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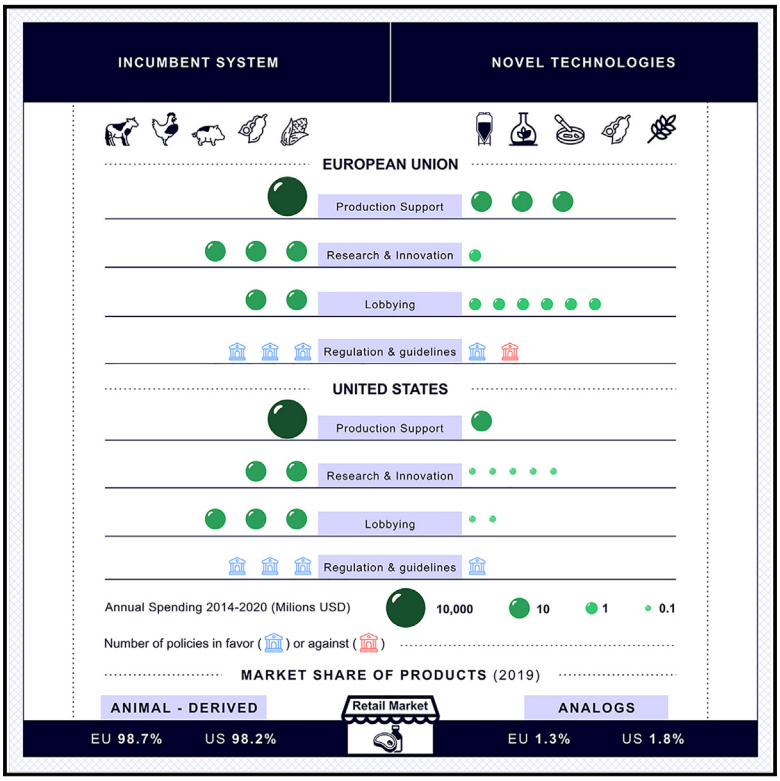
Public policies and vested interests preserve the animal farming status quo at the expense of animal product analogs

Graphical abstract



Highlights

- Animal farming receives most of the public financial support for food producers
- Animal product analogs are spearheaded by a few private sector companies
- The livestock sector resists a food system transformation through instrumental power
- Governments largely ignore the climate-mitigation potential of animal product analogs

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In brief

Despite the need to reduce society's reliance on animal-derived foods, the animal farming system is still heavily supported by public policies, public finances, and dietary guidelines, both in the United States and the European Union. Powerful vested interests exert their political influence to maintain the status quo. As a result, the climate-mitigation potential of novel technologies associated with animal product analogs is largely ignored. A significant policy shift is required to reduce the food system impact on climate, land use, and biodiversity.

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Public policies and vested interests preserve the animal farming status quo at the expense of animal product analogs

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SCIENCE FOR SOCIETY Livestock production, including animal rearing and feed production, has large environmental impacts. A shift in dietary habits, particularly a reduction in animal product consumption in affluent countries, could mitigate these impacts. Technological innovations (i.e., precision fermentation, animal cell cultivation) are producing alternatives to animal-source products.

Public funding for the novel technologies is smaller than that for animal products by factors of 1,200 in the EU and 800 in the US. Compared to the animal product sector, the spending by trade and non-profit organizations in lobbying activities for the innovation sector is smaller by factors of 3 (EU) and 190 (US).

Research to improve animal product analogs is led by private companies and has only recently been supported by public funds. A shift in food policy is required to improve technologies to produce sustainable alternatives to animal-source products and reduce the environmental impact of the food system.

SUMMARY

A transformation of the food system that heavily relies on animal-derived foods is required to reduce its impact on climate, deforestation, and biodiversity. This challenge demands an understanding of the policies and vested interests enabling or hindering progress toward sustainable production systems. We applied the multilevel perspective framework to evaluate the incumbent sociotechnical regime—animal farming—and the niche innovations producing animal product analogs. We conducted a comparative analysis of the United States and European Union to assess possible trajectories of food system transition. Our findings reveal that, although in recent years both governments have invested in niche innovations and have started to modify regulations, they mostly preserved the status quo of animal-based production and consumption. Despite the urgency to increase food system sustainability, policies failed to address the environmental impacts of animal-based technologies. Powerful vested interests exerted their political influence to maintain the system unchanged and to obstruct competition created by technological innovations.

INTRODUCTION

A transformation of the food system is required to reduce its impact on climate, deforestation, and biodiversity. Greenhouse gas (GHG) emissions of the food system, especially livestock production, which is the largest emitter of methane of agricultural origin,[1] must be greatly reduced to avoid the most extreme impacts of climate change.[2] The high warming potential of methane and its short atmospheric lifetime[1] make the reduction of methane emissions an effective climate action with immediate benefits. Livestock production is also the main direct cause of tropical deforestation,[3] mainly due to pasture expansion but also feed crop production, with major impacts on carbon emissions and biodiversity.

Diets in affluent countries are rich in animal-derived products. The growing demand for animal products associated with higher incomes in emerging economies poses an additional challenge for the environmental sustainability of the global food system. Numerous studies have demonstrated that dietary changes hold great potential to reduce humanity's ecological footprint,

especially a reduction in red meat consumption.[2,4–6] Beliefs that meat is necessary to maintain good health and appreciation for its taste are important motives for consumption of animal meat.[7] In the past decade, substantial investments have gone into developing a new generation of animal-derived food analogs, such as meat, milk, and dairy products derived from plants, biomass and precision fermentation, and cell cultivation. Technological innovation enables the manufacture of novel foods with flavor, textural, aesthetic, and nutritional qualities comparable to those of animal products, likely contributing to lowering the barriers for reducing consumption of animal-source products. A niche market has developed that is attracting the interest of the big food industry, adding legitimacy and resources to these niches.

Products derived from plants and microbial fermentation such as veggie patties and soy milk have been on the European and United States markets for about four decades.[8,9] They are mostly made from familiar ingredients (soy and peas) using well-established processes (fermentation and extrusion). Although their sensory qualities have improved in recent years, many products still require optimization to compete with animal products. While the health, environmental, and social impacts of these novel technologies have not yet been thoroughly assessed, plant-based animal analogs and microbial-derived proteins represent promising low-emission alternatives to animal products because they avoid carbon emissions from land conversion and methane emissions from ruminants.[10,11] Cultivated (or cultured) meat is grown from animal cells in bioreactors—a more energy-intensive process—and incorporated as a flavor- and texture-enhancing ingredient or used to construct whole tissues. Most of its sensory and nutritional characteristics are still unknown. Commercially available only in Singapore (as of 2023), with more companies approaching the market, it still faces technological, scale, and cost challenges to reach competitive production and become a feasible and sustainable alternative. Although cultured meat processes may require less land than animal farming and have a smaller global warming potential than beef,[12] there is large uncertainty regarding its climate-change impact due to its high energy demand.[12]

The objective of this study is to analyze the policies that shape or hinder a transition from an exclusive reliance on animal-based products to a greater consumption of more sustainable alternatives. While a growing number of studies are demonstrating the need to decarbonize the food system and are investigating novel technologies and consumer behaviors, an assessment of interactions between policies and actors generating barriers to and drivers of system change, and adoption of novel technologies, is lacking. In a global context of wider adoption of western-style diets, a systemic analysis to identify pathways toward more sustainable food production and consumption is needed.

The multilevel perspective to sociotechnical transition[13,14] identifies three analytical elements: (1) the incumbent sociotechnical system (animal-based farming, including animal raising and feed production; denoted as INC henceforth); (2) the niche innovations (novel alternatives to animal products; denoted as NOV henceforth); and (3) exogenous developments in the broader policy and socioeconomic landscape. Animal farming is regulated by policies and anchored in an established production system with institutionalized competencies and a highly developed infrastructure. This system has been shaped for decades by public institutions, industry, non-governmental organizations, and consumers. The alternatives to animal foods are the product of technological innovations, experiencing growing consumer interest and attracting an expanding pool of stakeholders. They are often presented as a low-carbon solution to animal farming. These niche innovations likely require new policies and financial incentives to be scaled up.

