time, or over a chosen interval of time. Critically, depending on the climate metric chosen, the relative importance of different GHGs varies. The issue for ruminant livestock industries is that while there are substantial opportunities for CO_2 sequestration in landscapes, GHG emissions are substantially non-CO_2. As such, there has been much recent interest in methods of GHG assessment that can be used to align climate action consistent with the Paris Agreement’s climate stabilization goal (FAO, 2023).

For ruminant livestock industries, two main alternatives to the traditional 100-year global warming potential (GWP100) have emerged in recent years: the GWP* climate metric (del Prado et al., 2023) and the radiative forcing (RF) footprint (Ridoutt, 2021). The GWP* climate metric is similar in many ways to GWP100 except that pulses of long-lived emissions are evaluated alongside permanent rates of change of short-lived GHG emissions, such as methane. Through this approach, GWP* results are more easily interpreted in relation to future warming than when pulses of short- and long-lived GHG emissions are combined. The other approach, the RF footprint, is based on the same IPCC-derived equations as GWP100. However, the RF footprint reports present radiative forcing from current year emissions together with radiative forcing from historical emissions remaining in the atmosphere. As such, it presents what might be described as a radiative forcing balance sheet. Climate neutral (in contrast to carbon neutral and GHG neutral; Matthews et al., 2021) is a term that has been applied when a system makes no net contribution to additional temperature increase or no net contribution to increase in radiative forcing (FAO, 2023). This study explores pathways for the Australian red meat industry to reach climate neutrality using the RF footprint approach.

Methods

Disaggregated time-series of GHG emissions (CO_2, N_2O, CH_4), covering cattle production (including feedlot finishing), sheep meat production, goat production, and domestic red meat processing were compiled for the years 1990 to 2020. These data were primarily sourced from the Australian Greenhouse Emissions Information System that contains the emissions data used to support Australia’s national reporting under the UNFCCC. These data covered emissions from enteric fermentation, manure management, agricultural soils, liming and urea applications, along with land use and land use change. Other sources were used to estimate energy use. For the national sheep flock, a protein mass allocation was used to partition emissions between wool and meat production. These emission time-series were extrapolated to 2030 using forecasts for livestock numbers supplied by the industry. In summary, sheep/lamb numbers were forecast to increase almost 18% from 2020 to 2030. For beef cattle, the forecast increase was almost 13%.

In consultation with industry, a list of GHG mitigation and sequestration interventions was compiled (Table 1).

Only interventions with realistic potential for implementation prior to 2030 were considered. These interventions included feed additives, forage crops, breeding for lower enteric methane emissions, as well as improved herd/flock management. Vegetation management interventions included trees on farms, soil carbon storage, and savannah burning management. For production system interventions, estimates of efficacy and adoption were obtained from recent reviews, with the aim of reflecting what might be reasonably possible in production environments compared to controlled trial conditions. For vegetation management, adoption rates were based on published industry targets. An S-shaped adoption curve was assumed.

Radiative forcing footprints were quantified following Ridoutt (2021) and Ridoutt et al. (2022) using parameters and equations reported in Myhre et al. (2013).

Results

The profile of RF over time informs about the trajectory of RF and whether progress is being made to stabilize

Table 1. GHG mitigation and sequestration interventions

Intervention	Sector	Efficacy	Adoption (initial)	Adoption (2030)
High impact feed additives (3-NOP, algae)	Feedlot	49%	2023–5%	80%
High impact feed additives (3-NOP, algae)	Grazing	11%	2026–2%	30%
Other feed additives (tannins, etc.)	Feedlot	10%	2023-2%	10%
Other feed additives (tannins, etc.)	Beef cattle (grazing)	5%	0%	0%
Other feed additives (tannins, etc.)	Sheep (grazing)	1%	2023-2%	10%
Leucaena forage crop	Beef cattle (grazing)	2%	2023-2%	20%
Desmanthus forage crop	Beef cattle (grazing)	4%	2023-2%	20%
Breeding (lower methane emissions)	Grazing	0.25%/y	2023-1%	3%
Trees on farm	Grazing	25 MT/y	2023-5%	100%
Soil carbon storage	Beef cattle (grazing)	7.8 MT/y	2023-5%	100%
Savannah burning management	Beef cattle (grazing)	10.7 MT/y	2023-5%	100%
Herd management	Beef cattle (grazing)	15%	2023-5%	80%
Flock management	Sheep (grazing)	10%	2023-5%	50%

Fig. 1 Australian red meat industry radiative forcing (RF) footprint (mW/m2) under a business-as-usual scenario. Historical data 2005 to 2020. Projected data from 2021.

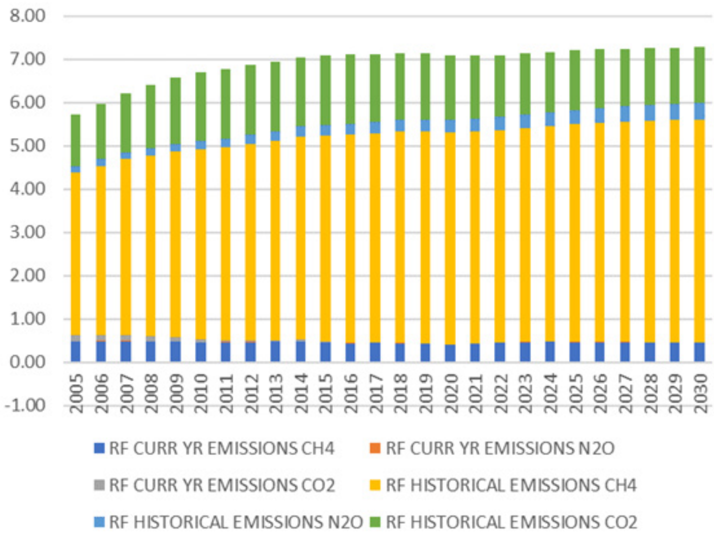
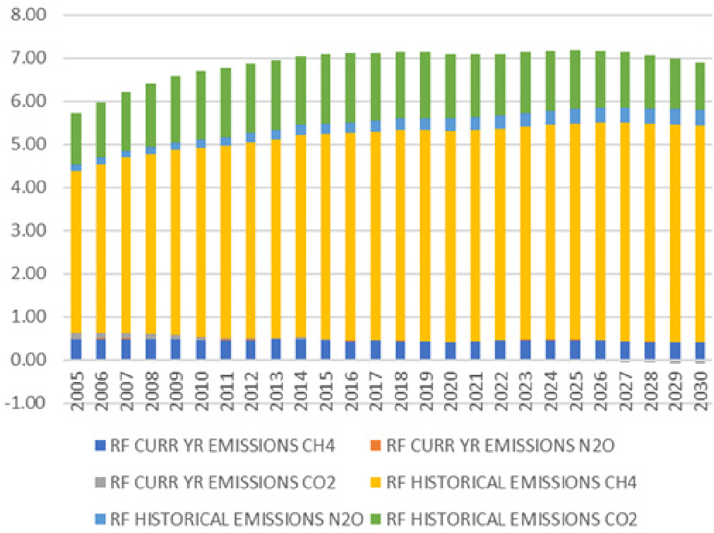


Fig. 2 Australian red meat industry radiative forcing (RF) footprint (mW/m2) with adoption of GHG mitigation and sequestration actions. Historical data 2005 to 2020. Projected data from 2021.



total RF, which is a requirement for climate stabilization. Considering the Australian red meat industry, the RF footprint increased from 5.71 to 7.09 mW/m^2 over the decade 2005 to 2015, after which it plateaued, reaching a local maximum of 7.13 mW/m^2 in 2018 and decreasing back to 7.07 mW/m^2 in 2020 (Fig. 1). With future expansion of the herd and flock, the RF footprint is projected to increase marginally to 7.26 mW/m^2 in 2030 under a business-as-usual scenario. In contrast, with the combination of interventions described in Table 1, the RF footprint remains relatively flat, but declines marginally to 6.81 mW/m^2 in 2030 (Fig. 2). The reduction in RF footprint relative to the business-as-usual scenario was mainly attributed to vegetation management and improved cattle herd management.

Discussion and conclusions

The RF footprint is an alternative approach to reporting and managing GHG emissions. A key point of difference is avoiding the problem of establishing equivalence between different GHGs which requires subjective value choices. The RF footprint quantifies the present contribution to RF associated with current and historical emissions and can be used to inform strategies to stabilize RF (a prerequisite for climate stabilization) or to manage toward a lower RF target. The Australian red meat industry has made an historical contribution to the global RF increase (Fig. 1).

However, since 2015, the RF footprint has essentially plateaued and in 2020 it decreased. As such, the Australian red meat industry can be described as climate neutral, no longer contributing to further climate change. Indeed, the decrease in RF footprint observed in 2020 represents a modest retraction in the historical contribution, equivalent to a net negative CO_2 emission in that year.

With a forecast expansion in the Australian herd/flock, the RF footprint will likely increase modestly under a business-as-usual scenario (Fig. 1). However, GHG mitigation and sequestration interventions have the potential to further reduce the industry's RF footprint, even while allowing for increased production. The RF footprint transparently demonstrates how the red meat industry can align with the goal of climate stabilization, while also contribute to global food security, and support other industries to meet their climate goals. Greater use of the RF footprint to guide climate action in the livestock sector is recommended.

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The Dublin Declaration – About roles, services and impacts of livestock

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Background: the societal role of livestock

In today's complex world, characterized by resource scarcity, population growth, and geopolitical uncertainties, the pursuit of sustainable decision-making presents significant challenges. Food systems stand at the crossroads of delivering vital nutrients to billions of undernourished individuals while simultaneously navigating complex sustainability concerns – a crossroad in which the role of livestock has emerged as a nexus, requiring rigorous scientific scrutiny, a balanced perspective, and clear communication.

In this context, the Dublin Declaration for Scientists aims to amplify the voices of scientists worldwide who are diligently, honestly, and successfully researching various facets of animal agriculture, contributing to a holistic view of its future.

The Dublin Declaration

This declaration originated from the Dublin Summit on the Societal Role of Meat, held in October 2022, where an array of globally renowned scientists converged to discuss multidisciplinary facets of livestock's role in society. Their collective aim is to raise awareness among consumers, researchers, and policymakers, emphasizing the critical role of meat in society. Considering these developments, society and policymakers alike are increasingly recognizing the pivotal role of meat in various societal facets, to the extent that it has been recognised by media streams and scientific journals such as Nature Food (Leroy and Ederer, 2023).

However, it is not merely a declaration but an amplification of existing research. In his conference presentation Peer Ederer highlighted the foundation of this declaration, which rests on a robust body of scientific evidence, much of which has been published in the journal *Animal Frontiers* (Ederer and Leroy, 2023). In this comprehensive review, key domains, including nutrition, economics, society, and the environment, were scrutinized, emphasizing livestock's indispensable role across these domains.

To highlight a few key takeaways, Leroy et al. (2023) emphasized that meat provides high-quality protein and essential nutrients, some of which are challenging to obtain through meat-free diets. Moreover, Johnston et al. (2023) revealed that when meat consumption is part of a healthy diet, harmful associations often vanish, emphasizing the importance of dietary context.

The societal role of well-managed animals is another critical point, as elucidated by Thompson et al. (2023). Livestock efficiently convert non-edible biomass, recycle nutrients, sequester carbon, enhance soil health, and offer numerous ecosystem services. However, Manzano et al. (2023) cautioned against oversimplified environmental assessments of the livestock sector, advocating for a more nuanced approach.

Ederer et al. (2023) noted that expanding animal production output is a readily available means to ensure global food security. Furthermore, Croney and Swanson (2023) urged the exploration of alternatives that protect both animals and the environment without de-prioritizing human food rights.

Polkinghorne et al. (2023) stressed the importance of evidence-based decisions and policies rather than ideological ones, a sentiment echoed by the scientific community. While substantial investments have been made in cellular agriculture, Wood et al. (2023) pointed out significant challenges, including technical, ethical, regulatory, and commercial hurdles.

The above summaries, among many other evidence-based statements within the mentioned publication, emphasize that livestock has a pivotal role to play in sustainable food systems, aligning with the key sustainability domains recognised by the Food and Agriculture Organisation (FAO) i.e. nutrition, the environment, and economics & society.

Importance of contextualised data and its communication in sustainable food systems

Despite the body of evidence on the role livestock has to play in society, sustainability decision-making, production and consumption still rests on how efficiently each of the aforementioned domains are measured, which poses yet another challenge.

Nutrition is typically assessed in terms of nutrient content per unit volume or weight, often compared to daily requirements. Economic viability, on the other hand, is commonly evaluated through the price per unit weight. Environmental impact, crucially, is often represented by the carbon footprint, encompassing factors such as land and water use, as well as various greenhouse gas emissions.

