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Abstract The objective of this chapter is to study how public policies and governance actions may be addressed to support and accelerate the transition to cell-based foods as more sustainable and ethical means of protein production and consumption. In this regard, we assessed different impacts of public policies as maintainers of the current production system, the structure of policies for transformative innovations to be applied to cultivated meat, and the structural dimensions of planning, including supranational, national, and subnational plans. Besides, the selected concepts of governance actions such as dialogue among stakeholders, transparency, and inclusion were introduced, as they are regarded as essential for facilitating a successful transition. Finally, we address the challenges for the development of cell-based meat and conclude by emphasizing that public policies and governance actions are central to this transition, guiding investments, funding and decisions while considering social, ethical, and technological aspects.

Keywords Public policies · Transformative innovation policy · Planning · Governance actions · Cultivated meat

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1 Introduction

A policy may be simply “anything a government chooses to do or not to do” (Dye 1972, p. 2) or, in a more specific definition, a “statement by the government of what it intends to do, such as a law, regulation, ruling, decision, order, or a combination of these. The lack of such statements may also be an implicit statement of a policy not to do something” (Birkland 2019, p. 6). While numerous alternative definitions exist, they typically refer to the actions or inactions of governments in addressing societal issues (Kraft and Furlong 2021). Public policies have a significant influence on production and consumption systems. Besides defining the government’s active role as a highly relevant agent in society, public policies also affect various domains, encompassing aspects such as regulation and tax rates. Hence, public policies may be associated with changes in current systems, including the food systems.

Food production systems include at least the activities involved in food production, processing, packaging, distribution, marketing, and consumption (Ericksen 2008). Due to their vast scale and social and economic relevance, the food production systems may also have various undesirable impacts. Studies have shown that changing how food is produced and consumed is essential for a transition to a more sustainable landscape (Ammann et al. 2023; Cai et al. 2023; Eisen and Brown 2022; Moberg et al. 2021). In this context, the production of meat-based foods stands out for its many negative consequences for sustainability and common well-being. The effects are mainly related to the emission of greenhouse gases (Gerber et al. 2013), excessive use of water (Palhares et al. 2021) and soil (Pereira et al. 2020), inadequate animal welfare practices (Narayanan 2016), public health (Papier et al. 2021) and the risks of new pandemics (Wallace 2016).

Such severe impacts increasingly demand fundamental changes in the protein food production system, with cell-based foods and other alternative proteins such as plant-based and other meat analogues being promising proposals. The fact that the newly cultivated meats deliver real animal protein and not analogues puts this system in a special position. However, structural changes will be required as a radical innovation related to entering an entirely new territory (O’Connor and McDermott 2004) and altering previously known production and market patterns (Dean et al. 2022). These alterations may be related to existing institutional systems, such as laws and regulatory aspects, and social-economic factors, such as education, consumption patterns, food production, and distribution systems.

Considering the many aspects involved in establishing innovative food production systems, this chapter aims to study how public policies and governance action may be addressed to support the transition to cell-based foods as more sustainable and ethical means of protein production and consumption. To achieve this, we addressed public policies as maintainers of the status quo in food production, the perspective of transformative innovation policies, the emergence of cultivated meat, and the structural dimensions of planning and policy actions that may be employed to make the transition process more equitable.

2 Public Policies to Maintain the Status Quo in Food Production

Public policies have contributed to establishing the current pathways of food production and consumption. Historically, some of these policies, for instance, provided subsidies to ensure competitiveness in international trade while facilitating access to innovations in inputs and technologies to increase productivity.

According to Baffes et al. (2022), policy interventions in agricultural commodities began to increase after the First World War. As European imports declined, leading to a price drop, government measures were designed in the United States to protect American producers. In Western Europe, policy intervention started after the formation of the European Union in the early 1960s, with the creation of the Common Agricultural Policy. The goal was to keep farm incomes comparable to those of non-farm workers. Emerging markets and developing economies introduced high taxes on crop exports to keep food prices low and to promote food self-sufficiency. The same self-sufficiency strategy was observed in centrally planned economies through public ownership and control over production and trade. So, the main reasons to insert public policies into agricultural commodities were price control, food self-sufficiency and maintaining farmer incomes.