The policy and socioeconomic landscape, which forms the broader stage where the transition takes place, influences niche and incumbent system dynamics.[14] Sources of pressure that could accelerate the transition may be found in new social norms and values around animal welfare, attention toward diet-related diseases, awareness of the environmental impacts of the food system and its contribution to the climate and biodiversity crises, and the growing "eco-anxiety" and concerns about the future among young generations. A destabilizing role could also be played by critical events bringing to the forefront, for example, the interconnectedness of animal production systems, habitat loss, and zoonotic diseases.

This study is based on a comparative analysis between the European Union (EU) and the United States (US). These regions are characterized by: high levels of consumption of animal-derived products per capita; large meat and dairy production volumes; policies strongly supporting agriculture; comparable total support for agriculture relative to GDP and the size of the sector[15]; institutionalized innovation support; differences in science and technology performances[16]; and historically divergent consumer and environmental policies.[17] Through a comparative analysis, we aim at better understanding the influence of policies, technological innovation, and lobbying by trade and non-profit organizations on the food system transition and consumer adoption of alternatives to animal products. Our main hypothesis is that governments are de facto hindering the diffusion of animal product analogs through a policy mix that preserves the dominance of animal farming systems. Our second hypothesis is that the incumbent industry is playing an active role in obstructing a sustainability transition of the food system through political influence.

We reviewed the major agricultural policies that support either the incumbent system or alternative technologies for the period 2014–2020, identifying initiatives that directly impact product stages across the supply chain. When well-documented data were available, we compiled government spending to compare financial contributions to the incumbent system and to niche innovations. The influence of non-governmental organizations through lobbying was evaluated to gain insights into the role of industry and non-profit organizations in influencing the transition. The data sources and method are reported in experimental procedures.

RESULTS

Market of novel products

In 2019, per capita retail sales of animal meat, milk and dairy, and their non-animal analogs combined were 4% higher in the EU than in the US (Table 1). Higher EU per capita expenditure on animal products and smaller volume consumed indicate EU consumers spending on average US$0.7 more per unit of animal

Table 1. Sectoral and regional comparisons of public and private spending, and retail market sales

	Incumbent		Novel	
	EU	US	EU	US
Public spending (2014–2020)				
Annual spending (a + b + c + d) (million USD)	33,620	10,727	29	13
a. Research & innovation	26	20	1	0.5
b. Production	33,507	9,245	27	12
c. Commercialization	–	92	–	–
d. Commercialization/ adoption	87	1,370	–	–
Lobbying spending (2014–2020)				
Total spending (million USD)	18	30	5	0.2
Annual spending (million USD)	3	4	1	0.1
Retail market (2019)				
Total market share (i + ii)	98.7%	98.2%	1.3%	1.8%
i. Meat market share	99.4%	99.4%	0.6%	0.6%
ii. Milk & dairy market share	97.5%	95.1%	2.5%	4.9%
Total retail sales (million USD)	328,391	234,491	5,018	4,180
Total retail sales per capita (USD)	745	714	10	13

product. On average for the two regions, plant-based meat, milk, and dairy retail sales represented 1.5% of the combined animal and non-animal products retail sales, although the US plant-based NOV market share was 35% greater than that of the EU. The difference between the two regions was primarily driven by dairy sales. Milk- and dairy-alternatives per capita sales were almost double in the US compared to the EU (Table 1).

Trade organization data showed that the rate of establishment of new brands, processors, ingredients, and equipment companies in the NOV supply chain increased in the two regions over the years, accelerating after 2010. In the US, the NOV business density was 36% greater than in the EU: adjusted per capita, 11 and 15 new firms were established respectively in the EU and US for every 100,000 people (Table 2).

Financial support and performance of technological innovations

During 2014–2020, grants for research and innovation (R&I) of NOV technologies represented 3% of the R&I spending for animal and novel technologies combined, on average for both regions. The EU public financial support to R&I was 75% greater than the US expenditure. This was mostly due to the EU's spending on NOV technologies, which was about 1.5 times greater than in the US (Figure 1). About 80% and 90% of 2014–2020 support to NOV R&I was awarded between 2019 and 2020 in the US and EU, respectively. Nearly all these grants were awarded through small business innovation programs, mostly to finance piloting, scaling, and process optimization. Cultivated meat, insects, and mycoprotein received comparable funds in the US, while in the EU most funds went to cultivated meat followed by the advancement of NOV ingredients, such as optimization of extraction, isolation, taste, extrusion, and functionality of plant proteins.

In both regions, INC-related research support focused mainly on: (1) mitigating negative externalities, such as antibiotic resistance, manure and wastewater management, and GHG emission capture and reduction; (2) productivity-related objectives such as breeding, animal health, disease prevention, and nutrition; and (3) product quality and safety. Projects advancing both animal systems and niche technologies were notably better supported in the EU, focusing on alternative protein sources for food and feed, such as microalgae, mycoprotein, and insects.

The US outperformed the EU with respect to innovation output. In 2012–2020, organizations headquartered in the US published six times more patents related to plant-based and cultured meat than their EU counterparts (Table 2). In both regions, nearly all plant-based meat patents were published by private companies or individuals, with just one US company (Impossible Foods) owning half of the patents. Universities were involved in one-third of the cultured meat patents published in the US and in 60% of those published in the EU, which were all from the United Kingdom (before Brexit on February 1, 2020).

Public support for supply and demand

Policy instruments supporting supply, such as farmer income support, conservation measures, and domestic and foreign markets support were generally comparable in scope in the two regions. Most of the financial support afforded to EU farmers was delivered as decoupled payments (i.e., independent from the type of product and level of output). Conversely, most of the payments granted to US producers were conditional on the type (i.e., livestock or specific crops) or quantity (i.e., number of head of livestock) of farm output. The EU's annual financial support to the INC system was 2.7 times greater than the US expenditures as share of GDP (Table 2), representing 52% and 11% of the projected annual budget for the Common Agricultural Policy (CAP) in the EU and Farm Bill in the US, respectively. However, if nutrition assistance, a demand-side measure, is excluded from the Farm Bill budget, 46% of supply-side spending is allocated to livestock and feed crop production. Among the stages of the INC product's life cycle, production was by far the most supported in both regions, absorbing nearly all the financial aid in the EU (99.7%) and most of it in the US (86%). Financial support for the production of ingredients of plant-based NOV was about 0.1% of the annual spending for INC. Both NOV sectors received 0.01% of total public spending, adjusted for gross value added of the agricultural sector.

Consumer nutrition assistance, a US demand-side measure that had no equivalent in EU's CAP, was the largest item of the Farm Bill budget. On average, 2% of the projected US budget for domestic nutrition assistance was spent by the US Department of Agriculture (USDA) agency to purchase animal-derived food each year, mostly to the benefit of children

Table 2. Regional comparison of factors impacting incumbent system and niche innovations

Sector	Factor	EU	US
INC[a]	consumer spending per unit of animal-derived product (USD/kg product)	$2.6	$1.9
	public spending as share of gross value added of the agricultural sector	16%	6%
	support to production, as share of CAP or Farm Bill budget	52%	11%
	support to production, as share of CAP or Farm Bill budget (excluding nutrition programs)	52%	46%
	subsidies distribution, main criteria	decoupled from current production	coupled to current production
	demand-side spending at national/ regional level	absent	present
	dietary guideline—link between diet and environmental impact	in 15% of states	absent
	lobbying spending, as share of gross value added of the agricultural sector	0.001%	0.002%
	largest spenders by industry	diary; feed; breeder	dairy; meat producers
	lobby resistance to NOV, main topics	marketing standards	marketing standards; dietary guidelines
NOV[b]	market share of NOV dairy	2.5%	4.9%
	new NOV business density	11 in 100,000 people	15 in 100,000 people
	public R&I grants, including those also benefiting NOV (million USD)	63	5
	published patents	16	97
	public R&I, primary areas	cultivated meat, plant ingredients	cultivated meat, insects, mycoprotein
	public spending as share of gross value added of the agricultural sector	0.01%	0.01%
	public support to supply, as share of CAP or Farm Bill budget	0.022%	0.004%
	dietary guideline— stance on NOV products	recommended as alternative to animal in 21% of states	soy milk and vegetarian diet are healthy alternatives
	marketing standards–attempts to restrict use of animal terms for NOV dairy and meat	yes	yes
	marketing standards—status for NOV dairy products	ban for most NOV dairy products	no ban
	cultivated meat regulation	pre-market authorization process in effect	FDA-USDA agreement to oversee production and commercialization
	lobbying spending, as share of gross value added of the agricultural sector	0.0004%	0.00001%

[a]Incumbent.
[b]Novel.

and elderly persons. However, the largest portion of consumer assistance consisted of benefits redeemable for a variety of foods, which were not included in this analysis. Therefore, US government subsidies to the INC system reported here are underestimated.