The challenge with these quantifications, along with their numerous variations and sub-measurements, is that they are frequently presented in isolation or within poorly communicated contexts. Consequently, these data are not readily applicable across different production systems or products and may be misinterpreted when used outside their original scope. Only recently have sustainability studies started to integrate these metrics in relation to one another, offering a more holistic perspective on sustainable food systems. Nevertheless, the dissemination of these integrated findings to the broader scientific community and policymakers remains limited.

This fragmented presentation of metrics and their insufficient communication can lead to misinterpretations and potentially detrimental decisions. A prominent example is the debate surrounding the sustainability of livestock. When considering climate warming impact alone, livestock has typically been cited as being responsible for 14.5% of global greenhouse gas emissions, a number deriving from the seminal Livestock Long Shadow analysis, which has since been frequently revised downwards (Steinfeld, 2006). Without considering its role in nutrient supply and ecological balance, this statistic has fuelled calls to reduce livestock farming. The insights previously highlighted underscore that livestock plays a multifaceted and indispensable role in society, benefiting the economy, environment, and nutrition supply.

This highlights the need for transparent and contextualized perspectives on sustainability, pertaining not only to how sustainability is measured but also to how the results are communicated, as seen within the Dublin Declaration, and expressed in modern examples of contextualised measurement approaches.

Modelling and refining existing data

As the first example of data contextualisation, the Global Observatory for Accurate Livestock Sciences (GOALSciences) presents an innovative approach to contextualizing data within the global food system. Its primary goal is to provide a clear and comprehensible visualization of the inputs and outputs of the food system within their respective contexts. This is achieved by employing food balance sheets from the Food and Agriculture Organization (FAO) to create a data visualization tool that offers both a global overview and a country-level breakdown of agricultural commodities across various processing stages: from the harvest stage to processing, then to animal rearing, and finally to the finished product.

While this tool represents a substantial improvement in making data more reader-friendly and putting it into perspective, it is important to note that it may still suffer from inaccuracies, as the source figures lack detailed refinement and may consequently exaggerate certain values. This is particularly relevant in the context of livestock, where multiple factors influence resource usage, with herd structures being a critical component.

To address this limitation, Elna de Lange and her colleagues at GOALSciences conduct research on different production systems across species, presented as a poster at the conference. They explore how species-specific herd structures are divided within these production systems. Taking pigs as an example, commercial swine herds are categorized into various groups, such as suckling piglets, weaned piglets, grower pigs, lactating sows, and gestating sows. Each of these groups has distinct dietary and management requirements, resulting in varying resource consumption patterns. For instance, weaned piglets consume a higher percentage of full-fat soya and fishmeal per kilogram of intake but a minimal amount of wheat bran, whereas grower pigs or gestating sows prioritize wheat bran and maize in their diets. These dietary differences significantly impact the flow of resources through different production stages.

The refinement of these insights comes from industry research on production systems, which considers factors like farrowing rates, mortality rates, liveweights, dressing percentages, and production efficiencies. These parameters provide a detailed perspective on swine herd structures. Combining this knowledge with expertise in the nutrient requirements of each pig's life cycle, particularly concerning standard diet composition, energy, and protein requirements, enables an accurate breakdown of resource inputs and outputs. This approach provides a comprehensive view of the global swine population at any given moment.

By modelling nutrient and resource flows in this manner, decision-makers, whether policymakers or producers, can gain a thorough understanding of the timing and attribution of specific inputs throughout the production process. This approach also offers structure to frequently cited but often misinterpreted figures regarding the use of livestock in food production.

Holistic and conceptual measurements

As another example in the understanding and measurement of aforementioned sustainability indicators within a specific context, Enrike Maree has introduced a novel tool, the Sustainability Index for the Environment, Economics, and Nutrition (SiEEN), which has been adapted into the Dairy Index for Environment, Economics, and Nutrition (DiEET) for the South African dairy industry, also presented as a poster at the conference.

SiEEN expands upon the Nutrient-Rich Food Index (NRFi) framework by considering factors like nutrient bioavailability, protein quality, food matrix effects, age and sex-specific dietary needs, demographic strata, global nutrient contributions, and associations with diseases or protective effects as revealed by epidemiological studies (Drewnowski and Fulgoni, 2020; Beal and Ortenzi, 2023; Mente et al., 2023). It applies life-cycle analysis (LCA) principles but adapts them to practical industry contexts, relying on readily available on-farm and production system data. Common indicators such as blue water use, fertilizer consumption, land use, electricity usage, recyclable materials, and waste, are included based on their presence in raw materials and processing inputs. These collectively contribute to an environmental score. Given uniform system boundaries, LCA results can be integrated with other environmental indicators.

Evaluating consumer affordability involves analysing product prices relative to poverty levels, weighted against the population distribution across these income strata. Economic indicators encompass financial contributions to the nation, employment figures, and producer cost efficiencies, among others. While producer data is self-reported, retail prices and literature are used to ascertain cost and population parameters. Additional binary and point-based self-report questions contribute to the final economic score. (Riddout, 2021; Mendoza-Velázquez et al., 2023)

Unlike recent methodologies that rely on single metrics, SiEEN employs shorthand notation to express individual indicators alongside each other, providing a more transparent view of the results. The outcomes are transparently expressed as "Ni: EnS: EcS," with higher Ni or NS, and lower EnS and EcS, indicating favourable results. "EnS" signifies the Environmental Score, while "EcS" represents the Economic Score. This index can be adapted into an online model, and allow for analysis of individual products within the context of its country and local consumers, or comparison with a variety of products within the same context - both globally and locally.

Conclusion and outlook

The Dublin Declaration amplifies the evolving body of evidence on the societal importance of meat, giving a new perspective within sustainable food systems. Nevertheless, as perspectives shift, ongoing measurement and innovative methods which are practical, transparent, and contextual, are equally important. The examples highlighted, which include exploring deeper food system dynamics and the development of tailored sustainability models, depict the innovative ways in which research on livestock and sustainable food systems are, and should be growing.

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Can we do without livestock?

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Introduction

Available agricultural area per human is severely shrinking due to continued growth of global human population and losses of valuable lands along with urbanization, erosion, and desertification. Smith (2018) considers this to be one of the greatest challenges facing humanity, which is even exacerbated by climate change. On the other hand, livestock production is accused of competing with humans for food through consuming about one third of global harvests of cereals and more than three quarters of soybean (e.g., Ritchie, 2023; Ritchie and Roser, 2023). Provision of feedstuffs on arable land causes emissions and contributes to global warming, particularly if associated with land use change. Methane (CH_4) from enteric fermentation of ruminants adds to discussions about livestock being a significant driver of global warming. All these aspects have been condensed into high carbon footprints per unit of meat, milk, or other animal-based food. In the public debate, such figures have been leading to the simple conclusion that less consumption of animal-based food reduces pressure on environment, and climate. More extremely, linear extrapolation to zero consumption of meat, milk, etc., results in the hypothesis that agriculture without livestock should be the most sustainable and climate-friendly method to produce human food. Indeed, many current practices of highly intensive livestock production are questionable in view of global hunger, environment, and climate, particularly when livestock competes with humans for edible biomass and for valuable arable land. But is it really justified to linearly extrapolate these figures to an agricultural system with much less or even no livestock? Can we really do without livestock?

Wilhelm Windisch, TUM

Non-edible biomass, the forgotten pillar of agriculture

In the first instance, agriculture does not produce food. It rather generates accessible biomass and harvests large quantities of entire plant materials. Food to humans arises along with the second step of laborious extraction of edible components out of the harvested plant materials, both on the side of agriculture as well as during processing in the food industry (Windisch and Flachowsky, 2022; Tompson et al., 2023). For example, only one third of the harvested biomass of wheat plants ends up in wheat flour while two thirds consist in non-edible co- and by-products (straw, bran, etc.). For many other crops, the proportion of food extracted from harvested biomass is much less and generates even larger quantities of non-edible residues. In addition, maintenance of soil health and fertility forces plant production to avoid repetitive cultivation of crops on the same spot and to follow a multi-annual system of rotation of different plants. Particularly in organic farming, this rotation system includes plant cultures that do not deliver food to humans at all (e.g., clover, alfalfa). Another huge source of non-edible biomass is permanent grassland that cannot be used as arable land for mainly topographical and climatic reasons. These permanent grasslands cover around three quarters of global agricultural area and even regions with intensive crop production still contain significant proportions of permanent grasslands. In total, agriculture generates, by far, more non-edible than edible biomass. For the situation in Central Europe, for example, it may be estimated that each kilogram of plant-based food is inevitably associated with at least 4 kg of non-edible biomass (Vorndran et al., 2023). Globally, the relative proportions of non-edible biomass should be far higher.

Circularity of non-edible biomass with livestock is win-win

Non-edible biomass harbours large quantities of plant nutrients (nitrogen, phosphorus, etc.) that must be returned to the soils to maintain fertility and hence to continue generation of plant-based food. In principle, three strategies of recirculation are available: rotting on the field, biogas production and using residues as fertilizer, or feeding to livestock and using the dung as fertilizer. Rotting is inefficient since the release of plant nutrients is not synchronized with the needs of plants that grow during the next cycle of vegetation. It ends up with high emissions of plant nutrients into the environment and, vice versa, low harvests of crops and resultant plant-based food. More efficient are residues from biogas plants as well as dung from livestock since they may be stored and applied during the next vegetation cycle in a targeted way. Accordingly, losses into the environment are lower and crop harvests are significantly higher. The superiority of these two strategies of circularity over rotting ranges in the magnitude of 2:1 when comparing nitrogen fertilizer efficiency and, vice versa, harvest levels of cereals (Bryzinski, 2020).

From the viewpoint of plant production, biogas residues and dung show comparable efficiencies to maintain high production levels of plant-based food. But only livestock further adds food on top of the basal production of plant-based food. Assuming 4 kg of non-edible biomass being inevitably associated with 1 kg of plant-based food, the quantities of extra kilocalories and top-quality protein may account for about 50% to 100% of the basal production of plant-based food. In other words, deploying livestock into circularity of non-edible biomass increases the number of humans that may be fed from the identical spot of agricultural area by at least one half. Since this effect occurs without food competition, no inherent antagonism exists between plant- vs. animal-based food. On the contrary, both production lines are coupled synergistically within the agricultural system of circularity. Inclusion of livestock into agriculture not only fosters plant production through delivering an efficient fertiliser, but also supports food security through provision of significant quantities of high-quality food on top of the basal plant production (see also Windisch and Flachowsky, 2022; Thompson et al., 2023).

'Climate-killer-cow' is a misleading narrative

Ruminants are the most efficient converter of non-edible biomass into human food. But carbon footprints of milk and ruminant meat as calculated by standard metrics are high compared to plant-based food. The main reason is CH_4 emission by ruminants which arise from digestion of non-edible biomass in the forestomaches. It is a transient manifestation of carbon within the natural carbon cycle because it originates from ingested plant materials, and – after release into the atmosphere – decays to carbon dioxide (CO_2), which is then picked up again by plants to form new biomass. CH_4 is a strong greenhouse gas but is quickly degraded (half-life time around 10 years). This leads to different climate effects depending on the local population dynamics of ruminant herds.

At constant numbers of emitting animals, the atmospheric concentration of CH_4 turns into an equilibrium, where newly formed CH_4 does not heat up the atmosphere any further, since it is compensated by degradation of formerly emitted CH_4 (e.g., Neu, 2022). This is the situation e.g., in Central Europe, where head counts of ruminants as well as corresponding emissions of CH_4 have been decreasing well below the pre-industrial level (Kuhla and Viereck, 2022). The corresponding equilibrium of atmospheric CH_4 is so low that even complete elimination of ruminant livestock would hardly impact the climate (Guggenberger et al., 2022). Currently used metrics of carbon footprints do not consider this effect and hence massively overestimate the climate impact of such ruminant production systems (Manzano et al., 2023). Limitation of livestock feeding to inevitably occurring, non-edible biomass would further reduce the head counts of ruminants and would keep the equilibrium of atmospheric of CH_4 even lower. In this situation, CH_4 from ruminants should be largely irrelevant to the climate.

Nevertheless, ruminant CH_4 emissions need to be carefully watched. Rising head counts of ruminants and/or increasing the production intensity would introduce fresh CH_4 into the atmosphere. It would then fully express its strong warming potential since it is not yet compensated by degradation. This situation can be found in many parts of the globe. The future challenge is to assess the climate impacts of ruminant production systems on a regional scale considering the complex interactions between the climate drivers (Manzano et al., 2023).