Recent data from the OECD (2022) reveals that the support the agricultural sector has received in recent years has grown. Over the period between 2019 and 2021, the total support reached US$ 817 billion annually for 54 countries, representing an increase of 13% over the US$ 720 billion support from 2018 to 2020. Of the total values, US$ 500 billion per year came from public budgets and US$ 317 billion through higher prices paid by consumers. The European Union and the United States, large agricultural producers, account for two-thirds of this total. Individual producers received 60% of this amount in the form of support through higher market prices paid by consumers or by taxpayers through budgetary transfers. In contrast, public investments in agricultural innovation systems, biosecurity services, and off-farm infrastructure accounted for only US$ 80 billion. These values are represented in Fig. 1. Despite their importance for climate change and food systems goals, they have been low compared to the sector's size.

These data indicate that public policies have played a fundamental role in supporting the current food production system despite its numerous problems. According to OECD (2021), the food system faces a triple challenge: to deliver food security and nutrition for a growing population, to provide incomes and livelihood for people involved in farming and other segments of the chain, and to do this in a sustainable manner. On balance, the agricultural policies do not address these three dimensions effectively.

Regardless of the benefits brought by alternative proteins and the need to transition from traditional production to solutions with less environmental impact and fewer issues concerning animal ethics, both in Europe and the United States, animal production remains widely subsidized by public policies and funding. Powerful vested interests exert their political influence to maintain the status quo. Animal

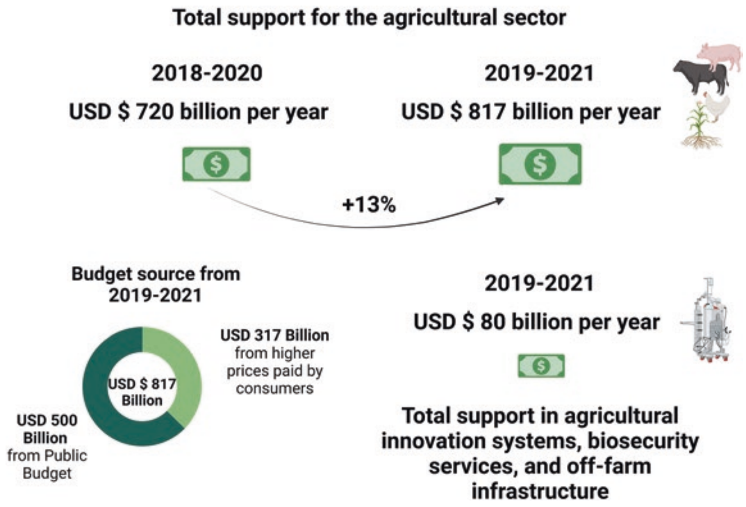

Fig. 1 Total support for agricultural sector and agricultural innovation systems in 54 countries, adapted from OECD (2022). Created with BioRender.com

production receives the majority of public financial support for food producers and resists the transformation of the food system. Private companies lead the alternative protein products, while governments overlook their potential for climate mitigation. Public funding for new technologies is lower than traditional animal products by a factor of 1200 in the European Union (EU) and 800 in the United States (Vallone and Lambin 2023).

To achieve a higher degree in relation to the food system's sustainability and effectively mitigate climate change, it is imperative to systematically eliminate market price support and payments that have significant potential to harm the environment and disrupt markets and trade. Instead, redirecting budgetary support to encourage environmentally sustainable agricultural production, focusing income support on households facing the most acute needs, and implementing a robust pricing system for agricultural greenhouse gas emissions are crucial steps to incentivize the shift towards low-emission agriculture (OECD 2022). However, although governments have invested in innovations and started to alter regulations in recent years, they have preserved the status quo of animal production and consumption. Despite the need to improve the food system's sustainability, policies have failed to address the environmental impacts of animal production. Political influence has been used to keep the system unchanged and block the competition created by technological innovations (Vallone and Lambin 2023).

Therefore, despite the various challenges related to the continuity of meat food production in the conventional way, a profound change to a more sustainable standard will inevitably depend on changes in public policies. Public policies for solving societal problems are known in the literature as transformative innovation policies.