Public guidance on food consumption

National dietary guidelines are used to guide public procurement on food provision and to educate citizens on healthy food choices and lifestyles. Dietary guidelines are a federal policy in the US and are developed by individual countries in the EU

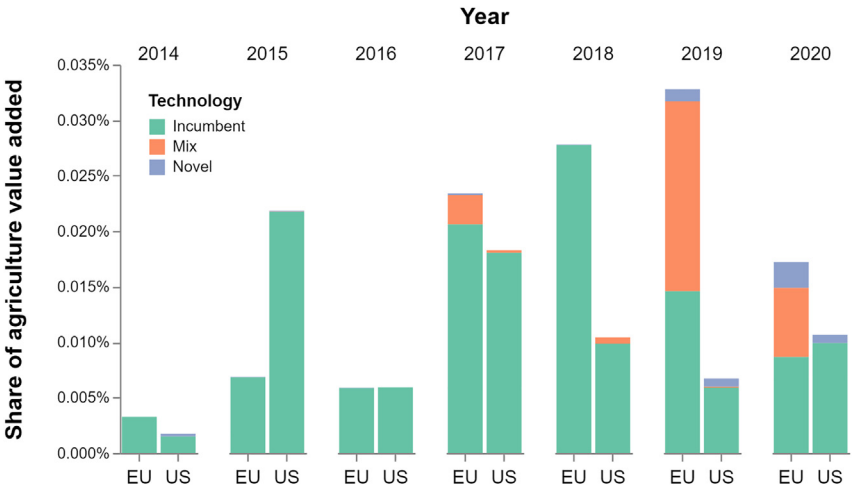

Figure 1. Public spending in research and innovation on the incumbent and novel technologies varied over the 2014–2020 period

The mix category, including projects advancing both technologies, received large investments in the EU, while it was absent in the US.

(see summary on the EU Knowledge Center[18]). In the US guidelines,[19] lean meat was a key component of healthy diets as part of a diversified protein food group including legumes and soy products. Daily consumption of INC milk and dairy was recommended, but soy milk was presented as a healthy alternative. The vegetarian diet was presented as a viable healthy choice. The EU recommendations were not uniform across countries but mostly aligned on the consumption of INC products and much less so on NOV products. The daily consumption of low-fat INC milk was widely supported, but only a few countries recommended NOV milk alternatives. Almost all EU countries advised limiting high fat, salt, and/or red meat consumption, and mentioned legumes as a possible replacement for meat. However, only a minority of countries mentioned NOV products as viable alternatives. There was no mention of the connection between animal products and environmental impacts in the US and in most EU guidelines. Four EU member states (Belgium, the Netherlands, Finland, and Sweden) explicitly linked the substitution of animal-derived products by plant-based foods to environmental benefits.

Public food procurement, while conceived to alleviate food insecurity in the US or support domestic job markets and business growth in the EU, may have indirect effects on the commercialization and consumption of food products. For example, the EU school milk program was explicitly aimed at educating children on the consumption of milk and dairy products. Only INC products were supported by these measures.

Regulations affecting novel product commercialization

The regulations defining the nature and composition of meat, dairy, and their analogs were repeatedly challenged over the years both in the US and the EU. Since 2017, the Dairy Pride Act, a US bill proposing to prohibit food not containing animal-derived ingredients from being marketed as dairy, was repeatedly introduced in the US Congress. Also in 2017, following a European Court of Justice ruling, dairy terms such as milk and cheese could no longer be used to market most alternative milk and dairy products. Two years later, the amendment 171 to the EU 1308/2013 regulation, aiming at further restricting the dairy marketing descriptors by banning direct or indirect use of dairy terms, comparison to, and evocation of animal-derived products, was proposed. Initially voted by the European Parliament majority in 2020, the amendment was withdrawn in 2021.

Efforts to limit the use of animal-derived product terms for their non-animal alternatives also impacted meat. Amendment 165 to the EU 1308/2013 regulation, restricting the use of descriptors of meat products and preparations, such as steak and burger, to exclusively animal products was proposed in 2019, only to be withdrawn a year later. Concomitantly, the Real MEAT act, an amendment to the US Federal Food, Drug, and Cosmetic Act, proposed to prohibit the sale of alternative meats unless the product label included the word "imitation" and other clarifying statements indicating the non-animal origin. The need to modernize regulations while protecting consumer interests was recognized by the designated authorities. Starting in 2018, the Food and Drug Administration (FDA) and the European Commission initiated public consultations to collect consumer feedback to update labeling and marketing standard regulations. Meanwhile, in both regions, initiatives to ban or limit the use of animal-derived product names for their alternatives have been proposed in many states with different degrees of success.

Regarding food originating from cell cultures, the EU Regulation 2015/2283 on novel foods went into effect in 2018, updating the pre-market authorization process with the goal of improving and facilitating the introduction of innovative foods to the market while preserving consumer safety. In 2019, the FDA and USDA Food Safety and Inspection Service formally agreed to oversee the production of food composed of or containing cultured animal-derived cells, albeit these were not yet commercialized. While these initiatives demonstrate an opening toward these novel technologies at the higher level of governance, states in the US or countries in the EU passed bills to prohibit the term meat on labels of cultured meat products (e.g., Missouri, 2019) or, more recently, proposed bans on their production and commercialization (e.g., Italy, 2023).

Priorities of non-governmental actors

The US INC non-governmental organizations spent $30 million from 2014 to 2020 lobbying Congress, 65% more total spending than their EU counterparts (Table 1). Dairy organizations led the spending in both regions, followed by pork producers in the US and feed and breeder associations in the EU (Figures 2 and 3). A significantly larger presence of lobbying groups promoting a transition out of animal farming was observed in the EU, where their total expenditure in lobbying for the 7-year period amounted to $5 million. The EU NOV lobbying groups consisted mostly of animal welfare advocates, with a smaller or recently established presence of NOV trade