Too many as well as too less livestock harm environment and climate

Circularity of non-edible biomass releases the carbon, nitrogen, phosphorous, etc., bound therein. This is an inevitable process which occurs independent from the pathway of recycling (rotting, biogas, livestock). Consequently, the emissions of livestock fed with this biomass are part of the natural circulation of agricultural matter and do not additionally affect environment or climate. This also applies to CH_4 from ruminants as indicated above. Abstinence from livestock would just annihilate the extra meat, milk, and other animal-based food and would thus cut down total food production from a given spot of agricultural area. An agriculture without livestock would be forced to compensate these food losses by intensifying plant production and/or expanding the use of arable land (e.g., Van Zanten et al., 2018). Both would increase the emissions per nutritional unit of human food (kilocalories, protein, etc.). In other words, with absence of livestock the pressure on the environment and climate to nourish one human would be higher than with a mixed agricultural system, where livestock is balanced with plant production on base of inevitably occurring, non-edible biomass. Of course, if livestock production is intensified above circularity, extra feed must be produced at expense of human food. Hence, the pressure on environment and climate would rise as well. In total, the minimum impact of food production on environment and climate may only be achieved by smart inclusion of livestock into the entire system of agriculture on base of circularity of non-edible biomass.

'Alternatives' to animal-based food require livestock to become sustainable and climate friendly

Vegan products are often advertised to be sustainable and climate friendly alternatives to animal-based food. However, the processing of harvested plant materials along the food industry up to the final vegan products inevitably entails large amounts of non-edible biomass. For example, oat drinks utilise only one third of biomass that is introduced into the production process via the oat kernels. The remaining two thirds of biomass must be utilized as well, mainly through feeding to livestock, e.g., pigs or dairy cows. Metaphorically speaking, every glass of oat drink entails another glass of cow milk. From an environmental and climatic point of view it is reasonable to combine both production lines since they make complete use of the biomass input at maximum gain of human food (plant-based plus animal-based). Consequently, these 'alternatives' should be judged as synergistic partners to livestock products rather than alternatives.

With cellular meat, however, the situation is quite different. Apart from (bio)technological and biological restrictions (e.g., Wood et al., 2023), such products must also be assessed in view of circularity of agricultural biomass. Cellular meat develops from muscle cells which are fed with a culture media containing only pure nutrients (glucose, amino acids, fatty acids, etc.). Such a media represents the highest possible degree of nutritional quality that human food ever could achieve, and it is produced out of already existing plant-based food by elaborate and energy consuming technical procedures. Therefore, cellular meat turns out to be a food competitor to humans rather than an environmental and climate friendly alternative to animal-based food.

Conclusion and outlook

We cannot do without livestock at present time. Apart from other societal, ecological, economical, nutritional and ethical aspects (e.g., Croney and Swanson, 2023; Ederer and Leroy, 2023; Ederer et al., 2023; Johnston et al., 2023; Leroy et al., 2023; Polkinghorne et al., 2023; Thompson et al.. 2023), livestock makes use of non-arable areas, keeps non-edible biomass in circulation thereby providing high-quality fertilizers, and generates high-quality food in addition to basal production of plant-based food. These benefits are utilized best when intensity of livestock production is balanced within circularity of non-edible biomass and does not compete with production of plant-based food.

However, circularity also entails limitations of quantity and quality of available feed. Hence, it considerably restricts provision of animal-based food compared to the current situation of intensive livestock production. This mainly affects poultry production, and, to a lesser extent, also pig production since these categories of livestock depend on feedstuffs with high nutritional quality. The smallest reductions of production occur with ruminants, because the dominant proportion of their feed is already non-edible and originates for a significant part from permanent grasslands that do not compete with production of plant-based food.

Limitations of feed resources forces livestock production to maximise feed efficiency. This not only includes best practice in harvest, preservation and feeding techniques of non-edible biomass, but also plant breeding to improve nutritional feed quality, as well as management of healthy and long-living animal herds (Windisch and Flachowsky, 2022).

In total, agricultural biomass is the fundamental pillar to feed humans. It is a regenerative, but limited resource, and must not be spoiled, neither the edible nor the non-edible part. Livestock in balance with circularity of non-edible biomass is an essential component of responsible agricultural systems that generate food to humans with minimum impact on environment and climate.

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Place of animal products in more sustainable diets: a nutritional perspective

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To be considered sustainable, diets have to be 1) nutritionally adequate, safe and healthy; 2) protective and respectful of biodiversity and ecosystems; 3) culturally acceptable; 4) economically viable, accessible and affordable (1). The sustainability of our diets is influenced in two ways: firstly by 'demand', i.e. our food choices, and secondly by 'supply', i.e. the characteristics of the food products available. Unfortunately, the different dimensions of diet sustainability are not always spontaneously compatible with each other. In particular, there is a potential conflict between nutritional adequacy and affordability because fruit and vegetables, which have an excellent nutritional profile and are essential for good health, are, like meat and fish, the most expensive sources of calories in our diet (Darmon and Drewnowski, 2015). However, fatty/sweet/salty products (e.g., crisps, biscuits, and all food products made from flour, oil and sugar, etc.) are among the cheapest sources of calories in our diets and have a low environmental impact (because they come from mass plant production) but are harmful to health when consumed in excess. What's more, these products are very palatable, practical, easy to store and prepare, and there's no risk of them going to waste – all attributes sought after by consumers, especially the most disadvantaged among us. As for refined cereal products (ordinary pasta, white rice, white bread), they offer similar benefits to fatty/sweet/salty products, with a nutritional composition that is less problematic but far from optimal.

Nicole Darmon, INRAE

In nutrition and public health research, the issue of food sustainability has only been tackled relatively recently, at the turn of the 2010s, in particular in connection with the definition for the first time by an international body – the FAO – of the concept of sustainable diets (FAO, 2010). In this field of research, studies have mainly focused on assessing the environmental impact of food choices, understanding the synergies and conflicts between the different dimensions of sustainable food, and in particular between nutrition and the environment, and identifying the changes needed, in terms of food choices, to move towards healthier and more sustainable diets. Unlike approaches such as life cycle assessment (LCA), which target a particular food sector and/or foodstuff, it is diets (real or theoretical, population-based or individual) that are studied, which means that all the foods making up the diet (i.e. the dietary repertoire or dietary diversity) must be considered simultaneously, along with the quantities and frequencies at which these foods are consumed (or could be consumed, in the case of theoretical diets).

These studies have mobilised four main types of approaches (Perignon and Darmon, 2022):

1. Proposing theoretical diets that are supposed to be more sustainable, designed on the basis of a priori considerations (e.g. Mediterranean diet, Eat Lancet reference diet, substitution of animal products by plant products, etc.), with a posteriori verification of the potential benefit of these diets in terms of various sustainability criteria;
2. Identifying diets that are more sustainable than others within existing diets, also known as the positive deviance approach, with the aim of isolating, among existing diets, those that best reconcile different sustainability requirements – for example, this approach was used to identify, among the diets consumed in the French adult population, those whose nutritional quality was higher than the median nutritional quality and whose carbon impact was lower than the median carbon impact (Masset et al., 2014);
3. The design of theoretical diets using a multi-criteria approach with no a priori criteria, based on the constrained optimisation technique: this method allows to go further than with existing diets, by generating diets that meet several performances on different dimensions of sustainability (Gazan et al., 2018).
4. Mathematical optimisation under constraints has several advantages over the other three approaches. Thus, if the data is available and reliable, it is relatively easy to include in the same model constraints on various sustainability dimensions (e.g. nutrition and environment) and different criteria associated with these dimensions. This enables a quick assessment of whether or not these constraints are compatible with each other, given the foodstuffs available and their known characteristics. If the constraints are compatible, the proposed solutions (i.e. the theoretical diets designed with the optimisation model) will de facto comply with all the constraints imposed. If the constraints are not compatible, the reasons for this incompatibility can be explored, and alternative solutions can also be considered, such as the use of new foods, or the softening of certain constraints to find solutions that respect them "as best as possible". In any case, this ability to simultaneously integrate numerous requirements on a large number of metrics related to different dimensions of sustainability has made this technique an approach of choice for the study of sustainable diets (Gazan et al., 2018).

In France, as in many Western and industrialised countries, we consume more protein than is strictly necessary to cover our protein requirements (while remaining below the limit considered in excess), so that reducing the consumption of protein-rich animal products for environmental reasons should not pose any problems to cover protein requirements of most people, with the exception of certain vulnerable sub-populations with high protein requirements and/or low protein and/or calorie intakes (particularly the elderly or the ill). However, as foods that are sources of protein are also vehicles for other essential nutrients, it could prove difficult to reduce protein intake, particularly animal proteins, while covering all other nutritional requirements. A balance between animals and plants would seem to be required, but no public health agency has issued any quantified recommendations on this ratio. A 1:1 ratio (1 g of vegetable protein for 1 g of animal protein) is often presented as desirable but is not the subject of any official recommendation. In a recent study, we used constrained optimisation to determine, for different sub-populations of French adults, the theoretical minimum intake of total protein, as well as the proportion of protein of animal origin in total proteins, compatible with compliance, at no extra cost, with all the recommended intakes of non-protein nutrients (Vieux et al., 2022). The results show that, depending on age and sex, 45% to 60% of animal protein in total protein is required to meet recommendations based on non-protein nutrients, with variations due to age and sex. And why is that? Because animal protein sources are sources of many other essential nutrients, some of which are not found (or not sufficiently or not sufficiently bioavailable) in plant protein sources (in particular vitamin B12, iodine, iron, zinc, vitamin D and long-chain omega-3 fatty acids).

To wisely reconcile the different sustainability requirements, it will therefore be necessary to diversify and increase consumption of unrefined plant products (fruit and vegetables, wholegrain products, oilseeds and pulses), while reducing consumption of animal products and redirecting it towards the least environmentally damaging sources, such as fresh dairy products and eggs, as well as meat from more sustainable production systems. The cultural acceptability of this shift depends as much on changing people's attitudes and beliefs, particularly towards meat, as it does on facilitating the adoption of these new behaviours by developing a range of products tailored to consumers' expectations. Advice aimed at eliminating entire food categories is unjustified, especially as it calls into question a central dimension of diet sustainability: its cultural acceptability.

But above all, let's not forget that the first lever for reducing the environmental impact of our diet is certainly to buy less, waste less, and eat just what we need, which is entirely consistent with public health messages to fight overweight and obesity. It also helps to keep the food budget under control.

In conclusion, a more sustainable diet is diversified, flexitarian and frugal. It is generally less expensive, as meat represents the largest share of the food budget of French people, whatever their socio-economic status. However, it is not necessary to eliminate entire food categories to improve the sustainability of the diet.

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Consumer acceptance of novel proteins

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Introduction

In recent years, the global landscape of food consumption has been undergoing a significant transformation driven by a complex mix of factors ranging from environmental concerns to food security and health considerations. Facing these challenges asks for major shifts, and a shift from animal-based to plant-based proteins is a compelling and innovative solution, offering a potential answer to the challenges posed by traditional animal-based protein production. Alternative more sustainable proteins, which include plant-based, cell-cultured, and microbial-derived options, present a unique opportunity to revolutionize the way we approach food production and consumption.

Consumer patterns of alternative proteins stands at the forefront of this paradigm shift, whereby especially behaviour change and acceptance play a major role. Adoption of novel and alternative proteins is not widespread on the moment, and considerable attention is needed to support these transitions. More specific on the one hand individuals become more cognizant of the environmental impact, ethical implications, and health consequences associated with conventional meat production, the appeal of alternative proteins has grown, promising a more sustainable and diverse future for global food systems. However, on the other hand the path to achieving widespread consumer acceptance is nuanced and multifaceted, involving considerations of taste, texture, cultural preferences, pricing, and perceptions of novelty.

This exploration, and the presentation at the OECD CRP-sponsored future foods conference, delve into the intricate interplay between consumer attitudes, beliefs, and behaviours in relation to alternative proteins. By examining the drivers behind consumer choices, the barriers to adoption, and the strategies that effectively bridge the gap between tradition and innovation, we can gain a comprehensive understanding of the complex dynamics at play. As society navigates this pivotal juncture in the evolution of food consumption, it becomes increasingly imperative to dissect the factors shaping consumer acceptance of alternative proteins, ultimately paving the way for a more sustainable and adaptable global food future.

Framework for developing effective interventions via systematic steps

In order to develop effective interventions it is highly relevant to understand which steps to take towards developing, designing and choosing interventions. Below follows a detailed breakdown of the four steps of interventions to reduce meat consumption as also described in the open source published article (Onwezen, 2022):

Step 1: Define Problem and Target Groups

In this initial phase, the aim is to clearly define the problem at hand – in this case, the high meat consumption – and identify the specific groups of people who are the primary consumers of meat. Regarding meat consumption there exist several strategies towards supporting the protein transition, for example reducing moments of meat consumption, reducing portions sizes, or replacing meat. This involves collecting data on consumption patterns, dietary preferences, and socioeconomic backgrounds. Regarding target groups, this could include different age groups, socioeconomic classes, or regions. Moreover, consumer segments are mostly most meaningful when including dietary patterns, like vegetarians vegans, flexitarians and meat lovers. Understanding the diversity within these groups is crucial as it helps tailor interventions to resonate with the unique characteristics and needs of each demographic.