3 Transformative Innovation Policy

Transformative innovation policy may be considered a new paradigm within public policies to support innovation, science, and technology (Diercks et al. 2019). Its originality covers general and global challenges, such as environmental concerns, public health, sustainable food, and population aging (Haddad et al. 2022). Despite its importance, transformative innovation policy is a recent concept. The specific literature has highlighted at least three types of policies to boost science, technology, and innovation. The first is related to government support for research and development to fill private market failures that depend on new knowledge; the second is related to support for the national or regional innovation system in the formation of networks and the connection among agents; the third is the most distinctive of the three and is related to the transformative innovation policy, in which socio-technical systems of production and consumption related to the fulfillment of the Sustainable Development Goals (SDGs) are encouraged (Schot and Steinmueller 2018). The three types of policies are represented in Fig. 2.

The first two types of conventional innovation policies focus on the general increase in competitiveness and economic growth of nations (Haddad et al. 2022). Still, they are considered inefficient in facing global social and environmental challenges (Diercks et al. 2019). Although not replacing the previous types (Diercks et al. 2019), the transformative innovation policy presents the intentionality and directionality of incentives for innovative solutions that meet society's needs as relevant characteristics (Weber and Rohracher 2012). Thus, instead of focusing on a

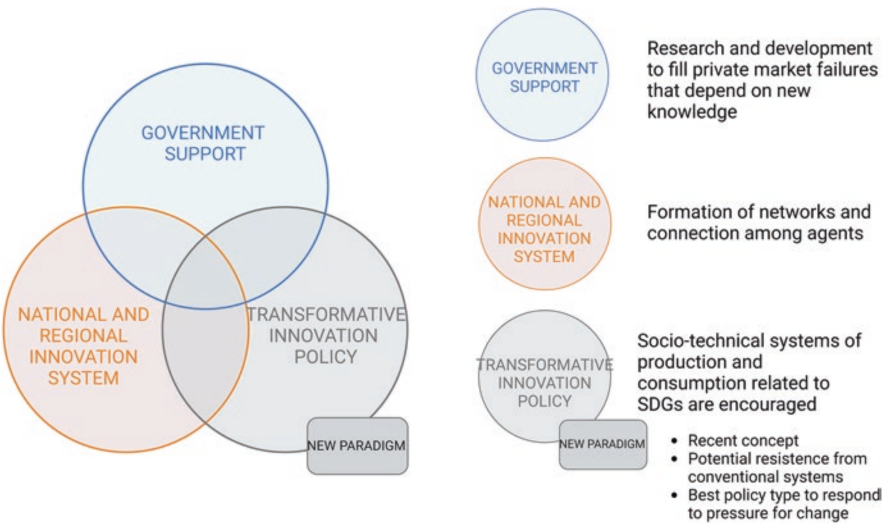

Fig. 2 Types of policies to boost science, technology, and innovation according to Schot and Steinmueller (2018) and relevant information in the context of innovative meat production systems. Created with BioRender.com

specific domain of knowledge or on the development of an innovative technology that is being demanded by the market, the transformative innovation policy aims at a concrete, multidisciplinary challenge that generally affects the global context socially or environmentally.

By defending that innovation should not be sought only for economic development but mainly to solve major societal challenges (Haddad et al. 2022), transformative innovation policies usually encounter resistance from conventional systems. The literature has already emphasized that industries within dominant systems are likely to resist significant technological changes in their business models (Turnheim and Geels 2012). The dominant regimes begin to suffer when some actors abandon behaviors, beliefs, and values that sustain the current systems (Kainiemi et al. 2019). On the other hand, existing industries, although generally highly resistant to change, begin to abandon the existing system when institutional patterns, such as social behaviors, public policies, and economic issues, increase the pressure for change (Turnheim and Geels 2012).