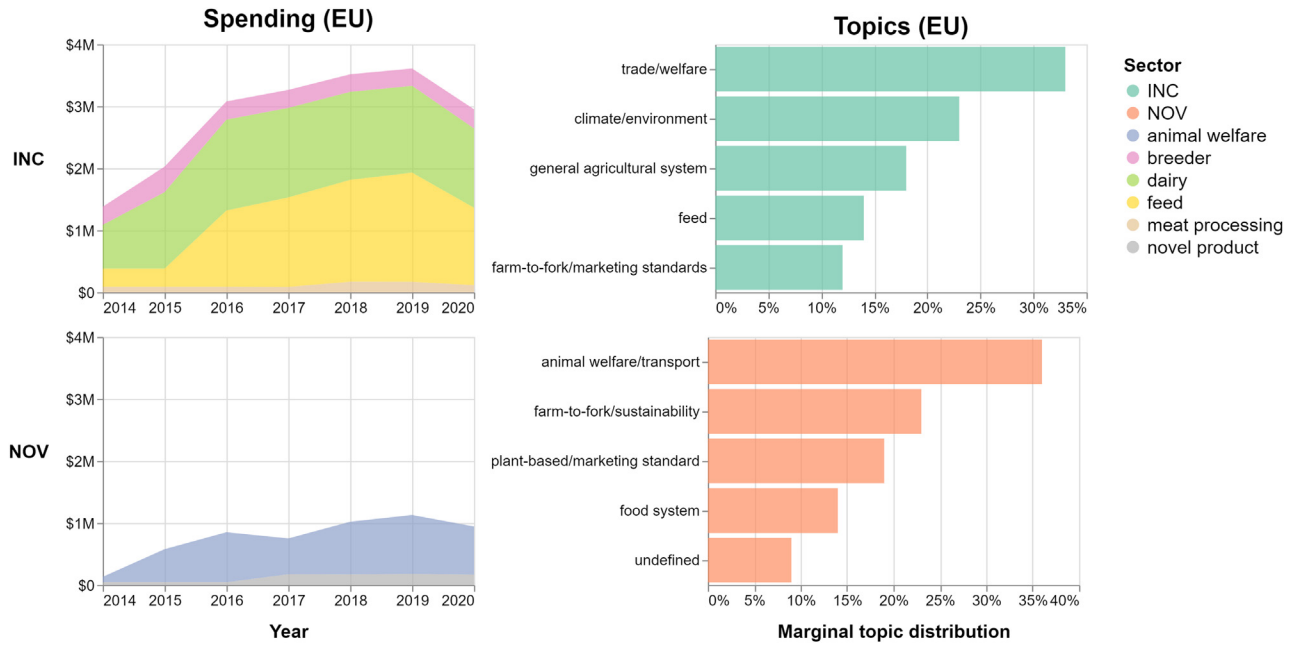

Figure 2. Cumulative lobbying spend of EU organizations increased over time

Associations representing the dairy and feed industries and animal welfare movement were the largest spenders. Issues regarding trade/welfare and environmental/climate were the most debated in INC meetings, while animal welfare in transport and sustainability of the industry were the priorities for the NOV sector.

organizations. Non-governmental representatives with an exclusive focus on animal farming and alternative products had an extremely limited presence in the US industry and non-profit lobbying organizations.

A topic modeling analysis of lobby meeting reports revealed that trade-, animal-, and environment-related themes were the most recurrent meta-topics discussed by INC lobbying organizations (Figures 2 and 3). Although less frequently than other topics, marketing standards and labeling of alternative products were also discussed in both regions. US lobby meeting reports showed support for restricting the use of the term beef and increasing enforcement related to the standard of identity for milk through the Dairy Pride Act. US lobbying reports also showed attempts to influence the content of dietary guidelines. The EU-specific topics were animal welfare in trade and feed-related issues.

The major meta-topics discussed in NOV lobby documents in both regions concerned plant-based NOV products and marketing standards. The US lobby groups focused more on appropriation of funds for research on alternative meat, whereas EU organizations lobbied for improved animal welfare and food system sustainability. Owing to a lack of detailed lobby documents resulting from a less rigorous reporting process in the EU, a comparison of specific topics between regions was not possible.

DISCUSSION

Private investments and publicly funded R&I for niche innovations

In 2014–2020, the EU and US NOV niche industries displayed a dynamism mostly driven by the private sector. The density of new businesses and privately funded technological innovations were greater in the US, where private investments were higher. In 2019, 77% of the $1 billion private capital raised globally by the NOV industry was invested in the Americas (presumably, mostly US) versus 17% in Europe. Global investments increased 5-fold by 2020–2021, but the majority was still invested in the Americas, even though the geographical allocation of investment shifted, with Europe receiving 30% of the total.[20]

Significant public support for NOV research and innovations was also recent and, by contrast, stronger in the EU. The positive trend in grants awarded to R&I observed at the end of 2014–2020 may indicate a growing interest in supporting NOV innovation. Our data showed that early-stage innovation, process optimization, and scaling received most public R&I investments in NOV technologies in both regions. This signals a public contribution to experimental research in line with historical involvement of governments in high-risk phases of technology development.[21] In the US, while the private sector has been historically the primary investor in applied research, most of the basic, high-risk research has been publicly funded.[21] For example, public support was fundamental in the US advances in agricultural genetic engineering, with universities authoring more than 70% of US publications cited in biotechnology patents.[22] In the context of climate action, investments in general-purpose technologies that drive innovation in the entire industry (i.e., enabling technologies) have positive returns in terms of both effectiveness in mitigation actions and diffusion of technologies and innovation. This justifies greater direct government support.[23]

Dominant support for incumbent systems

Despite public support for R&I for NOV, financial assistance still privileged animal production, including both livestock raising

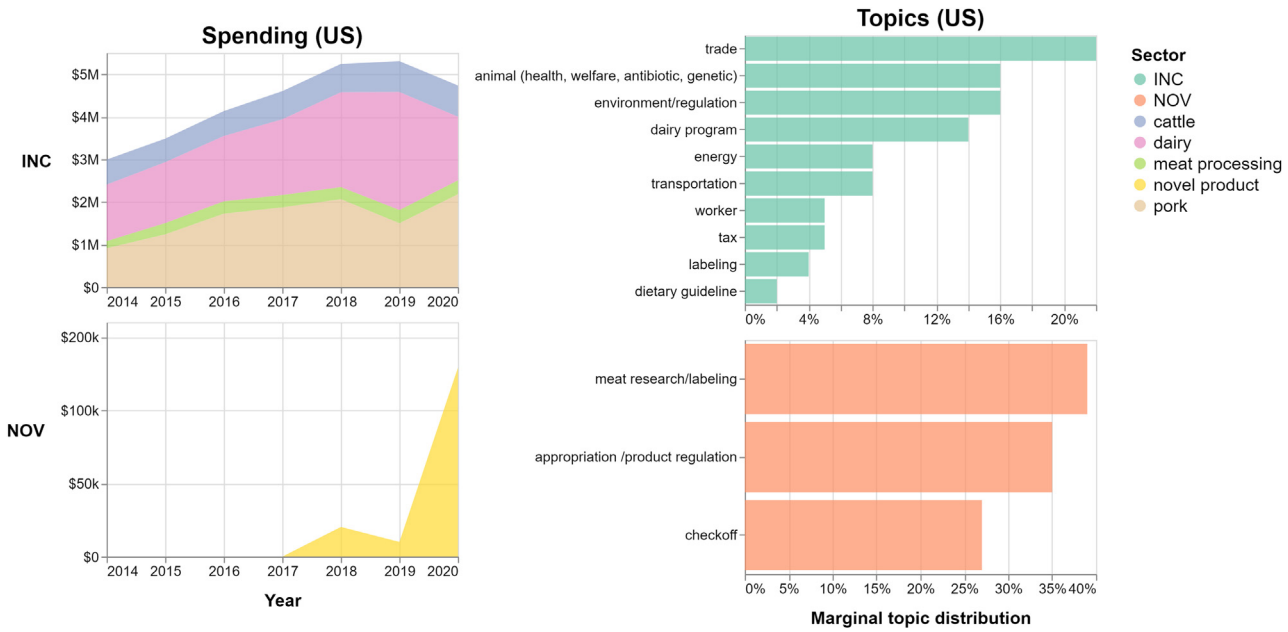

Figure 3. Cumulative lobbying spend of US organizations increased between 2014 and 2020

A large imbalance in lobby presence between the INC and NOV sectors was observed in the US, with only one novel product organization becoming active in 2018. The dairy and pork industry were the largest spenders, and INC's main priorities were trade, animal, and environmental issues. Most of the NOV lobby meetings focused on increasing funds for alternative meat research and product regulations.

and feed production. The production sector of the INC system was the largest beneficiary of government spending. In line with historical support to agricultural producers at large,[15] the INC producers in the EU received greater assistance than those in the US. The criteria for the distribution of financial support affects producer behavior, potentially locking in the system in producing livestock and feed crops and preventing a transition toward more sustainable products. Subsidies linked to current production, such as the US crop insurance and EU voluntary coupled payments, induce farmers to become less risk-averse and less motivated to leave current production systems or to abandon the sector.[15,24] The Organization for Economic Cooperation and Development (OECD) found that, between 2018 and 2020 and compared to the EU, a higher share of total US agricultural producer support was delivered through market-distorting measures that hinder a transition of production systems, such as payments based on commodity output and input use.[15] Examples of these US measures are the Market Facilitation, Environmental Quality Incentives, and Livestock Indemnity programs.