Step 2: Understand Drivers of Behaviour

The next step involves delving deep into the psychological, social, economic, and cultural factors that drive meat consumption within the identified target groups. We mostly differentiate between motivation, skills and the environment, though within these broad categories factors are included such as taste preferences, convenience, social norms, health beliefs, emotions and perceived environmental impact. Details on drivers of interventions can be found in the open sourced article Onwezen et al (2021).

Qualitative research methods like surveys, interviews, and focus groups can help gather insights into why individuals make the choices they do. By uncovering the underlying motivations, the intervention designers can gain a comprehensive understanding of what factors need to be addressed to effectively influence behaviour change.

Step 3: Link Interventions to Specific Drivers and Barriers

Based on the insights from Step 2, the next task is to design interventions that directly address the identified drivers of meat consumption while mitigating the associated barriers. This involves developing a range of strategies that appeal to fit to the drivers of the target group(s).

Moreover, each intervention should be evaluated in terms of its feasibility, practicality, and potential societal impact. Consideration should also be given to potential unintended consequences, ensuring that the interventions don't inadvertently lead to other negative outcomes.

Step 4: Assess Impact

The final step involves implementing the chosen interventions and rigorously assessing their impact. This includes measuring changes in meat consumption patterns among the target groups, as well as monitoring any broader societal effects. Data collection methods could include surveys, sales data analysis, and qualitative feedback. The impact assessment should also consider short-term and long-term effects, as well as any potential resistance or backlash from certain segments of the population. Adjustments can be made based on ongoing feedback and evaluation.

By following these four steps, intervention designers can create a comprehensive and effective strategy to reduce meat consumption within specific target groups. The iterative nature of this process ensures that interventions are continuously refined and improved based on real-world results and changing behaviours. Details can be found in the open sourced scientific article of Onwezen (2022).

Examples of interventions that reveal consumers can be supported towards meat reducing strategies.

Intention-behaviour gap

There is a gap in intentions and behaviour. Our research reveals that consumers are more positive and open, and also becoming more positive and open over the years (2015-2019) compared to their consumption behaviour. The consumption behaviour also remains stable over time (Onwezen et al., 2022). This phenomena is the so-called intention-behaviour gap.

The intention-behaviour gap, also known as the attitude-behaviour gap or the intention-action gap, is a concept frequently discussed in psychology, sociology, and behavioural science. It refers to the disparity or lack of consistency between an individual's intentions or stated goals and their actual behaviour or actions. In other words, it highlights the discrepancy between what people say they intend to do and what they ultimately end up doing.

This phenomenon is of particular interest because it raises questions about the reliability of self-reported intentions as predictors of future actions.

It suggests that even when people genuinely intend to perform a certain behaviour, various factors can prevent them from translating those intentions into actual deeds. These factors can include external barriers, conflicting motivations, unforeseen circumstances, or simply a lack of self-control.

Ignorance and value activation

There are several consumer groups, one of these groups are strategic ignorant consumer. These consumers seem indifferent, though in essence they are not. These consumers do have environmental and animal welfare values though wilfully choose to ignore those on the moment of decision making (Onwezen and van der Weele, 2016)

Strategic ignorance, also known as deliberate ignorance or wilful ignorance, is a concept used in various fields, including psychology, sociology, ethics, and decision-making research. It refers to a conscious or purposeful decision by an individual or group to remain uninformed or unaware of certain information, facts, or realities. In other words, strategic ignorance involves actively avoiding or ignoring information that may be relevant or important to a particular decision or situation.

We developed an experiment in the zoo in which we explored whether cognitive dissonance can be utilized to encourage desirable dietary choices, particularly the adoption of vegetarian meals. Specifically, the study examines whether activating individuals' pre-existing concerns for animal welfare by prompting them to contemplate its importance can trigger cognitive dissonance and subsequently promote the preference for vegetarian options.

A field research conducted in a restaurant setting in a zoo shows that value activating doubles the proportion of vegetarian burger orders.

In conclusion, the study underscores the potential of stimulating individuals to reflect on the significance of animal welfare, thus evoking cognitive dissonance, as a means to drive more environmentally conscious dietary choices, such as opting for vegetarian meals. This approach offers promise in addressing the incongruity between values and meat consumption behaviour.

Changing the default

A default mechanism, in a scientific context, refers to a preset or automatic choice or action that occurs when a decision or behaviour is required but no specific choice has been explicitly made. This default option is typically one that is preselected or established as the default choice in a given context or system.

Default mechanisms are commonly used in various fields, including psychology, economics, and user interface design, to influence or guide people's decisions and behaviours. The primary purpose of implementing default mechanisms is to simplify decision-making and encourage specific outcomes that align with certain objectives or goals.

Experiments in restaurant settings reveal that changing the standard, for example adaptation the week menu in such a way that consumers receive plant-based options as the standard and actively need to ask for a meat option (instead of the other way around) also turn around the proportions of choices from the customers such that the majority chooses the plant-based option when it is the standard (Hielkema et al., 2022; Taufik et al., 2022)

Emotions and affect

Although consumers and policymakers often debate conscious drivers of alternative protein acceptance, research reveals that the emotional and more affective drivers are also highly relevant. A recent study reveals for example that emotions are the most prominent driver in consumer acceptance, also in understanding these intentions over time (Onwezen et al., 2022). Using this knowledge in product positioning can for example be done on product packaging. A research on insects reveals that consumers are more willing to accept insect burgers when these are promoted in an affective (compared to a cognitive manner). For example thus using feel good about yourself instead of research shows.

Conclusion

In conclusion, our exploration into consumer behaviour concerning meat consumption underscores several key aspects. Firstly, consumers demonstrate a willingness to change their dietary habits in favour of more sustainable choices, such as reducing meat consumption. However, this willingness often requires support and intervention to translate into concrete actions. The presence of the intention-behaviour gap is evident, highlighting the need to bridge the divide between consumers' stated intentions and their actual behaviours.

We also shed light on the significance of knowledge rules in comprehending consumer behaviour. By identifying and leveraging these rules, we can gain valuable insights into the decision-making processes underlying food choices, particularly those related to meat consumption.

Moreover, we included 4 examples of our research that underscore and reveal that consumers are not always rationale, though that we can understand their behaviour and support more sustainable choices.

For example, the role of cognitive dissonance and value activation in influencing consumer decisions. By prompting individuals to reflect on their values, especially in terms of animal welfare and environmental concerns, we can trigger cognitive dissonance and motivate more sustainable choices, such as opting for vegetarian meals.

Additionally, we recognize the importance of the food environment, particularly default options, in shaping consumer behaviour. Making environmentally friendly choices the default or more readily available can encourage consumers to select these options, reducing the effort required to make sustainable decisions.

Finally, our findings suggest that addressing consumer behaviour often involves tapping into more unconscious and affective routes to influence choices. These routes, which may involve emotions and automatic responses, can be powerful drivers of behaviour change and should be considered in strategies aimed at promoting sustainable food choices.

In summary, our research highlights the complex interplay of factors influencing consumer behaviour related to meat consumption. To effect meaningful change, interventions should take into account the intention-behaviour gap, knowledge rules, cognitive dissonance, value activation, the food environment, and the influence of unconscious affective routes. By understanding and addressing these aspects, we can better support consumers in making more sustainable and conscious dietary choices.

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The European Feed Forum. How do we build the future of food and feed?

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Thank you very much! I am not important, I am elected so it's a short-term contract that I have with all the European citizens. So, first of all, good evening and thank you for having me today. I learned a lot of things, and was quite astounded by what I have learned. Thank you for giving me the honour of closing the event, which I will try to make short, but maybe I will not succeed.

The theme was food and feed for the future and maybe the question that we have to answer is how do we build the future of food and feed. As highlighted in the last presentations, the consumers are the real policy makers and they have a strong influence. But there is a massive gap between what I have heard today and what the consumers know when they decide what to buy. And I'm talking about the consumers who can afford to buy food, because there is an increasing number of consumers in Europe and outside of Europe that are on food aid, which means that they eat what they are given. We could collectively build on this policy opportunity to make sure that food aid, or school meals, or all organized routes to market are sustainable for food and feed. It's not the case at the moment.

Irène Tolleret, European Food Forum

We need massive and coordinated communication to the consumers about what is at stake – I don't think they understand the enormity of the risks –, and education about what is sustainable food and why they should be proud of all the progresses made today by our farmers in Australia, in Europe or elsewhere. You demonstrated the breadth of the research and research outcomes that have been achieved though enormous effort.

Of course, informing the consumer with a label is challenging. Label-wise there is a private initiative like Planet-score, but I believe that when you go to buy your food, the price is key. There is also private interest by the owner of the label. There is also complexity as discussed today which influences the trust of consumers in a label, due to lack of consumer knowledge on what metrics and data underpin the logo claims (what we measure and how we measure it?). To be totally frank, I do not believe in the magic label at all. If it would exist, it would have been put on all the products a long time ago.

I believe in education, starting in school, especially in kindergarten, but also that we should think about live long learning. Why don't we talk about companies about sustainable food? How do we expect consumers to change if we don't talk to them? I was astounded today at the level of technical innovation and new practices, new organisations for circularity that are ready to go to market. Enabling innovation to reach consumers successfully is a key factor for achievement. On the novel food legislation, I think we need to aim for a step change as well as a change in scope. Maybe we need to have fast track lanes or stop the clock mechanism while at the same time we must include environmental and biodiversity and all social and economic impacts that are have not been tackled yet.

However, let's be clear: a small number of innovations have enabled us to reduce our emissions. So, I do believe in freedom of research, freedom of consumption, once the food safety studies have been carried out. Food safety is compulsory. But let's stop presenting novel foods as an alternative to traditional agriculture. There are two separate things that have separate objectives, and for both we need to find a more sustainable way of producing them. We have talked a lot about breeding, but let's talk about water. Cellular meat does not emit methane, but it does consume a lot of water in its production. It's a concern. We have a lack of water and this will continue, with an increased frequency of droughts. So we also need to think about our sustainable food innovation as being sustainable in 20 years. If we invest in factories now, let make sure that the places where they are put have all the inputs that they need to produce the relevant food.

So, I think that we really need to save water for human consumption and for agriculture. We need to protect arable land and grow crops on them, as well as having cattle on non-productive land to produce food. That's something that is part of our culture, it's part of our rural communities, it's very good for the climate, it's very good for the food and also for our well-being, because a lot of very good cheese come from this very ancient and traditional practices

No one denies that traditional livestock farming has an impact on climate change. A lot has been done already to reduce emissions, especially through feed, but much remains to be done, and I think that the professionals need to come with a proposition. I've learned things today that I have never even discussed with the farming communities that I talk to on an everyday basis about the CAP or other subjects. So, it is important the farmers to embrace these innovations.

So, we need more research, we need science, we need to listen to science facts and believe in the results of EFSA. We have an independent agency in Europe, which is very good, but when scientific facts do not agree with some very vocal minorities we have a social media storm, and your everyday person doubts the scientific facts. And we cannot live in a society where people have concerns about what they eat. So, it's very important that we communicate existing research and upcoming innovation to the public.

Technology neutrality is fundamental.

Can you imagine – when radiography was invented people said "Oh, now we stop, that's the only technology for medical imaging." Research would have stopped, and we would not have scanners, ultrasound scans and other devices. We need to agree that the innovations of today will be followed by new innovations that do not exist and that will need to be given the consideration they deserve.

We must not forget that livestock farming does not provide just us with food. It has also an important role to play in biodiversity, in maintaining the landscapes, especially in mountain areas, and in preventing fires or natural catastrophes. It is in the interest of our society to maintain livestock farming and grazing in Europe and all temperate places on the planet. Emerging countries, while investing in research into new protein sources, are also investing heavily in agriculture. China, India, and Brazil are becoming major meat and milk producers. If we want to preserve Europe's food sovereignty, we must continue to invest and carry out research on the environmental impact of livestock farming and not make the mistake of thinking that the solution lies in one single technology. We need a toolbox with as many tools as possible and make sure that all the farmers know how to use these tools. As Europeans, we also need to take responsibility for the rest of the planet. If we produce less, which is the trend of all environmental policies, we will import more, except if we waste less. However, all things being equal today, if we produce less, we will import more, and that will have two consequences: increased prices and less volumes for hungry countries, and greenhouse gas emissions leakage. So, it's very important that we consider and that we protect all our arable lands, and that we produce crops on them, because otherwise it will result in deforestation.