Although the focus of transformative innovation policy is often evidenced mainly in supporting emerging niche innovations (Fagerberg 2018; Smith and Raven 2012), the implementation of measures to destabilize existing systems is also necessary if they represent obstacles to the socio-technical transition process towards sustainability to support more sustainable innovations (Kivimaa and Kern 2016). Turnheim and Geels (2012) agree that the transition to sustainable systems is multifaceted and includes destabilizing harmful systems or those that contribute little to sustainability. The destabilization of dominant systems is also essential to make room, or windows of opportunity, to advance niche technologies (Ghosh et al. 2021), especially if they are more sustainable and ethical than the previous ones. International organizations and recent studies (Brassesco et al. 2022; Bigliardi and Filippelli 2022; Herrero et al. 2020; Moberg et al. 2021) have warned that future technologies and systemic innovation are crucial for transforming the food system, one of the most relevant and complete socio-environmental impacts.

The literature on transformative innovation policies has been advancing in various directions, pointing to the need for direct action to strengthen and stimulate systems that contribute more to global sustainability, especially new clean energy generation systems and innovations that enhance people's quality of life. In this chapter, we argue that government agents may take a set of actions related to transformative innovation policy to facilitate the transition to a more sustainable and ethical food production system. These policies may accelerate the transition process and make it fairer and more inclusive, with supportive actions to mitigate challenges as changes disturb the status quo.

4 The Emergence of Alternative Proteins in a Complex Scenario

Alternative proteins comprise products generally made from plants and cell cultures that can replace conventional meat (Onwezen et al. 2021). However, substantial changes in public policies may be necessary for its insertion into the market. A study on cell-based meat policies reveals that countries and regions justified their support for cultivated meat to implement action plans for decarbonization and food security. However, the main policies observed are related to regulations and focus on safety and security (Miyake et al. 2022). Although these measures are already being taken in some regions around the world, they are still non-existent or incipient in many places.

Other studies also point towards implementing transformative innovation policies in the protein food production system. Herrero et al. (2020) propose accelerating a healthier food production system, including alternative proteins, to reduce the demand for animal farming products, which have a more significant environmental impact and are associated with animal suffering, slaughter, and excessive land use. These actions address specific incentives for alternative sectors, a friendly regulatory environment, and stakeholder dialogue.

Bryant and van der Weele (2021), Morais-da-Silva et al. (2022) and Newton and Blaustein-Rejto (2021) argued that countries may face challenges due to changes in the food production matrix, especially those with sizable conventional production. It is important to consider that challenges are likely inevitable because technological advancement is global, the reasons for changes are clear, and any specific disincentive actions will not be sufficient impediments to stop alternative protein advancement worldwide. However, advantages are not so straightforward if the challenges seem to be posed. To take most advantage of the potential benefits of the emerging sector, including economic, social, and other benefits, countries need to engage in joint efforts, starting with government public policies to strengthen the sector. In addition, superior policies tend to emerge as central actors are heard, such as universities, companies, and society (Morais-da-Silva et al. 2022).

Considering the imminent scenario of change (Gerhardt et al. 2020) and the reasons for the development of alternative proteins (Sinke and Odegard 2021; Heidemann et al. 2020; Nobre 2022), distinct actions are being carried out around the world regarding public policies to support the emerging sector. We highlight, in particular, structural dimensions of planning, including supranational, national, and local plans, as well as specific policy actions that have been applied or that seem important at this time, i.e., at the beginning of the transition to alternative food production systems.

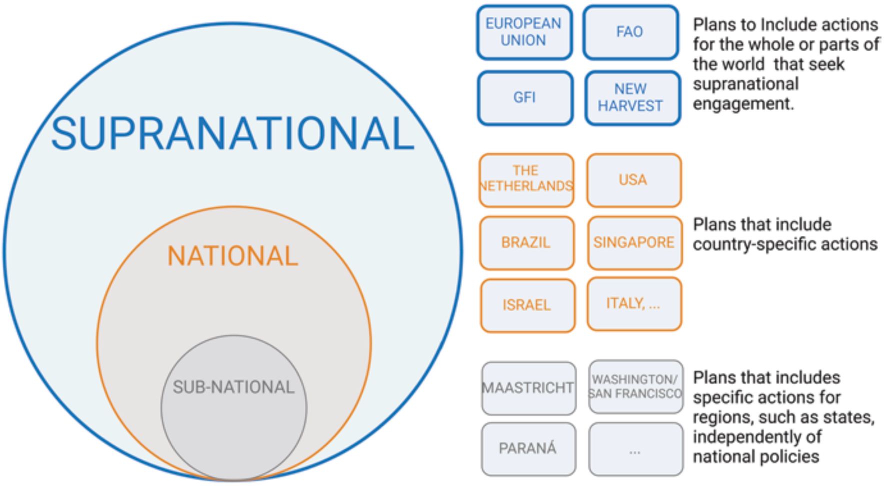

Fig. 3 The three dimensions of supranational, national, and sub-national planning and examples of the diverse engagements of different government agencies and other institutions in the sector. Created with BioRender.com