Contrary to the US, support in the EU was mostly decoupled from current production. Decoupled payments, which are based on non-current production, are considered as having a low distorting impact on production, since farmers are not dependent on producing a specific commodity to receive a subsidy.[25] However, some coupled subsidies to livestock production remained; the cattle population was stable in the EU during 2014–2020 and cattle producers were highly dependent on direct payments, which constituted at least 50% of their income.[24] These payments incentivized farmers to maintain herd size, keep pasture in production, or increase the level of supported activity, potentially hindering climate-mitigation efforts.[26,27]

Weak environmental requirements

The lack of climate-mitigation conditionality to financial support and the weakness of penalties for non-compliance decreased the effectiveness of agricultural support in lessening negative environmental externalities and in contributing to climate-mitigation actions. Although the EU CAP 2014–2020 was aimed at addressing the climate crisis, the climate-mitigation potential of decoupled payments was hindered by the absence of requirements to limit or reduce the livestock population.[24] Cross-compliance with environmental requirements failed to produce measurable improvements in farmland biodiversity[24] in the EU. Similarly, in the US, the lack of penalties for non-compliance and of appropriate monitoring in high non-compliance areas of the corn belt reduced the effectiveness of environmental provisions.[28]

Recently, new policies and initiatives aimed at addressing the climate and ecological crises have been launched in both regions. In the US, the Inflation Reduction Act includes investments in technical and financial assistance to support farmers and ranchers implementing practices to reduce GHG emissions or sequester carbon. In the EU, the Farm-to-Fork strategy, as part of the CAP 2023–2027, aims at accelerating a sustainable transition of the food system to support climate-mitigation solutions and reduce biodiversity loss and environmental impacts. The greener path of the new CAP and its success in mitigating impacts of agriculture will greatly depend on its implementation and the member states' ambition to meet sustainability targets.[29]

Demand-side policies

Our estimates of public financial assistance to the INC system excluded the demand-side subsidies. The OECD estimates

that the EU and US allocate a comparable share of GDP to support agriculture. However, EU producers receive virtually all of it, while in the US over 50% goes to consumers.[15] Among OECD countries, only the US has a high level of budgetary transfer to consumers[15] by subsidizing demand through nutrition programs. Demand-side support policies are considered less market-distorting measures. They improve food access and food industry competitiveness and are, in theory, a better strategy to promote healthier foods.[15] However, evidence shows that participation in nutrition programs was not associated with an improvement in diet quality or healthfulness: diets could still be high in processed meat and whole milk and low in plant-based foods.[30,31] Because consumer food choices may hold the biggest potential to reduce the food system's footprint,[4] supporting consumer demand could improve accessibility to NOV products for lower-income populations.[32]

National dietary guidelines

National dietary guidelines represent an opportunity to inform the public about alternative consumption patterns, including through meals offered in public canteens. However, our evaluation of dietary guidelines revealed that recommendations still pivoted mostly on INC products, with sparse or secondary mentions of products such as soymilk and vegetarian patties. A modeled scenario of full adherence to national dietary guidelines by the public showed that meat intake would be much smaller than is currently the case, with 48% and 36% less meat in North America and Europe, respectively.[33] However, agricultural GHG emissions would still exceed the Paris Agreement targets by 300% and 150% in North America and Europe, respectively.[33]

Consistent with previous research,[34,35] our analysis showed that guidelines mostly omitted the link between consumption of animal-derived products and its environmental impacts. In the US, even after recognizing the importance of environmental sustainability in consumer education, sustainability was explicitly declared outside the scope of the dietary guidelines. Before the release of the 2015 Dietary Guidelines for Americans (DGAs), Mr. T. Vilsack and Mrs. S. Burwell, Secretary of Agriculture and Secretary of Health and Human Services, respectively, announced that they did "not believe that the 2015 DGAs [were] the appropriate vehicle for this important policy conversation about sustainability."[19] Considering the mounting evidence regarding the link between food consumption and environmental damage and the lack of consumer awareness about the impacts of meat production,[36] failing to address this connection in the dietary guidelines is a missed opportunity for consumer education and for guiding health, nutrition, and agricultural policies, as well as the food system in its entirety.[37] Still absent in the 2020–2025 US guidelines, the topic of sustainability and the link between nutrition and climate have been recognized as important by the 2025–2030 Guidelines Advisory Committee in the US, which delegated its evaluation to experts in the Health and Agriculture departments.[38]

In Europe, the Nordic countries began updating their dietary guidelines in the early 2020s to include sustainability and environmental topics as informed by major assessment reports, including those from the Intergovernmental Panel on Climate Change and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Scientific experts were invited to conduct *de novo* systemic reviews on topics relevant to plant-based diets such as plant protein intake in children and adults, and vitamin B12 in susceptible groups—a highly relevant topic for vegetarian and vegan diets.[39]

Mechanisms of technological lock-in

Analogous to research findings on the decarbonization of energy systems,[40] food production appears to be locked in an animal-based technological system, a persistent condition maintained by technological, institutional, and social pressures despite the high environmental externalities of this system. This "lock-in" situation creates barriers to the diffusion of alternative technologies.[40] Our analysis showed that the commercialization of NOV products encountered obstacles in both the US and EU. Food labeling regulations were invoked to preserve the distinction between animal-derived products and novel versions on the market. Marketing standards regulations could have a lock-in effect. By defining products according to key aspects of the dominant technology (i.e., being derived from animals), these regulations could increase business uncertainties for innovators and deter investments.[40] It is argued that a clarification of the legal interpretation of marketing standards has a positive effect on both animal and non-animal dairy industries by establishing guardrails and therefore de-risking investments.[41] The absence of a legal definition of non-animal dairy products, the narrow definition of "milk" and "milk products," and different interpretations of the regulations at the state level are expected to hinder the NOV dairy industry.[41] Terms used to describe NOV products can impact consumer attitudes and behavioral intentions toward these products by generating negative associations or confusion.[42] For consumers, terms describing products and preparations (e.g., milk, burger) carry expectations around usage and functionality. For a company, limiting the ability to communicate expectations about and characteristics of the product may hinder innovation and communication.[41]

The results supported our main hypothesis by documenting how public policies mostly hindered the establishment and diffusion of non-animal products as viable substitutes for animal products. Except for their R&I support in recent years, governments impeded the transition by investing most of their agricultural financial support in livestock and feed production systems, thus failing to incentivize a scaling down of the incumbent production system. Moreover, they missed the opportunity to highlight the environmental sustainability dimension of food production in nutrition guidelines, and policymakers attempted to introduce regulatory hurdles to the commercialization of NOV products.

Lobbying by organizations representing incumbent systems

In support of our second hypothesis, our results showed that influential incumbents exerted their instrumental power on governments, actively pressuring against the inclusion of NOV products in the current system. The INC lobby groups in the two regions showed different spending trends but a similar discourse: greater expenditures by US compared to EU groups, but shared priorities and comparable attention toward NOV-related issues such as marketing standards and labeling. These commonalities are not surprising given the similar trends of

industrialization and consolidation of the INC industry in both regions.