In summary we need to move, as we have been able to do for the COVID crisis, from competition with third countries to cooperation, something that you have all shown today that you are doing very well. Climate change and its consequences that we are facing today, oblige us to mitigate and to adapt at the correct rhythm, including the legislative rhythm. The issues are complex, and we need to consult with all the stakeholders if we want to build policies without radical solutions that would be unacceptable to the consumers or to some producers.

Because we need collective intelligence to tackle complex issues, in 2019 I founded with four other MEPs what we have called the European Food Forum. The European Food Forum is an independent, politically-led, non-partisan multi-stakeholder forum, led and governed by elected members of the European Parliament, of which I have the honour of being President. The EFF aims to promote open dialogue. We do not take political positions, but we discuss with all the stakeholders when a coming strategy is proposed by the Commission. Democracy is a dialogue where people with different opinions can interact respectfully, and collectively arrive at an agreement. They progress on the agreed outcomes together and then focus on the things they disagree on to find solutions. This process ensures the policies that we work on, that we vote on, are feasible and do not leave anybody on the outer. The result is very good because the European Commission comes to all our meetings now.

Food is a prime connection between people and the planet. The policies that regulate the food supply chain in the EU and globally need to be constantly evolved and reviewed to respond to societal needs, and of course to contribute to tackle climate change. However, the way by which we are going to achieve the goal of zero CO_2 emissions in 2050 gives rise to highly polarized opinions or even conflicts. We tested it in France with Sainte-Soline, the water reservoir problem, and it demonstrated clear examples of tensions. This is why we need dialogue forums that give a voice to all the stakeholders. The Europe Food Forum does not take position on specific policy issues. It is a space for open dialogue based on science and research. Our forum remains open to new players so do not hesitate to contact us if you would like to take part in our work.

As a final point, food is an arm of war, especially right now. So, I believe that at the same time that we are talking about building and strengthening international governance on weapons or communication we also need strong international tools to make sure that we decrease hunger at the same time as our environmental impacts, with public, private cooperation and technology transfer to the hungry countries. There is no planet B, we need to be proactive, responsible, sustainable, and show the best of our humanity. Access to quality food in enough quantity should not become a privilege for the more developed countries. It is a fundamental human right. Thank you very much.

Conclusion to the workshop

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Good afternoon Ladies and Gentlemen. I am delighted and honoured to be among you this evening to conclude this workshop, which has featured high-quality presentations and engaging, sometimes divisive, discussions. It is not easy to conclude such a rich event and I won't be complete. So I apologize in advance for the missing some aspects and I apologize too for my English which is not as good as I would like. I will try to make it short because we had a day full of information.

To provide context for my perspective, allow me to introduce myself. I am Jean-Baptiste Moreau, former French deputy of the French parliament from 2017 to 2022 and spokesperson for the presidential party. I am fortunate to be closely connected to President Emmanuel Macron and continue to have his ear on agricultural and agri-food issues.

Jean-Baptiste Moreau, RPP Group

With a background in agricultural engineering, I spent 16 years as a farmer and beef cattle breeder in central France, in the Creuse region. I've also served as a cooperative president and as the head of a slaughter house. Despite my political background, I can assure you that I am anything but a supporter of jargon and political correctness. I have attentively followed today's presentations and some from the preceding days at EAAP, viewing them with a perspective that I can describe as anything but neutral.

I'm known to speak frankly (isn't it true, Irène?) and not being particularly friendly to activists and the brand of political ecology practiced in France. Often, on various TV programs and platforms, we hear criticisms of meat and livestock practices as environmentally destructive, among other things. First and foremost, many of these criticisms are voiced by individuals who know next to nothing about agriculture. Furthermore, these assertions are often presented as scientific when they are nothing more than non-scientific nonsense. We need that you, the scientists, go to explain in the media what science really says.

I was very interested in Anne Mottet's presentation. We have in France and in a large part of Europe a very sustainable livestock. The problem of waste is a real problem. We have to reduce it and it could assist in reducing a lot of livestock emissions. The ruminants turn human inedible protein into protein we can eat. That is very important because the antagonists of meat consumption promote that we could replace livestock with crops for human nutrition. I am waiting impatiently for someone to show me how we grow crops in the mountainous region in the centre of France. France has a large number of small scale livestock producers. We have to protect our producers from an international market which could destroy these small farms because of their lack of competitiveness. The point of circularity in agriculture is very interesting and definitely one to develop.

I followed the debate on insects with interest, and diversifying protein sources could be a valid point. However, when it comes to discussions about lab-grown meat or synthetic milk, which I personally refer to as "bench-top meat" or "bench-top milk," my enthusiasm decrease. Allow me to reaffirm that livestock farming is not only useful but also indispensable to agroecology and, of course, to maintaining sustainable, environmentally friendly, and biodiverse agriculture in our countries. I'm pleased to see that several studies presented during these days support this assertion.

Beyond my concerns about the purported environmental harm of lab-grown meats, there are two major dangers I see. Firstly, we have seen this morning that this technology is far from mature; it often involves patenting life forms and it is driven by financial interests rather than considering the social, societal, economic, environmental, and health consequences. Many of these potential consequences are not yet properly assessed, and there are reasons to exercise caution before moving forward with the commercialization. The industry that want to commercialize the technology is to me a sorcerer's apprentice with purely financial objectives. Secondly, I have seen the study that says that cultivated meat capturing 0.4% 2030 meat market share would require 22 times more current global bioreactor capacity of the current global pharmaceutical industry. That is insane. Rest assured that I will do everything within my political influence to oppose the commercialization of lab-grown meat in Europe and France.

This does not mean that I disregard the environment. I believe that agriculture and livestock must continue their efforts to minimize their environmental impact. Livestock, in particular, should reduce its greenhouse gas emissions. I heard doubts on the evaluation and the real impact of these emissions. It would be interesting to air this discussion in the media to ensure a balanced representation of the topic. Research has to continue in areas like animal nutrition. I found the study on incorporating algae into animal diets, presented by Benoit Rouillé, particularly interesting. Using genetic approaches as well, measuring and improving feed efficiency and reducing greenhouse emission from livestock is crucial. However, drastically reducing livestock production, especially in Europe as proposed by countries like Ireland or the Netherlands, is both ludicrous and self-destructive.

As global demand for protein rises, I'm fully aware that we can't keep deforesting to establish livestock operations. Yet, the more we decrease existing livestock production, the more we push for its establishment in regions where it is absent. Wanting to reduce livestock farming in Europe is in fact counterproductive on an environmental level. The meat we are not producing, we will import, so it will have a dramatic impact in fact on the environment globally, because it is produced in other countries and shipped to Europe. It is pure hypocrisy.

In Europe, we are of a generation who has been fortunate enough not to experience hunger. But let's be cautious that our actions don't lead us to exactly that situation. Our European agriculture is not productive enough to meet our needs, and we rely on imports.

Being a livestock farmer is a challenging occupation, with meagre pay and diminishing appeal for younger generations. It will be a great challenge for the years to come. Because my fear is not the public policy of reducing livestock numbers but the natural reduction in number of agricultural producers because of a lack of vocation. It is a real and great danger for humanity.

These international gatherings of scientists like EAAP or today to discuss topics related to livestock and the environment are crucial for farmers and as politicians. Faced with some scientists who misuse their supposed scientific authority to advance their anti-meat agendas, we need scientists like you to reassert that scientific fact is not a belief or conviction, but an actual fact. Progress, and progress in agriculture, need science, more science, and not less science. And you have a role to play as scientists, it is to explain to our citizens and consumers and politicians the scientific facts.

So, I extend my gratitude to Jean-François Hocquette and INRAE for organizing this week. Long live science, long live agriculture, and long live livestock. Thank you for your attention.

Other invited talks

Alternative way of milk protein production

Hélène Briand

Bon Vivant, France

Sustainability of insects for feed and food

Thomas Lefebvre

Ynsect, France

Sommet de l'élevage 2023 announcement

Benoît Delaloy

Sommet de l'élevage, France

Posters

Herd structure and nutrient requirements in livestock across the World: A modeling approach

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Winner of the poster competition

A collaborative platform for meat industry innovation and scientific evidence for policy development

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The International Meat Research 3G Foundation (IMR3GF) was established in 2017 by scientists to facilitate independent international scientific collaboration with eating quality a primary focus. The objective is to combine compatible global consumer sensory data to deliver the far greater power of pooled knowledge and more efficient dissemination of services through the industry across countries and organisations. This followed significant interaction between scientists and joint activity with industry players to establish common carcase measurement and consumer sensory protocols within a UNECE framework.

The IMR3GF domain is hosting the Dublin Declaration platform, already signed by over 1,100 scientists and provides a non-aligned structure to store, discuss and disseminate high quality scientific evidence pertaining to livestock systems and meat.

The Foundation houses an exceptional volume of interconnected animal, carcase and sensory data, generated over 30 years in 12 countries, together with sophisticated experimental design software to enable high quality compatible data from a wide range of users. Prototype consumer grading models have been developed from Polish, French and merged European data. An updated version will be available to enable commercial grading that can deliver individual muscle eating quality segregation. The application of accurate predicted consumer meal satisfaction at individual retail pack level enables powerful product branding and, when linked to payment systems from consumer to retailer to processor to farmer, direct alignment of consumer value and industry delivery. This alignment provides a dynamic relationship that can drive decision making and continued evolution of a sustainable, responsible and profitable industry.

A new multivariate sustainability index: Milk and Milk Analogues

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Sustainable decision-making is critical in tackling global issues like climate change, resource depletion, and inequitable food distribution. The dairy industry, significant in environmental, economic, and nutritional terms, faces these challenges. This study proposed a localised sustainability model for a country's dairy sector - in this case with South Africa as an example -, emphasising the environmental impact of milk and milk analogues. The model aims to assist industry stakeholders and consumers in assessing environmental impacts of these products and making informed decisions. While FAO-approved generalised sustainability measures exist, they inadequately cater to the dairy industry or address specific national contexts. Thus, the study identified a need for a dairy-specific, country-relevant sustainability model for milk and its analogues. This model incorporates the environmental, economic, and nutritional footprints of dairy products, adaptable to diverse national conditions. Our model includes novel measures such as a nutrient indexing metric that accounts for protein quality, amino acid sufficiency, bioavailability, and population-specific nutritional needs. The model also integrates bioavailability measures, whole food risk-benefit analysis, product affordability relative to local economic profiles, and a life cycle analysis adapted to Global Warming Potential and half-life corrected CO_2 equivalent. These measures provide a detailed, country-specific view of dairy sustainability indicators, enhancing the communicability of these findings to consumers.

Barriers to adoption of technology amongst European farmers

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The agricultural sector is under increasing pressure as it tries to feed a growing population. The sector is also facing growing competition and scarcity of land, water and energy for food production. This is expected to be exacerbated by climate change. Simultaneously, agriculture contributes a third of global greenhouse gas (GHG) emissions. Digital technology plays a role in providing farmers with the opportunity to address sustainability challenges, make informed decisions and increase productivity and profitability. However, the role of technology hasn't translated into behavioural change. Thus, there is an urgent need to design targeted approaches which drives the adoption of digital technologies. Knowledge about farmers' attitudes and experiences with the use of digital technologies in agriculture is crucial for developing these targeted approaches. The aim of this study is to determine the barriers and opportunities to the adoption of technology amongst farmers in Germany, Poland, and Northern Ireland (N.I.).

This study uses data from 1039 farms across South-East Germany (805 farmers), Poland (101 farmers), and N.I. (133 farmers) collected February-October 2022 using an online survey using LimeSurvey and computer-assistant telephone interviews (CATI).

Initial investment in technology was listed as the top factor preventing the uptake of technology by 59% of German, 50% of Polish, and 48% of Northern Irish farmers. Other factors inhibiting adoption related to running costs (53% of farmers in Germany and 43% of farmers in Poland). Other factors of importance related to the compatibility of different systems (38% amongst German farmers), IT know-how (33% amongst Polish farmers), and the time required to research the new technology as well as poor broadband networks (39% and 41% for N.I. farmers). Factors listed as promoting technology adoption relate to the facilitation and quality of work (77% in Poland, 73% in Germany, and 48% in N.I.), and user-friendliness of the technology (65% in Poland, 55% in Germany, and 52% in N.I.). IT knowledge was also listed by 59% of German farmers, while the manufacture service was important for 63% of the sample, and the economic efficiency of the technology was important for 54% of N.I. farmers. Farmer and experience exchange groups were cited as the main influencing factor by 40% of German farmers, and 47% of Polish and Northern Irish farmers. However, other sources were also importance for each country. 21% of German farmers said that trade fair visits, field days, trade journals and specialist magazines were important. While 27% and 25% of Polish farmers were influenced by researchers, universities, colleges, and young people coming onto the farm. In N.I., 39% of farmers were influenced by the financial support provided by government and 26% by their local farm advisor.