5 Structural Dimensions of Planning

There are different dimensions of planning and policy development to advance alternative protein fields. In different parts of the world, the landscapes of policies around cellular agriculture seem to be taking different shapes. We present the three dimensions of supranational, national, and sub-national planning and show examples of the diverse engagements of different government agencies and other institutions in the sector. This is a very dynamic area, and this section presents a picture of the three dimensions in 2023, discussed to provide an inspiring and historical description (Fig. 3).

5.1 Supranational Plans

Since transitioning to more sustainable food production systems is a global challenge, some institutions have been drawing up plans and engaging actively in different countries in global integration. For example, the Food and Agriculture Organization of the United Nations (FAO) focuses on supporting governments and development agencies by coordinating activities to improve and develop agriculture and food systems. It operates in 130 countries, and its goal is to achieve food security for all and guarantee that people have regular access to high-quality food. By providing expertise and facilitating international cooperation, the FAO plays an important role in the development of alternative proteins, such as publishing reports that aim to gather state-of-the-art knowledge in the field and making it accessible to different stakeholders (FAO 2023).

As a second case of supranational action, the European Community established the European Green Deal (EGD) in 2019 to be climate-neutral in 2050. The deal has 0.6 trillion € investment from the Next Generation EU recovery plan—part of the EU's 7-year budget (European Commission 2023a). The European community also presented The Farm to Fork in 2020 as a fundamental strategy for the previously mentioned agreement. It aims to make food systems fair, healthier, and environmentally friendly. The strategy seeks to accelerate the transition to a sustainable food system with neutral or positive environmental impact, reverse biodiversity loss, ensure food security, nutrition, and public health, and preserve food affordability while generating fairer economic returns. Although the initiative of plant protein is mentioned, there are more initiatives related to clean energy, as we can observe in the suggestion to the farmers to use renewable energy in their properties (European Commission 2023b). As the strategy has ambitious objectives, proportionally sized initiatives are required for key areas. So far, European countries have adopted different strategies regarding alternative proteins. France and Italy maintain a more conservative position, especially regarding cultivated meat, while The Netherlands, on the opposite side, has made significant investments to develop robust alternative protein chains. The country was one of the first to invest in cellular agriculture and, in 2022, recommitted 60 million € in funding for the development of the industry (GFI 2023a).

In the European context, Cellular Agriculture Europe (Cell Ag EU 2023) is a representative agency for the alternative protein sector. Cell Ag EU has affiliations with several startups in the industry, such as Mosa Meat and Super Meat and leading established firms, such as Nestle, which seek to actively contribute to the advancement of alternative proteins within the European territory. Besides the plans from traditional organizations, there is increasing action by non-governmental organizations, such as The Good Food Institute (GFI) and New Harvest. The GFI is a non-governmental organization founded in 2016 that promotes the transformation of the food system to a more sustainable, secure, and just protein supply (GFI 2023b). They have offices in the United States, Brazil, Israel, India, Asia-Pacific and Europe. The institute aims at changes in the food system with an impact on policies, industry, and science. With a broad range of industry analyses and knowledge-sharing through their reports, besides connecting players, they have made a relevant contribution to the alternative protein field. With an important participation in the definition of labelling, mainly with plant-based products and regulatory frameworks, GFI's contribution to alternative protein policies is present in all countries where they maintain offices.