Environmental and climate-related issues and regulations have been consistently lobbied against by major US meat and dairy companies[43] and supply chain actors at large.[44] Industry power may hinder a reduction in meat consumption by exerting its influence throughout the supply chain, for example to maintain low meat prices. Discursive and instrumental power manifests itself through governments' implicit acceptance of negative externalities (i.e., GHG emission, pollution) and the industry's ability to influence policies on land privatization in countries that produce feed, environmental standards, product standards and labels, and animal welfare.[44] A transition pathway that involves the substitution of an existing technology (i.e., livestock) requires institutional changes that suit the niche technologies, which involves power struggles.[45] This is particularly challenging when the political influence of the incumbent sector is strong. A 2021 analysis showed that, when adjusted for industry size, the lobby expenditure of the entire US farm sector was twice as large as the average industry, with the farm sector ranking 12th highest among 60 sectors between 2003 and 2020.[46]

A "core alliance" formed by policymakers and incumbent firms is sustained by mutual dependencies and tends to maintain the status quo.[45] Signs of this dynamic may be found in incumbents lobbying to exclude sustainability language from dietary guidelines in the US or maintain a narrow definition of "milk" and "milk products" in the EU. Resistance to fundamental changes in the incumbent system also manifested itself through lobbying and government-aligned support for climate-mitigation solutions that remain within the incumbent system or for limiting the reach of environmental regulations. An example is found in the support for sustained exemptions of livestock operations from reporting GHG emissions under the Clean Air Act. Other major negative externalities of the incumbent system, such as deforestation and biodiversity loss, are largely left out of mitigation strategies, except for the 2022 EU directive on imported deforestation.[47]

Study limitations

We chose the highest level of governance (Federal and Union governments) as unit of analysis. However, we recognize that relevant initiatives impacting the sustainable agriculture transition also take place at lower levels of governance. Public support for INC reported here is likely underestimated as it did not include other measures that benefit farmers, such as fuel tax exemptions. The analysis of lobbying influence was limited by the quality of the EU lobby activity reports, preventing a sound EU-US comparison. Moreover, the criteria used to select non-governmental actors may have excluded other influential players, such as large organizations working on multiple environmental issues, and smaller, local organizations that are exerting pressure through other routes. The method used to identify R&I initiatives may be biased toward applied research, with an under-representation of basic research projects. The evaluation of plant-based ingredients was based on the simplified assumption that ingredients used by the NOV industry are only sourced domestically, which is unlikely to be the case.

Niche innovations have been treated as "green technologies." While there is evidence of reduced environmental impact for some of them, more research is needed to assess impacts of technologies at scale and throughout their life cycle. This includes their potential social, health, and environmental impacts, such as job transition and retraining, alternative paths for protecting ecosystem services in rural environments, nutrient delivery and nutritional quality of alternative products, and land-use impacts and emissions of the supply chains of ingredients.

Finally, this study did not address the root causes of policy discrepancies between the US and EU with respect to animal-source foods and their analogs. For example, one could hypothesize that differences in the cultural relationships with meat underpin observed differences in policies. While, on average, per capita meat consumption is higher in the US than in the EU, there is great variability in meat consumption, culinary traditions, and attitudes with respect to meat, ultra-processed foods, and environmental sustainability between and within EU countries and US states, thus calling for fine-grained studies.

Conclusion

In the wave of niche innovations on animal product analogs that is primarily spearheaded by the private sector, a weak sign of government support was identified in the recent awarding of research funding and initial steps to update regulations. However, the incumbent system of animal farming still received most of the financial support allocated to food producers, preferential endorsement in dietary recommendations, and dominant-technology advantages in marketing standards. Active resistance to a food system transformation from the incumbent sector manifested itself through its instrumental power, mostly unobstructed due to the imbalance in influence between the incumbent and niche innovation sectors.

Despite the climate and biodiversity crises and the urgency to implement effective mitigation measures, both the EU and US governments are slow to act decisively to mitigate the environmentally damaging role played by the dominant animal production systems. They largely ignored the mitigation potential of niche technologies that provide viable alternatives. The lack of policies focused on reducing our reliance on animal-derived products and the lack of support to alternative technologies at a level sufficient to allow them to compete on the food market against a well-supported incumbent system are symptomatic of a sociotechnical system still resisting fundamental systemic changes. A significant shift in food policies would be required to allow these alternative technologies to realize their potential in contributing to a transition toward more sustainable food systems.

EXPERIMENTAL PROCEDURES

Resource availability

Lead contact

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Simona Vallone (vallone.sm@gmail.com).

Materials availability

This study did not generate new unique materials.

Data and code availability

The dataset "Public policies" analyzed in the study (Data S1), the dataset "Annual spending of lobbying organizations" (Data S2), and the dataset "Lobbying reports" analyzed (Data S3) have been deposited at Zenodo under

https://doi.org/10.5281/zenodo.8111682 and are publicly available as of the date of publication. The python code for the topic modeling has been deposited at Zenodo under https://doi.org/10.5281/zenodo.8111821. Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

Method

Overview

We applied a multilevel perspective framework to describe innovations in the segments of the food system associated with products traditionally derived from animals. To compare different paths of system innovation, we carried out a comparative analysis between the EU and US. We focused on public and private policies that impact incumbent and novel products. We identified government policies impacting product stages and their financial or regulatory support to either technology, and we evaluated the influence of the private sector and civil society on policymaking by analyzing the major themes discussed in lobby meetings.

Framework

A multilevel perspective framework[13] was employed to analyze the incumbent sociotechnical system and niche innovations. Animal farming is the incumbent (INC) sociotechnical system producing animal-derived food. Within the system, livestock is regarded as biological machines in its function of converting inputs such as feed and water into food. The system includes the processes to produce animal-derived foods, such as meat, milk, and dairy (MMD), and the societal functions including regulation, institutionalized infrastructure, public and private investments, and consumer adoption. The novel (NOV) technological niches aim at producing alternatives to animal-derived products—limited here to plant-based, cultured, and fermentation-derived MMD—and includes the new and established food companies, technical expertise, inventions, investments, processes, and regulations.

Data

The evaluation of the INC system and the NOV technologies was based on the following data: retail sales and supply chain size; technological innovation performance; public policies, including regulation, financial instruments, and guidelines; and lobby spending and discourses of non-governmental organizations.

Retail sales and supply chain size and growth were used to describe the niche market. As a proxy for NOV technological innovation performance, published patents were evaluated. The major agricultural and food policies were reviewed, and initiatives were selected based on their relevance to and impact on the life stages of INC and NOV products, namely R&I, production, commercialization, and adoption. Because of differences in reporting methods and types of data, financial support for production and commercialization stages were estimated using methods specific to each region, grouped according to the product life stages, and reported below in separate sections. Methods used to identify public support for R&I and labeling regulations are described in the same section as data types, and sources were comparable between regions. Lobby spending and lobbying topics were analyzed to assess the non-governmental pressure in shaping policy.

Niche market and innovation performance

Retail sales data were used to estimate the size of the combined INC and NOV markets. The NOV category included only plant-based MMD products. Because of limited information available for multiple years and to exclude the potential distorting effect of the COVID-19 pandemic on the sales of the target products, the estimated retail sales values were calculated only for the year 2019. Data were retrieved from several market research reports. Passport, Euromonitor, ING Research, and Mintel Consumer expenditures on meat (fresh and processed) in the US and EU28 were used for the INC market. Retail sales for milk and dairy included yogurt, cheese, and ice cream. For the NOV market, the following retail sales data were used: plant-based alternatives for beef, chicken, pork, milk, yogurt, cheese, and ice cream. Growth and size of the niche innovation were estimated using the number of new brands, manufacturers, ingredients, and equipment companies in NOV supply chains. Data were retrieved from The Good Food Institute, a trade association present in both the US and EU. As a proxy for technological innovation performance, a patent search was conducted to identify the number of publications regarding NOV technologies published in 2012–2020. The Patenscope[48] database, developed by the World Intellectual Property Organization and providing access to international Patent Cooperation Treaty applications, was searched. The search was limited to the terms "plant-based meat" and "cultured meat," and it included all patent family members published at the US and European Patent offices and member states. The identified publications were screened for relevance and removed when a connection with the technology was not established.

Public policies

The 2014–2020 period was analyzed as it coincided with the period when the development and commercialization of novel products accelerated and major agricultural policies were implemented in the EU and US (EU CAP 2014–2020 programming period; US Farm Bills, Agricultural Act of 2014, and Agricultural Improvement Act 2018). Public policies included in the analysis are listed in Data S1. A five-person expert panel was consulted to ensure that all relevant, impactful policies were included. The panel was composed of experts selected on the basis of their roles in organizations focused on animal farming or alternative product sectors. They held positions as policy manager, agriculture policy director, advisor on agriculture, rural development, and animal welfare for a member of the European Parliament, and government affairs manager.