Brazil Beef Quality Certification: Standardization of beef for palatability

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Brazil, one of the world's leading consumers and exporters of meat, is experiencing a growing demand for standardised meat with quality assurance. To meet this demand, the Brazil Beef Quality, a start-up supported by the São Paulo Research Foundation (FAPESP), has developed a meat classification and certification system. By implementing this grading system, Brazil Beef Quality aims to address the increasing demand for high-quality meat products while offering consumers transparent information. The certification process incorporates scientific and statistical concepts, considering the expectations of Brazilian consumers. The grading system involves analyzing approximately 15 specific carcass traits: gender, tropical breed content, dentition, hot carcass weight, fat layer, hang method, pH, Hump height, ossification, meat color, fat color, marbling, loin eye area, rib fat and ageing days. More than 58,000 carcasses were evaluated in total and each carcass received a grade and was classified with 3, 4, or 5 stars. To develop the prediction model, over 117 experiments were conducted to evaluate the effects of various carcass characteristics, hanging methods, preparation methods and aging time. The results were evaluated individually and collectively. Sensory test of untrained consumer data was used to conduct analyses for the development of a quality index that combines information from tenderness, flavor, juiciness, and overall liking scales to describe consumer satisfaction. This index was developed using canonical linear discriminant analysis. Thus, the following equation was obtained and named IQ-BBQ = 0.28 x flavor + 0.23 x tenderness + 0.36 x overall liking + 0.13 x juiciness. This classification is the result of scientific research combined with sensory analysis with 5360 consumers in 7 different states of Brazil. This initiative has the potential to significantly contribute to enhance consumer satisfaction in the Brazilian market. The prospects are to continue the research to monitor the efficiency of the algorithm and to introduce the classification system in other countries.

Consumer perception of meat and meat substitutes according to different socio-demographic factors

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This study was conducted with more than 16,000 respondents in 5 countries (Brazil, Cameroon, China, France, South Africa). It aimed at analyzing the consumption of meat and meat substitutes according to sociodemographic factors. For this, we asked for the criteria to choose food products at purchase time and for the proportion of people consuming meat substitutes and willing to consume “cultured meat”. The most important criteria when purchasing food products are the following: sensory quality (67%), price (56%), food safety (47%), origin/traceability (45%), ethics (42%), nutritional value (35%), environmental impact (33%), and then appearance (24%) and presence of a label (22%). Regardless of gender, this hierarchy is similar, although men place less importance on food safety (44% vs 50% for women, $P < 0.01$). There is also an age effect ($P < 0.01$), people over 51 years of age putting less importance on price (40% vs 52-69% than younger respondents). Respondents who rarely consume meat place price first, vegans/vegetarians place ethical and environmental concerns first, unlike meat consumers who consider sensory quality to be the most important criterion ($P < 0.01$). These results also depend on countries ($P < 0.01$): sensory quality, food safety, origin/traceability and price are more important in Brazil, China, France and then two African countries respectively. On average, 45% of respondents eat meat substitutes. Results depend also on gender (50% for women vs 39% for men), country (70% in China vs 29% in Brazil) and dietary habits, with flexitarians and vegetarians being 59%-60% to consume meat substitutes. Thirty nine percent of the respondents would be regularly willing to eat cultured meat (43% of women and 36% of men; 46% among 18-30 year-old respondents vs 33-36% for the oldest). This proportion is higher for flexitarians and vegetarians (47-49%). The French are the least ready to consume “cultured meat” (17%) vs 54% in Brazil. To conclude, perception of meat and meat substitutes depends on sociodemographic factors, mainly countries and dietary habits.

Dairy ruminants in France: are they in competition with human food?

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French dairy systems (cow, goat, ewe) are very diverse regarding the important number of different feeding systems in the country. Ruminants are often mentioned as inefficient with a low feed conversion efficiency for both protein and energy. With feeding systems mainly based on roughages, these animals also consume human edible plant materials and turn non-human edible materials into milk and meat. But for feedstuffs which can be used for human nutrition, there is thus competition between humans and animals for their use. Feedstuffs subject to such competition are referred to as ”edible” feeds (cereals, legumes, grains of maize silage). For other feedstuffs, such as roughages (grasslands, wild grass areas) and by-products from the food industry, this competition is low or non-existent; they are ”non-edible”. Around 200 feedstuffs have been characterised on their respective protein and energy edible content. The ratio between production and consumption is called conversion efficiency. Both energy and protein conversion efficiencies were evaluated for dairy systems. The feed conversion ratio is the ratio between edible animal products and total intake of plant resources. The net efficiency approach (or net feed conversion ratio) allows to better consider the ”feed-food” competition through the share of the edible part of each feed, implemented in the denominator (edible animal products / total intake of edible plant resources). The first results are that most of the protein and energy intake of dairy ruminants is not in competition with human nutrition. For instance, 89% of the total protein intake of cows and ewes, and 86% of goats is not human edible. Secondly, net protein efficiencies are respectively 1.16 for ewes, 1.12 for goats and 1.88 for cows, with variations between feeding systems for each species. This means that dairy cow systems in France turn 1 kg of edible plant proteins in feeds into 1.88 kg of edible animal proteins in foods. This underlines the ability of ruminants to convert non-human edible protein from plants into milk and meat. For energy, although the competition is also quite low, dairy systems are on average net consumers because of a low content in energy for milk and meat. The variability of the results allows us to implement technical improvements for dairy farms on this issue. When combined with other factors such as greenhouse gas emissions and land and resource use, such considerations will help to inform discussions on the future of livestock production.

Developing protein autonomy in ruminant farming: 330 farms share their expertise

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Protein autonomy of French herbivore farms is not an end in itself but a challenge for self- sufficiency, farm competitiveness and adaptation to and mitigation of climate change. In practice, farmers are implementing a combination of several agronomic and zootechnical strategies to achieve better autonomy. In 2022, the project ”Cap Protéines”, the pilot farms work package, mobilized 330 farmers and 120 advisers to demonstrate, describe and disseminate these solutions on a large scale.

Three groups of forage strategies are frequently mobilized by ruminant farmers to increase protein autonomy: grazing management (extending the grazing season, dynamic rotation), cultivation of pasture to improve quality (grass-legume and multi-species swards), and the implementation of legumes (alfalfa, clovers). In the field, these strategies are put in place in the reverse order to their theoretical classification by efficiency. Farmers start with the implementation of a simple strategy ”to try”, and then adding a succession of changes and technical adjustments related to the constraints of farms. All farms combine several strategies to gain autonomy. The transition period lasts 10 years: this is the time spent from the implementation of the first action to the achievement of a high level of autonomy.

On pilot farms, protein autonomy is on average 91% for the meat production sector (sheep and beef) and between 75 and 80% for the dairy sectors (goats, cattle, sheep). Residual dependence on imported soya is low on average: around 2-3% of needs for the suckling sector, and 8-12% for the dairy cattle and goat sectors. Across all farming sectors, those farms achieve protein autonomy, so it can be an accessible goal.

Digestibility of ingredients derived from food by-products (insect, single-cell) in Asian seabass

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The transformation of food by-product could become a more sustainable source of ingredients for aquaculture but currently only little is known about their digestibility for marine species. This study gathers the learnings of two trials conducted on 2700 (48.2g) and 840 (591.3g) Asian seabass (*Lates calcarifer*) grown in large-scale reticular activation system (RAS) and fed with experimental diets containing 30% of two types of black soldier fly meal (BSFM), and two types of single cell protein meal (SCP). Diets were produced with a twin-screw extruder and 0.1% Yttrium oxide was added to estimate digestibility. In small and large fish trials, thermal-unit growth coefficient (TGC), feed conversion rate (FCR) and nutrient retention efficiency were measured. Fish faeces were collected in each tank, diet and ingredient digestibility were estimated for protein, energy and amino acids. TGC of fish fed with BSFM and SPC was never significantly lower than TGC of fish fed with the control diet ($P < 0.05$). FCR of fish fed with BSFM (1.05) was higher ($P < 0.05$) than the FCR of fish fed with the control diet. Apparent digestibility coefficients (ADC) of BSFM were high for protein (90.2-91.9), energy (87.7-89.9) while ADC of SCP were moderate. The impact of extrusion parameters and water temperature on digestibility is discussed, together with the role these new ingredients could play in future Asian seabass feed formulations.

Effect of inoculated grass silage on rumen fermentation and methane emission in dairy cows

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The study aimed to analyze the effect of feeding dairy cows with a diet containing grass silage preserved with a commercial inoculant based on propionic (*Propionibacterium acidipropionici*, *Propionibacterium thoeni*) and lactate acid bacteria (*Lactobacillus buchnerii*, *Lactobacillus plantarum*). The research hypothesis assumed that the inoculant supplemented with grass silage will improve the fermentation process of the ensiled material and, finally, as a component of TMR (23.5% of total components) will stimulate milk production and decrease methane emission. In the two-month experiment, 20 dairy cows were randomly selected for the control (10) and experimental (10) groups. The results obtained confirmed the hypothesis demonstrating the positive impact of commercial inoculant on the ensiling process of grass. The inoculant increased the nutritional value (mainly total protein content) and aerobic stability of the ensiled material. Moreover, the grass silage with inoculant increased daily milk production (by 5%), improved milk composition (higher percentage of protein, lactose, and urea), and decreased methane emission (by 7%).

Effect of the Rumitech in a high-forage diet on feces methane and biogas production in dairy cows

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The effect of the Rumitech essential oil blend on methane and biogas production from dairy cows faeces during fermentation was tested. Three subsequent series (control and experimental) were carried out on dairy cows fed total mixed ration (TMR) rich in brewer's cereals and beet pulp equalling 20% DM of the total diet. Cows from the experimental group received 20 g/cow/day Rumitech essential oil blend. Based on the analysis of the results, the addition of Rumitech did not affect the average concentration of methane in biogas which was about 60% in the control and experimental groups. However, the study shows that Rumitech can increase the production of methane

and biogas from dairy cow faeces. It can be concluded that in the experimental groups, approximately 15.2% and 14.4% on a fresh weight basis and 11.7% and 10.9% on a dry weight basis more methane and biogas were generated compared to the control group. Similarly, high yields of methane and biogas were recorded when taking into account the content of dry organic matter in the faeces - on average about 13.1% and 12.3%, respectively. These are significant values also because the dry organic matter content in the experimental samples was more than 1.5% lower than in the control. Therefore, it can be assumed that the use of Rumitech in cow nutrition improved dietary digestibility which increased the efficiency of the use of faeces organic matter for biogas production.
Project CCCfarming National Centre for Research and Development (SUSAN/II/CCCFARMING/03/2021).

Feed, faeces and frass: getting over issues related to digestibility assessment in black soldier fly larvae

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Black soldier fly larvae (BSFL; *Hermetia illucens*) are one of the most promising species in the field of insects as food and feed. They are rich in proteins and lipids, can feed on a wide range of organic substrates, and have a high feed conversion efficiency. However, the mechanisms underlying feed conversion in this species remain poorly understood. BSFL live in their feeding substrate where non-ingested feed and faeces mix and form a material called 'frass.' Thus, digestibility studies are particularly hindered as ingesta can not be quantified, and it is impossible to collect pure faeces. The present study presents and evaluates two approaches to tackle these issues. Our first approach relies on estimated digestibility (ED), calculated on distributed feed and frass weight. This assumes that, for the same feeding time and amount of feed, working with increasing larval densities would ultimately result in an asymptote of ED, indicating the maximal digestible fraction of the tested feeding substrate. The second approach, approximate digestibility (AD), is based on a usual method to study digestibility in insects or in conventional livestock species and requires the use of an indigestible marker (chromic oxide) incorporated into the tested feeding substrate. Results of these two approaches are compared for three feeding substrates (chicken feed, discarded potatoes, and corn gluten feed). Strengths and weaknesses of both methods are also discussed. This work provides valuable insight into the feed efficiency of BSFL and lays the groundwork for diet formulation based on digestible instead of crude nutrient contents for this species.