New Harvest is also a non-governmental organization founded in 2004 to support open and public research on cultured meat. To maximize the impact of cellular agriculture, the organization provides funding for research through research fellowships and seed grants, among other initiatives (New Harvest 2023). New Harvest evaluates the cultured meat ecosystem and fosters collaboration between industry and academia through conferences and dialogues among various stakeholders. This collaborative effort helps build a core community for developing this emerging sector and its leaders. By engaging with diverse stakeholders and being a trusted organization, New Harvest is able to engage in productive discussions on crucial topics within this new sector. Initially operating in Canada and later in other countries, the organization played a significant role in facilitating the production of the first cultured hamburger in 2013 by Professor Mark Post, scientist and founder of Mosa Meat, a cultured meat company in the Netherlands. New Harvest coined the term "cellular agriculture"; interestingly, the term was cited in the United Nations' Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report in 2022.

5.2 National Plans

Some countries have stood out internationally for their development plans for the alternative protein sector. The Netherlands has been in the cultured meat media spotlight since Mark Post's first cultured meat burger in 2013. In 2020, the Dutch Government released its National Protein Strategy (Ministerie van Landbouw, Natuur en Voedselkwaliteit 2020), which aims to consolidate the country's leadership in the alternative protein sector and implement a strategy focused on addressing climate change and biodiversity loss due to food production. According to the GFI (2023a) The Netherlands set the world record for funding cultivated meat and cellular agriculture capabilities by committing $66.2 million to "building a full cellular agriculture ecosystem". That investment will fund cultivated meat and fermentation research, commercialization, education, and workforce transition programs."

On the other side of the Atlantic, a powerful player in food production is also active. The United States attracted worldwide attention in 2023 as two companies (GOOD Meat and UPSIDE Foods) cleared the final regulatory processes and were authorized to be the first ones to commercialize cultivated chicken. These are positive developments since the Biden Administration's 2022 Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy (The White House 2023a) and the 2023 biomanufacturing workforce plan (The White House 2023b), which aims to expand training and education opportunities for American citizens in biotechnology and biomanufacturing. Among the specific objectives of these guiding plans, they aim to offer direction to different government organizations regarding the engagement of relevant federal education and training programs. They also recommend new efforts to promote multidisciplinary education programs. A few excerpts of their contents: (1) US education and training programs can meet the rapidly changing skill needs for good jobs and careers in the bioeconomy and increasing demand for workers; (2) a diverse pipeline of workers, including women, people of color, people living in rural communities, individuals with disabilities, justice-involved individuals, individuals returning to the workforce, and others underrepresented in emerging fields, can prepare for, secure, and advance in good bioeconomy jobs and careers;

(3) federal resources are directed at evidence-based education and training approaches that advance equity. In addition, in 2022, according to GFI (2023a) "US Congress appropriated nearly $6 million for alternative protein research for the USDA's Agricultural Research Service, representing a $1 million increase over the previous year."

In May 2022, China published the Five Year Plan for the Development of Bioeconomy, which encompasses synthetic protein as it promotes the development of the biological agriculture industry. The plan identifies four priority areas for the development of the bioeconomy, including biomedicine, bioagriculture, bioenergy, and biological materials, to be at the forefront of the bioeconomy by 2035. It also looks for improvements in market access policies, establishing a biological product and biotechnology system that considers environmental risk assessment (NDRC 2022). The nation's first 5-year plan for the bioeconomy includes exploring alternative proteins as novel foods (Morton et al. 2023).

Under the Government-wide New Zealand-Singapore Enhanced Partnership, the Ministry of Business, Innovation & Employment (MBIE) and the Agency for Science, Technology and Research (A*STAR) have jointly announced the launch of the New Zealand-Singapore Bilateral Research Programme on Future Foods in May 2019. This Programme aims to deepen bilateral cooperation with Singapore across five main pillars: trade and the economy; defense and security; people-to-people; science, technology and innovation; and climate change and sustainability. In 2022, the Enhanced Partnership was extended to include a new pillar focused on climate change cooperation called the "Green Economy" pillar. New Zealand's investments within the Program amount to NZ$11.8 million.

On December 1st, 2020, the Singapore Food Agency (SFA) approved the public sale of Eat Just's cell-grown chicken in Singapore. This was the world's first regulatory approval of a cultured meat product. Singapore's government is supporting innovation in the sector as part of a strategic vision of the city-state to produce 30% of its own food needs by 2030, known as the 30 by 30 goal (MFAT 2020).