Government financial support from production to adoption

Government spending was compiled based on well-documented and publicly available data. Programs are listed below. Additional details on source and data are listed in supplemental experimental procedures. Projected policy budgets were retrieved from official websites.[49–51] Nominal values were deflated to 2019 using the Harmonized Indices of Consumer Prices[52] for all items, compiled by the OECD.[53] Euro figures were converted to US dollars using the 2019 average conversion rate reported by the European Central Bank.

European Union: Production. The financial support directed to the production of livestock and crops is regulated by the CAP. This includes market support in the form of direct payments, which represented the major expense, and rural development funds. These funds aimed at strengthening competitiveness, promoting innovation, restoring ecosystems, and supporting a transition to a low-carbon and climate-resilient economy. Since about 90% of direct payments were decoupled from production of specific commodities, the financial support to the sectors of interest was not explicitly reported. Therefore, the direct payments and rural development funds transferred to specialized livestock farms and farms producing feed were estimated using the Farm Accountancy Data Network[54] survey data. Data for the following types of farms were extracted: specialist dairying, specialist cattle, specialist granivores, specialist sheep and goat, and mixed livestock; and specialist cereal, oilseed, and protein crops (COP). Mixed crops and livestock farms were not included. The livestock dataset included the following subsidies: direct payments (decoupled and coupled) and rural development. Support to INC production was estimated as the sum of all specialist livestock plus the fraction of the COP crop subsidies used for animal feed. This was estimated based on the fraction of land under production for each crop used as feed and on the fraction of eligible land that receives payments. The complete procedure is detailed in supplemental experimental procedures. For the estimation of support for the plant-based MMD industry, the fraction of crop production used as ingredients of plant-based products was adjusted for processing losses. This included processing required to make refined ingredients (i.e., protein concentrate) or manufacture plant milks. For this, the following data were used: sales and production volumes for leading plant-based MMD (soy, wheat, pea, almond); protein content of commercially available plant-based products; protein recovery from extraction process; volume of crop production; and protein content of crop. Data sources and formulas can be found in supplemental information.

European Union: Commercialization and adoption. The EU financially supported the implementation of promotional measures to enhance the competitiveness, consumption, and consumer awareness of agricultural products, both internally and with third countries. The estimated cost and maximum grant amount for promotion programs for the period 2016–2020 was retrieved.[55] The EU school scheme supports the distribution of milk, fruits, and vegetables to schoolchildren, and educational measures. The scheme's objectives are to help children adopt healthy eating habits and learn about food production. The annual expenditure for the supply, distribution, and educational measures of milk and milk products was available only for school years after 2017. Additional initiatives supporting the distribution of agricultural

products and the adoption of specific foods included public procurement, the process by which public authorities purchase goods or services from companies. Relevant to the study is the purchase of food products for catering and public canteens. The EU Opentender portal[56] was used to identify and evaluate spending in the food sector. The analysis included expenditures under the category "animal products, dairy and animal feedstuff." Other relevant categories, such as "agricultural and farming" and "canteen and catering services," totaling over €300 million over the 2014–2020 period, were not included, as the expenditure was not itemized.

European Union: Adoption. The dietary policy recommendations to the EU-28 population were investigated by evaluating the analysis conducted by the EU Knowledge Center, which summarizes the main recommendations. The recommendations used in the analysis were those for adults or the general healthy population. For the detailed methodology, refer to the report by the European Food Safety Authority Panel on Dietetic Products, Nutrition, and Allergies.[57] Three food groups were selected: legumes, milk and dairy products, and meat. The legumes group was included to evaluate the recommendation for alternatives to meat. Guidance on overall diet and lifestyle as well as environmental sustainability were also assessed. The entries were evaluated for recommendations on consumption of INC meat, milk and dairy, and NOV products, and for references to sustainability in the context of food choices, including the presence/absence of an explicit link between diets and environmental impacts.

United States: Production. This included support for the production of livestock, feed crops, and crops used for plant-based MMD products. The US agricultural policy, commonly known as the Farm Bill, is a comprehensive, multiyear legislation that governs the agricultural and food programs. The Commodity Credit Corporation funds programs prescribed by the federal Farm Bill. These include commodity programs in the form of loans and income support programs for major crops, such as grain and oilseed, assistance to dairy and livestock producers, conservation, and export and foreign assistance. A brief description of the programs follows. For more details and data sources, refer to supplemental experimental procedures. The Marketing Assistance Loan program gives producers that have harvested a crop access to production loans, using the crop as collateral. Producers also have access to Price Loss Coverage or Agricultural Risk Coverage programs, which provide either price or revenue protection. Payments are based on acreage irrespective of actual planting. Covered crops include feed grain, wheat, coarse grain used for haying and grazing, corn, soybean, and other oilseeds. Milk producers have access to the Dairy Margin Coverage program (2018 Farm Bill) and Margin Protection Program (2014 Farm Bill); Dairy Indemnity program. The Agricultural Disaster Assistance Programs, authorized in 2014 and amended in the 2018 Farm Bill, financially support farmers and ranchers impacted by natural disasters. These programs are Livestock Indemnity, Livestock Forage Disaster, Emergency Assistance for Livestock, Honeybees, and Farm-Raised Fish. Federal crop insurance for eligible commodities and livestock helps producers with a loss in yield or crop revenue. The federal support includes payment of part of the producer premium and sharing the underwriting risk with the private insurance companies. Conservation programs are voluntary programs that support farmers and ranchers in the implementation of conservation practices on private lands. There are over 25 programs that can aid farmers and landowners in various capacities. Working land programs incentivize implementation of conservation practices while allowing the land to remain in production. The Natural Resources Conservation Service, a USDA conservation agency, reports the financial assistance obligations at the end of the fiscal year for many conservation programs. The obligations reported by the National Resources Conservation Service in the Conservation Practice Implementation report are contingent on the budgetary resources made available by Congress, and it does not include secondary adjustments after the close of the fiscal year. Moreover, between fiscal years 2014 and 2020, since most mandatory conservation programs were subject to sequestration (i.e., reduction of agency funds available), the federal financial support given to farmers and ranchers reported here may be overestimated.

United States: Commercialization. This included payments to producers and trade organizations to assist with disrupted markets and surplus commodities (Market Access Program) and expand the agricultural export market domestically and internationally (Foreign Market Development Program), as well as an ad hoc trade mitigation program to assist farmers damaged by unjustified foreign trade retaliation, such as the Agricultural Trade Promotion Program and Market Facilitation Program.

United States: Commercialization and adoption. Domestic food assistance programs provide food-insecure populations with cash transfer and/or food commodities. The USDA's Agricultural Marketing Service (AMS) agency is responsible for purchasing domestic commodities and processed commodity food products. The commodities purchased include meat, poultry, fruit, and vegetables. The AMS procurement activity[58] was evaluated and the total purchases by relevant commodities included. The Special Milk Program provides reimbursement for part of the cost of milk served to children to institutions that do not participate in other federal meal programs. This spending was included in the estimate of financial support.

Unites States: Adoption. The US 2015–2020 DGAs, 8th Edition, developed by the US Department of Health and Human Services and the USDA, were reviewed. Evaluation criteria were the same as for the EU.

Public support for research and innovation

The main R&I funding programs focusing on agriculture and food systems were evaluated to investigate the extent to which the regions had supported innovation in the incumbent system and novel technologies. In the EU, these were Horizon 2020, the leading research program, and LIFE program, EU's funding instrument for the environment and climate action. In the US, the National Institute of Food and Agriculture (NIFA), a USDA grant-awarding agency conducting extramural research and extension activities, and the National Science Foundation (NSF), a federal agency supporting fundamental science in academic areas as well as high-risk projects, were identified.