Greenhouse gas emission from livestock production in Poland and its impact on climate change – discussion of the farmers awareness survey

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The aim of the survey was to present information on the awareness of Polish farmers in terms of using available technologies to limit the negative impact of animal production on the environment. The survey was carried out on 44 farms in Greater Poland. Each one consisted of 87 open and closed questions which were divided into the following groups: farm characteristics, farmers experience, knowledge of measures to reduce greenhouse gas emissions, agricultural practices, knowledge of techniques to reduce ammonia emissions, support for environmental protection, general knowledge about greenhouse gas and ammonia. Based on the conducted surveys and interviews, it can be concluded that the awareness of Polish farmers about the risks arising from the above-mentioned phenomena is common but still insufficient. Most of the respondents knew about the existence of the phenomena

presented, but did not know the consequences of their occurrence and did not apply solutions aimed at limiting their negative impact on the external environment. The main reason for this situation is the relatively high costs of introducing changes. Project CCCfarming National Centre for Research and Development (SUSAN/II/CCCFARMING/03/2021)

Growth of black belly ewe lambs ingesting non-conventional feeds in the form of complete feed blocks

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Introduction

The co-products of crops and agro-industry are biomasses that can be used for animal feed. This reduces the need for land for animal feed and the associated carbon footprint of meat production (Archimède et al., 2018). Various constraints limit the application of this strategy, including seasonal availability, nutritional imbalances and practicality of use. The development of low-tech technologies on the farm, including complete feed blocks, is a solution that should be evaluated considering the socio-economic contexts of the territories and countries (Barde et al., 2022). The objective of this study is to compare the feed value of 4 complete feed blocks composed of crop co-products and agro-industry relative to a conventional feed based on hay grass and concentrate.

Materiel and methods

A fattening trial involving 50 ewes lambs Black belly for 3 months was conducted. Five diets were evaluated: Diet 1, control consisting of a 2-month-old tropical grass hay distributed *ad libitum* and 300 g of concentrate; 2) Diet 2, sorghum straw/molasses/cottonseed; 3) Diet 3, sorghum straw/sorghum grain/cottonseed ration; 4) Diet 4, sorghum straw/sorghum grain/*Leucaena leucocephala*; 5) Diet 5, sorghum straw/molasses/*Leucaena leucocephala*. The diets were formulated to be isoenergetic and isoproteic. The growth potential of Black belly ewe lambs recorded at INRAE is 150 g/day.

Results and discussion

The main results are summarized in the table below.

	Intake (g/d)	Daily growth (g/d)
Control diet	955.5[a]	91[a]
Diet 1	1219.6[b]	116[a]
Diet 2	1233.9[b]	110[a]
Diet 3	1223.8[b]	79[b]
Diet 4	1167.1[b]	66[b]
SEM	80.42	10.2
P	< 0.05	< 0.05

The daily growth rates recorded with the control diet are lower than the growth potential of Black belly ewe lambs. This result is attributable to the poor quality of the hay and its low intake. The highest growths, which represented about 70% of the growth potential of the ewe lambs, were recorded with rations 2 and 3 containing cottonseed. The lowest growth rates, which were about 45% of the ewe lambs' growth potential, were recorded with diets containing *Leucaena leucocephala*. The differences recorded between the two groups of feed blocks are probably due to the insufficient protein intake with *Leucaena leucocephala* compared to cottonseed.

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Herd structure and nutrient requirements in livestock across the World: A modeling approach

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Livestock play a vital role in global food systems and their production contributes significantly towards a sustainable future. Understanding the nutrient needs of livestock and the availability of feed resources is critical for developing sustainable and efficient livestock production systems. Herd dynamics influences the nutrient requirements of livestock (e.g., age, gender, and reproductive status), making it crucial to comprehend. Therefore, the aim of the study is to develop a model that illustrates the herd structure and nutrient needs of different livestock around the world.

The model will use a quantitative approach to understand the dynamics of herd structure and nutrient needs, using a variety of data sources from government statistics to scientific articles. Considering a broad range of variables, like an animal's biological limitations, performance parameters, production systems and more, the simulation model will be created using R-programming. The model will form part of the publicly available PLANET Food system explorer platform where the herd structure will be displayed as a Sankey diagram and nutrient requirements given in table format.

As global demand for animal products continues to rise, understanding the nutrient needs of livestock and developing sustainable livestock production practices will become increasingly important. Despite limitations in assumptions, data reliability, input data limitations, and model complexity, the model will still offer a valuable and rigorous approach to explore herd structure and livestock nutrient requirements. The model will create the foundation for future research including investigating total supply and demand of nutrients to livestock, identifying nutrient short falls and creating a tool for the exploration of different scenarios. Decision makers in the agricultural sector will be able to use this knowledge to inform policies and regulations related to livestock production, resource management and strategic future planning.

Impact of the long-cut chaff technology on milk yield and methane emission in dairy cows

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Long-cut-length chaff is a corn silage chaff technology in which the material is cut into 26-30 mm long pieces. This technology enables the mixing of corn silage in total mixed ration (TMR) as a structural feed component. Our hypothesis states that using long-cut-length chaff in high-productive dairy cows' nutrition increases milk yield, improves milk composition, and decreases methane emission. In the two-month experiment, 30 dairy cows were randomly selected for the control group (15) fed TMR with wheat straw (0.6 kg per day) and the experimental group (15) fed TMR with long-cut length corn silage chaff (+2 kg). The dairy cows were milked with the milking robots Lely Astronaut A5, Lely Industries, Maassluis, the Netherlands. An increase in milk yield was observed (+1.4 kg milk per day). A decrease in milk fat and urea concentration as well as methane emission was detected (by 5%, 17%, and 9%, respectively).

Insects as innovation parts in a circular economy: RLP InsectProEco – From regional Black Soldier Fly Larvae (BSFL) rearing to applications as feed and fertilizer

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Black soldier fly larvae (BSFL) rearing is, due to their efficiency in converting organic matter streams into high-value nutrients and raw materials, a promising component towards a more resource-efficient bio-economy.

The aim of the InsectProEco project was to demonstrate a "vision for insect farming" for a circular system which included testing of by-products and residues (grape pomace, vegetables, etc.) for their suitability for BSFL rearing. In addition, the potential of the insects as protein-rich "livestock feed" and possible animal welfare promoter was examined. Finally, the "insect frass" produced during larval production, was tested for its suitability as an organic fertiliser. The main results are the following:

The Black soldier fly larvae have special requirements for nutrients at certain life stages (e.g. 16% crude protein in fattening). Classical feed optimization delivers similar performance (prepupal dry matter weight: Binger diet=77mg/larvae; chicken feed=80mg/larvae) and represents a bioeconomic alternative to high-quality BSFL feeds (broiler fattening feeds) used so far.

In broiler feeding trials we found out that soy meal can be substituted by up to 20% with BSFL protein, without significant performance losses in broiler production or any negative effects on nutrient digestibility (CP, EE, GE). The feeding of 5% live larvae of the BSFL, increased the body weights ($P > 0.05$) and at the same time decreased the feed intake of the basic ration in aged broilers. In the potato, tomato and cauliflower crops, insect frass fertilizer has been compared with other organic fertilizers, achieved at least similar yields, and harvest qualities. Frass as a fertilizer is thus a good alternative to other organic commercial ones.

In summary, insects such as the BSFL are well suited as an innovation part in a resource-efficient circular economy (insect-livestock-plants) and thus contribute to an increase in regional value chains for consumers.

Label-free biomarkers of post-mortem aging and salt processing in fish to improve processes and food properties

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Predicting the metabolic shifts of fish fillets induced by post-mortem changes prior to processing such as salting is crucial in maximizing food performance. This study aims to better understand the characteristics of trout river fish muscle, in salted and non-salted fillets, over post-mortem aging. To do so, a comprehensive multi-scale analysis was performed to assess the structural and biochemical properties of fish fillets over 15 days. Conventional biochemical analyses revealed little modifications of pH, protein denaturation, Aw, colour, and protein solubility, over the post-mortem time, suggesting that storage conditions were appropriate. This also showed that conventional approaches are perhaps not sensitive enough in detecting precise variations. HPLC analysis of Na2+ and Cl- in muscles showed the post-mortem time was responsible for a much quicker absorption of the salt, and caused a high variability in final salt concentration over time. In fact, salt concentrations in aged samples were 2 to 4 times higher than at the beginning of the post-mortem time. Additionally, we took advantage of label-free spectroscopy (FTIR) to detect metabolic shifts in tissues caused by the post-mortem time. Spectral fingerprints were processed with machine learning to predict with high confidence the biomarkers of post-mortem aging. Our model can accurately predict the post-mortem time from label-free spectra of the fillet muscle. We envision that better food performance can be achieved by adapting processes accordingly to the structural and biochemical characteristics of the fillet. Precise salting adapted to each fish condition would also reduce the environmental impacts due to the presence of salt in the industrial effluents.

Optim'Al: an online tool for protein self-sufficiency of dairy cows rations

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Optim'Al is an online tool that optimises dairy cow rations in terms of economy or protein autonomy, or both, for dairy cows. Optim'Al is based on linear programming and incorporates the principles of the INRAE 2018 system, where feed values and animal requirements depend on the characteristics of the ration. Various simulations, using an iterative calculation process, allow an optimised ration to be found. For the calculation of "protein self-sufficient" rations, the protein-dependency value of feeds, which is a function of their supply range, can be used as an optimisation function instead of price. Alternatively, the "economy" and "protein self- sufficiency" approaches can be combined in a multi-objective function (for example 50% economy and 50% protein self-sufficiency). After optimisation, several other operations can be performed, such as sensitivity analysis of the optimised solutions, which allows the farmer to reflect on the value of feeds and purchasing strategies (shadow prices of feeds, sensitivity of the ration to the price context). Another post-optimisation calculation takes into account the non-linear responses of the animals and provides a technical and economic diagnosis based on the feed margin allowed by the rations and their environmental value.

Overview of the use of plant by-products from food industry in ruminants feeding

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At a time when feed prices are soaring and sustainability is the watchword, it is time to look for solutions to save resources, especially food. Animal feed represents the most significant cost on livestock farms, accounting for 60% of the total expenses. Therefore, it presents a viable opportunity for enhancing farm self-sufficiency and/or reducing costs. By-products from the agri-food industry, particularly fruits, vegetables and remains from plant production, appear to be a promising way of feeding ruminants in the region, especially since such a sector is likely to be part of a circular economy approach, aligning with modern sustainability goals. These plant by-products hold substantial potential for use in livestock rations and might, thus, be considered suitable for feeding to ruminants because plant by-products are a source of fibre, protein and energy. They are also a good source of micro- and macronutrients, and often of polyphenols. These elements are reputed to have antioxidant properties, and so act as barriers against cell ageing and the onset of diseases. Another interesting aspect is the potential enhancement of immunity derived from consuming plant by-products. In order to include these products in ruminants' diets, analyses must be carried out to determine the nutritional values and to detect potential Anti-Nutritional Factors. Once these two types of analysis and comparison with other feeds have been carried out, plant by-products might be used, especially if they are cost-effective (because many by-products have a low dry matter content, making transport costly for the quantity transported). Incorporating fruit and vegetable by-products from the food industry into ruminant feed has great potential from environmental, economic and nutritional points of view. The use of these materials provides greater autonomy and reduces farmers' dependence on feed merchants and the price of raw materials. It also reduces the environmental impact by cutting water consumption and the carbon footprint of livestock feed. However, it should be emphasised that these are alternatives and not a complete replacement for feeds currently on the market.

Perception of meat production and consumption in different parts of the World

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The production and consumption of meat are regularly discussed in the public and scientific spheres. A special issue of the scientific journal Meat Science provided objective data concerning perception of meat production and consumption in different parts of the World. Among the 24 papers in this issue, common motives and barriers to consumer meat were identified in all countries. An affordable price and eating quality are the main drivers to consume meat. The pleasure of eating meat, culinary culture, cultural aspects and traditions are also major drivers of meat consumption especially in some Southern countries in relationship with the personality and attitudes of people. On the opposite, safety but also health, animal welfare and environmental issues are among the factors which explain the decrease in meat consumption. Some papers highlighted different regional consumer attitudes. For instance, whereas debates around health, environment and welfare issues are quite strong in the USA, there is a sustained demand for meat in this country, despite success of meat alternatives for mostly young, highly-educated and rich consumers. In China, increasing income is the main factor explaining meat consumption, while the biggest concern is safety. Culinary culture, cultural aspects and traditions are important motives in Uruguay and Mexico in interaction with product variety and/or regional preferences. Social factors such as meat as a marker of social identity and part of socialization may be important factors such as in Ghana. Based on this complexity, a compromise has sometimes to be found for instance between sensory traits, price and ethical issues related to some livestock practices rejected by consumers. Whereas plant-based products are already commercialized, ”cultured meat” technology is not so well advanced and its production process and composition are not publicly available making it impossible to check product characteristics and sustainability. However, the reactions of consumers are dominated by affective, rather than by cognitive factors. To sum up, while the current market is disrupted, producers of meat and of meat substitutes must adapt their commercial strategies according to these general trends in meat consumption, nuanced by regional specificities. For sure, they should be more transparent.