Except for Horizon 2020, the LIFE, NIFA, and NSF databases either did not allow bulk download or files were too large. Therefore, project extraction was performed by keyword query using the following keywords: analog, animal, beef, cattle, cellular, cheese, cultivated, cultured, dairy, emission, feed, feeding, fermentation, livestock manure, meat, methane, milk, pea, plant-based, protein, soy. Each dataset was then processed with a Python script that searched the abstract (NSF), project object (Horizon, NIFA), or project title (LIFE) to encode presence or absence of 29 keywords. These included the keywords listed above (except for "cellular" and "feeding," which were yielding high numbers of unrelated results) and the following phrases: alternative protein, animal feed, animal feeding, cellular agriculture, cellular meat, cellular milk, cultivated meat, enteric fermentation, plant-based protein. To estimate the funding awarded to projects related to the relevant technologies, a manual coding was conducted of all the projects for which at least four keywords appeared. Projects were evaluated for their contribution to innovation in animal farming, novel products, or a combination of both. The cutoff of four keywords was chosen after a qualitative inspection of a randomly selected subset of 23 entries with three keywords revealed that relevant projects were more often only distantly related or too general to be assigned to either group. Nonetheless, it is possible that relevant projects were excluded.

Labeling regulations

Given their potential for impacting the commercialization phase and influencing consumer adoption, the regulations on product identity and labeling of animal-derived and alterative products were reviewed in both the EU and US. Although not yet commercialized in either region, the status regulations pertaining to cultured meat were also evaluated. In the EU, this included: sales description for milk and meat in Regulation 1308/2013, Article 78, establishing the common organization of the market for agricultural products, and relevant proposed amendments, such as 171 and 165; and pre-market authorization in novel foods, Regulation 2015/2283. In the US, it included: standards of identity for milk and cream, in Code of Federal Regulations (CFR) 21 CFR 131.110, Chapter 2, Volume 2; definition of meat, in 9 CFR 301.2, parts 301 and 319 of 1970; and USDA and FDA formal agreement to regulate cell-cultured food products.

Lobby activity by trade and non-profit organizations

The demands of major lobbying organizations were evaluated to gain insights into the industry and non-profit organizations' role in policy shaping. Because of time and resource constraints, food companies were excluded. Major lobbying organizations were identified based on annual spending. Reports from lobby meetings were analyzed for relevant lobbying topics, which were identified using a probabilistic topic modeling. The process is described below.

Lobby activity by trade and non-profit organizations: Data. A list of organizations engaged in lobbying activities was retrieved. For each region, only the organizations headquartered within the national or regional boundaries were considered. To rank the organizations, the 4-year average of the lobbying expenditure was used to select the most financially active organizations; campaign contributions were excluded. The lobbying spending of EU organizations was retrieved from LobbyFacts,[59] a project of Corporate Europe Observatory, and LobbyControl that compiles and archives data from the EU's Transparency Register database, which lists groups and organizations carrying out lobbying activities. Since registration is voluntary and unverified by independent organizations, the information retrieved may not be comprehensive, updated, or accurate. For the period 2018–2021, the categories trade and business and non-governmental were selected. The lobbying spending of US organizations was retrieved from OpenSecret,[60] a website that compiles and archives disclosure reports filed with the Secretary of the Senate's Office of Public Records. Firms and organizations spending less than $3,000 or $12,500 per quarter, respectively, are not required to file. For the period 2018–2021, the categories selected were: trade organization for the livestock and dairy industries; industry organization for food processing and sales; and non-profit organizations. All data were downloaded in March 2022.

Lobby activity by trade and non-profit organizations: Selection process. For each region, the organizations were ranked based on their average spending for the period 2018–2021. The resulting lists were processed to identify organizations relevant for this study. First, the following entities were removed: headquartered outside the study areas; belonging to unrelated industries (i.e., pharmaceutical) based on name inspection; having non-English names; and local chapters, if the national or regional level organization was on the list. For the US and EU non-profit organizations and the EU trade organizations, the websites were inspected for their main work areas. First, organizations were retained if work areas included "agriculture" or "food." Second, the selected entities were retained if their primary focus was animal farming or alternatives to animal and factory farming (plant-based alternatives, alternative sources of proteins, farm animal welfare). The US organizations included in the study were already categorized according to the industry as "livestock," "dairy," "food processing," and "non-profit." An average spending of $100,000 per year was used as a cutoff to select the influential organizations. An exception was made to include the organization The Good Food Institute, increasingly active toward the end of the study period in both regions. Organization and their yearly spending are reported in Data S2.

Lobby activity by trade and non-profit organizations: Topic modeling. Topic modeling was employed to explore and identify the key issues that the selected non-profit and trade organizations lobbied for at the US and EU government levels. The latent Dirichlet allocation (LDA) probabilistic model was used.[61] This method defines a topic as a distribution over a fixed vocabulary of terms. It assumes that a collection of documents is associated with several topics, and each document arises from multiple topics; the topics are present in different proportions across the collection of documents. The lobbying report (US) and list of lobbying activities (EU) were used in the model. These documents were short (maximum 300 characters), concise, and information dense. Python scripts include details of the document processing and model evaluation, which are described here.

The documents were processed prior to running the model to improve interpretability. First, the collection of documents was tokenized and transformed to lowercase, and common words contributing to little topical content, such as "but," and "and," were removed. To improve interpretability, co-occurring words (word pairs) were detected using a pointwise mutual information (PMI) score to measure how much more likely two words co-occur than if they occurred independently from each other. PMI^3 was chosen to reduce sensitivity for low-frequency data and find more general terms, ranking first the most frequent pairs of words.[62] The collocation and the co-document high frequency were inspected to identify words with high co-document frequency (e.g., general) that also rank high in collocation (e.g., general education). After inspection, the collocations were joined based on the PMI^3 threshold associated with meaningful collocations, meaning until the word pair was no longer recognized as a common pair. Highly frequent words were then removed. The threshold was selected after inspection of the terms. Highly frequent words were defined as terms that were expected to appear due to the nature of the documents or that were too general and reduced the specificity of the topic. Examples of these terms were support, bill, work, agriculture, policy, member, animal, and food.

LDA and Gensim models were used for model evaluation. For each collection of documents, the optimal number of topics was selected based on the maximization of the coherence metric. Topic labels were automatically generated based on the most relevant words. The relevance of a term to a topic is a measure that can be used to "rank terms in order of usefulness for interpreting topics."[63] It uses the weighted average of the logarithms of a term's probability (frequency) and its lift (ratio of a term's probability within a topic to its marginal probability across the corpus), which is a measure to rank terms within topics. Topic validation was then conducted as follows. First, the coherence metric was employed, this time to evaluate interpretability of the topics and ensure that most topics had relatively high coherence. The 30 most relevant words were extracted with lambda set at 0.7, since a lambda value of <1 can improve topic interpretability.[63] These words were used for the evaluation of the topic quality[64] and to assess semantic validity. Up to ten documents per topic were randomly selected for closer inspection to confirm the assigned topic label was consistent with the document content. Finally, the topic relatedness—"the extent to which topics related to one another in substantively meaningful way" (Quinn et al., 2010 in Boussalis and Coan[65])—was inspected. To assess topic relatedness, the distance between probability distributions was evaluated using pyLDAvis visualization, which maps the distances between each topic's probability distribution into 2D space.[66] To rank topics based on their relative importance in the full collection, the marginal topic distribution was computed. The marginal topic distribution was interpreted as proportional to the relative prevalence of the topics in the document collection (i.e., corpus).[63] This may be interpreted as a proxy for the importance of each topic for the document collection. Finally, to facilitate interpretation of the results, meta-topics (i.e., higher-order themes) were identified based on the relatedness and similarity of topics and reported with their cumulative marginal distributions.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.oneear.2023.07.013.

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AUTHOR CONTRIBUTIONS

Conceptualization, S.V. and E.F.L.; methodology, S.V. and E.F.L; investigation, S.V.; formal analysis, S.V.; data curation, S.V.; writing – original draft, S.V.; writing – review & editing, S.V. and E.F.L; visualization, S.V.

DECLARATION OF INTERESTS

The authors declare no competing interests.

INCLUSION AND DIVERSITY

We support inclusive, diverse, and equitable conduct of research.

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