Residual biomass can be converted to edible ingredients, but with limited environmental benefits

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This study documents the environmental performance of” waste-to-nutrition” strategies and assess their adequation with the transition towards sustainable food systems. These strategies consist in implementing technological pathways to transform unused or underused organic streams into food and feed commodities, to enhance the decoupling of food production from the demand on arable lands, among other benefits. Yet, it remains unclear to which extent the implementation of these pathways would generate environmental benefits, and which trade-offs may arise. Through a combination of a structured literature review, harmonized life cycle inventory framework and global sensitivity analysis, this work unravels the conditions under which the deployment of novel food and feed formulation technologies can mitigate climate change, eutrophication, land and water use environmental impacts.

To this end, we propose an integrated life cycle assessment (LCA) model to explore the forecasted technological performance of 15 emerging waste-to-nutrition pathways evolving within different future food, feed, fertilizer and energy market contexts. Performed on eleven residual streams, the simulations indicate that the direct reuse of edible streams in livestock feed formulations tends to always be better than any attempt to convert these into novel feed ingredients. We also found that regardless of the future performances of insect farming or mycoprotein production, these need to substitute animal-based proteins in human diets to effectively induce net environmental benefits. Moreover, the analysis shows that second generation microbial protein bioproduction only yields net environmental benefits if global impacts of conventional feed ingredients keep exacerbating (e.g. increased arable land expansion rates). Overall, the mitigation potential of novel food and feed technologies is largely conditioned by (i) the availability of dedicated environmentally-efficient power production capacities (e.g. wind, solar) and (ii) which commodities will actually be substituted (e.g. meat, protein crop, etc.).

The LCA model also allows to quantitatively document the sets of conditions (in terms of yields, efficiencies, etc.) required by waste-to-nutrition pathways to outperform conventional valorization options, and can therefore directly feed technology developers (e.g. towards process eco-design), as well as bioresource suppliers and funding agencies with tailored environmental data for decision-making.

Stability of faba bean protein nanoemulsions

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A reliable and economically feasible method to form a nanoemulsion from faba bean protein isolate (FBPI) and canola oil would make it possible not only to increase the nutritional content of processed foods, but to provide a vehicle for the delivery of nutraceuticals and to improve the shelf life of many foods, such as ready to consume baked goods. The formation of a nanoemulsion of canola oil and FBPI was sought with the aim of improving FBPI solubility and emulsion stability in order to more efficiently use homogenized FBPI at high pressure as an emulsifier with food, beverage, pharmaceutical and cosmetic applications. For this reason, the current study investigated the potential of FBPI to form nanoemulsions using high-pressure homogenization (20,000 psi) to act as a natural emulsifier in oil-in-water emulsions using canola oil. Nanoemulsions were prepared by high-pressure homogenization of 5w% oil phase and 95w%

aqueous phase at pH 2. The effect of homogenization parameters on physico-chemical properties, such as particle size and stability of FBPI nanoemulsions, were evaluated in order to identify conditions for optimal properties. To that end, the effects of nanoemulsion particle sizes (d32= 0.395µm) zeta-potential (+30 ± 1.46 mV), accelerated storage stability, in vitro digestion (64.54 ± 3.52% of the lipid was digested), confocal microscopy and interfacial tension (11.8 ± 0.85 mN/m) were investigated as well. The formation of a nanoemulsion from canola oil and FBPI without adjuncts was successfully achieved. These results have important applications for the production of functional foods and beverages containing faba bean protein-based ingredients. Reduced manufacturing costs for a nanoemulsion made from canola oil and FBPI using a relatively simple procedure makes the process developed a financially attractive means to take advantage of the many interesting and useful properties of this promising emulsifier in food production.

The European Food Forum

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The European Food Forum (EFF) is an independent, politically-led, non-partisan multi-stakeholder prominent organization led and governed by elected Members of the European Parliament (MEPs) dedicated to promoting open dialogue on sustainable food systems, fostering innovation in agriculture, and advancing the dialogue surrounding global food challenges. The European Food Forum was created at the end of 2019 by 5 MEPs and now counts 37 MEPs (from 15 EU Member States and all the 7 European Parliament Political Groups), 28 Business Members, 15 Public Institutions and Civil Society Members, 2 Special Members (the Committee of the Regions and EIT Food).

With the EFF's extensive number of multi-stakeholders debates that involved more than 300 speakers since its constitution, the EFF is a growing network of experts, policymakers, and industry leaders across Europe and worldwide, committed to driving policy debates for sustainable food systems. The European Food Forum does not itself take positions on specific policy issues but supports multi-stakeholders open dialogues.

For more info: https://www.europeanfoodforum.eu

The INTAQT project: tools to assess and authenticate poultry, beef and dairy products

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Stakeholders of the agri-food chain lack reliable and robust information to meet consumer expectations in relation to the multiple aspects of intrinsic quality of livestock products from various European livestock systems. The INTAQT project aims to assess the relationships between animal production systems and product quality in order to improve husbandry practices complying with high quality animal products and sustainability. This is the "One Quality" concept. The project focuses on chicken meat, beef, and dairy products and applies a multi-actor participatory approach which involves all stakeholders of the agri-food chain. The challenges are to:

i) develop comprehensive models to quantify the impact of livestock systems on product safety, nutritional value and sensory attributes, ii) propose, together with the agri-food chain stakeholders, fast, easy and cost-effective analytical tools to predict the intrinsic quality of livestock products and authenticate the associated livestock systems, iii) propose together with the same stakeholders multi-criteria scoring tools for the intrinsic quality of products, and iv) promote farming practices which can allow the production of safe, healthy and tasty animal products while ensuring a decent income to farmers and respecting animal welfare and the environment. The INTAQT project (EU H2020 No 101000250 - https://h2020-intaqt.eu/) started on June 1st 2021 for5 years.

The OR ROUGE brand: A virtuous association between sustainable, agro-ecological farming and the production of top-quality meat

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Climate change and environmental degradation are an existential threat for Europe and the rest of the world. Faced with increasing economic and climatic hazards, and with a growing general awareness, farming systems need to be rethought to make them more sustainable. Farming practices have a significant impact on the evolution of landscapes and the biodiversity they harbour. At the same time, the French have a strong attachment to livestock farming and animal products, which is rooted in their culinary culture: 89% of them say they like meat and 63% believe that a meal is more convivial with meat. The sensory quality of meat is essential to satisfy consumers and encourage them to buy it again. This is why the production of meat with a desirable taste is a key objective for the meat industry. With this in mind, and the awareness that ecological and environmental issues go beyond the farm gate, Plainemaison Aquitaine Beauvallet wanted to develop a beef brand that would effectively meet current and future consumer expectations, particularly in regards to the environmental and sensory qualities of meat. This is how the OR ROUGE brand was established in 2017, enabling the company to showcase premium meat produced in an area of high natural value by partner farms practising a diversity of crop rotation, extensivity of practices and developing agro-ecological infrastructures. In addition to their impact on the quality of the landscape, the evolution of farms towards agro-ecological practices helps to reduce their impact on the environment and thus limit their influence on climate change. Today, these agricultural areas are essentially mixed farming-livestock areas, corresponding to relatively homogeneous agricultural systems linked to specific terroirs, practices, animal breeds and products, which are generally promoted through official quality labels. This industry-wide approach is generating and will continue to generate more added value for the entire supply chain, and is helping to ensure the long-term future of cattle farming. These added values have been formalized, are the subject of several specific supply contracts, and they have been paid to farmers since 2018.

The potential of multispecies grassland swards for climate care cattle farming in the EU

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Cattle are a major source of anthropogenic greenhouse gases, particularly methane (CH_4), nitrous oxide (N_2O), and indirectly ammonia nitrogen (NH_3-N). Monoculture swards, such as ryegrass and Italian ryegrass used in cattle nutrition, require high fertilizer inputs. This leads to a surplus of N supply contributing to water pollution and increased GHG emissions. Therefore, green environmental approaches demand sustainable alternative feeding practices for cattle production systems. Multi-species grassland swards (grass + legumes or legumes + herbs) could be a sustainable alternative to monocultures in cattle nutrition due to their low nitrogen input, excellent herbage yield, and polyphenolic compounds (tannins, formononetin, biochanin A, quercetin, and polyphenol oxidase). The study was conducted to explore the effects of a multispecies grassland sward composed of perennial ryegrass (PR), red clover (RC), chicory (C), and plantain (P) on in vitro ruminal fermentation and dry matter degradability (IVDMD). The experimental groups were PR+RC with fertilizer (control), PR+RC, C+RC, and P+RC without fertilizers. The experimental substrates were collected from the first cuts in 2021 and 2022 and mixed within the years in equal proportions in each group. The Hohenheim in vitro technique results illustrated that P+RC treatment decreased CH_4 production compared to the control. The ruminal NH_3-N, acetate, and butyrate concentrations, the acetate-propionate ratio, and the total protozoal count were reduced in P+RC treatment. Propionate concentration increased in the experimental group (P+RC). The results show that the P+RC group without fertilizers can be utilized as a sustainable alternative feeding source for climate-friendly cattle production and thus fulfil the CCC Farming EU project's aims. Further in vivo studies are recommended to explore the full potential of P+RC treatment.
Project CCCfarming National Centre for Research and Development (SUSAN/II/CCCFARMING/03/2021).

Tools to optimise the carbon footprint of milk production

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It is estimated that about 14% of the total anthropogenic greenhouse gas (GHG) originates from global livestock production. Dairy farming is responsible for approximately 30% of these emissions.

Dairy herd improvement (DHI) testing, meaning monthly collection and analysis of milk samples from individual cows, is broadly used for herd health, feeding, and management purposes around the globe. The objective of this study is to investigate the effect of DHI on GHG emission of dairy farms.

Regular DHI results from Denmark (n = 193,321) and Thuringia, Germany, (n = 399,428) were available for data analysis.

Mastitis is known to impair the performance of dairy cows and milk somatic cell count is used as a proxy for detection of (subclinical) mastitis. We found that the daily milk production of cows with 250,000 to 1,000,000 cells/mL (15% of test day results) was 3 kg and of those with > 1,000,000 cells/mL (5% of test day results) was 6 kg below the production of cows with < 250,000 cells/mL. These losses, in turn, translate into considerable GHG emissions, which were estimated to be 75 t of CO_2 and 78 t of CH_4 per day in Denmark alone. Such milk losses also lead to an increased GHG emission per kg of milk produced. The risk for having ketosis, a metabolic disorder in high-yielding dairy cows, can be estimated by determining milk beta-hydroxybutyrate and evident differences in milk yield between low (70% of test days) and high risk (30% of test days) cows were seen. Moreover, milk urea results provide highly valuable information on the protein content in feed and about 20% of test day results had elevated urea results indicating an oversupply of dietary protein. Milk fatty acid profiles can be used as another indicator to evaluate and optimise dairy cow feeding.

In conclusion, our findings revealed that there is still potential to optimise productivity of cows and GHG emission per kg milk produced with respect to mastitis, ketosis and feeding. In this context, DHI testing programmes represent a practical and inexpensive tool for dairy farmers to manage and optimise herd health and feeding and thus productivity of their cows. This, in turn, is an essential component to achieve low GHG emission per kg of milk produced.

Two examples of eK-books for knowledge transfer of research results in the food domain

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The role of science in the upcoming societal transitions will be critical but the diffusion of research results via publications, reports, etc., to a large audience is generally inefficient. It suffers from the difference in background knowledge and goals between the source (e.g. research lab) and the recipient (e.g. industry, NGO, government). These barriers apply to the food sector for which a major problem is the difficulty to encode knowledge as symbols (Kansou et al., 2022). The encoded knowledge has higher degree of understandability and is more readily shared than tacit (not encoded) knowledge. With eK-book (electronic-knowledge book) (Ermine, 2000; Ndiaye et al., 2014) the knowledge is supposed to be encoded as diagrams (here Concept maps) and linked to contextual information. An eK-book takes the form of a hypermedia web-app which contains interlinked resources (documents, schema, images, movies, etc.) to favour the assimilation of knowledge by external users.

This poster presents two eK-books built to favour the use of research works in the context of the food industry or education. The first eK-book is MESTRAL (Suciu et al., 2020) for education in food engineering, with 15 modules, ˜150 hrs of teaching and a broad range of real systems, from a single unit operation (e.g. frying a banana) to a logistic chain (e.g. ham cold chain). Each module conveys information on a food product or a food process, and includes a simulator based on a published scientific model. The second eK-book is PROFILap for transfer research works about use of functional proteins in the dairy industry. This eK-book covers 6 PhD reports and focuses on the results most useful for developing technologies with fractal aggregates. PRORILap includes 58 Cmaps, 31 articles, 3 summarizing schemas, 2 simulators, to convey the important messages.

This communication aims at promoting knowledge transfer between and within academia, industry and other stakeholders, and at opening prospects for synergistic efforts that will allow the food community to face the oncoming challenges.

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