In 2015, cultivated meat companies were created in Israel, consolidating their role as pioneers in alternative protein innovation worldwide. Currently, 58 companies and startups are active in the field, 15 of which are in the area of cultivated meat (GFI Israel 2023). The country's investment in alternative protein companies started with $14 million in 2018, growing to $114 million in 2020 and increased 450% in 2021, with Israeli startups raising some $623 million in investments, according to GFI Israel (2021).

In Brazil, the Ministry of Agriculture and Livestock—MAPA—the Ministry of Science, Technology, and Innovation—MCTI—along with the Financer of Studies and Projects—FINEP—a Brazilian public company promoting science, technology, and innovation, allocated up to BRL $50 million in projects for the productive chains of the bioeconomy (MCTI 2022) and to foster new ingredients, alternative proteins, and emerging technologies (MAPA 2022). The MCTI Bioeconomy Productive Chains Program, targeted at both scientific research and businesses, focused on addressing bottlenecks within its chains. Meanwhile, the MAPA FoodTech program aimed to develop innovative solutions aligned with the thematic areas of research networks, technology-based entrepreneurship, and technological challenges.

As with individual responses, countries also vary in their enthusiasm and acceptance towards cultivated meat. Some countries are experiencing an active movement of organizations that aim to slowdown or prevent the development of cellular agriculture. Perhaps the most emblematic case is that of Italy, which in 2023 witnessed the creation of an alliance that brought together 39 associations under the leadership of Coldiretti and Slow Food. They aim to oppose the introduction of cultured food in Italy, reclaiming the defense of conventional meat (Gaddi 2023). However, in October 2023, Italy officially withdrew the notification for the bill that prohibits the production and sale of cell-based meat and the use of names such as burgers, schnitzels, and the like for plant products. No ban can be approved or come into force because it has not been subject to scrutiny and approval by the EU. The withdrawal of the notification can be seen as a way to avoid an official rejection by the European Commission, and at the moment, it puts a stop to the measure (Pomo 2023).

In virtually all countries there are initiatives in opposition to the development of cultivated products and markets, but these are rarely dominant. For some countries, the discussion is delayed by silencing, which may be either an absence of understanding of the magnitude of the meat revolution that is on the horizon or a strategy to deal with novelty. It is logical to expect different attitudes to lead to different actions and results. Thus, the frequently asked question of whether or when cell-based products will reach price parity and be widely available for consumers has no pre-set answer, as this depends on decisions yet to be taken. Within this context, there is a major role for decisions on national public policies in terms of how policies that either favor the status quo or innovative systems will be maintained, abandoned or expanded, and implemented, especially considering timeframes.

A final note on the national dimension of governance is to mention the potential role of independent Cellular Agriculture Associations, nicknamed Cellags. They may result from efforts stemming from the industry, the scientific community, or both and are formed by those interested in contributing to a better understanding of the possibilities of cell-based foods and alternative proteins in general. Cellags have been constituted in many countries, such as the Netherlands, Germany, Portugal, France, Italy, Greece, Canada, Brazil, and Australia; the equivalent Cellular Agriculture Society (CAS) is in the United States. Their role is usually associated with harmonizing efforts, bringing actors together to catalyze results and avoid the hurdles of many people or institutions working individually, needlessly replicating similar initial steps. Depending on the degree of representativeness each Cellag achieves in its country of origin, they may influence public policies directly by providing high quality information and consultancy, and indirectly, through providing significant support at different levels and contexts relevant to developing cell-based food systems and chains.

5.3 Subnational Plans

It is common for countries to have regional specificities, which holds true regarding food production. For example, it was from Maastricht, in the Netherlands, that in 2013 came the first cell-based hamburger. Later, an important project on milk production by precision fermentation started in Wageningen. Are these initiatives pointing towards the establishment of regional cellular agriculture niches within the Netherlands? The government has put efforts into developing clusters of specialization in different regions of the country and, in this sense, making them poles to attract and concentrate professionals and investment, fostering the development of these regions. This is an interesting question also because it may show how key subnational plans may be, especially when considering key food production countries with vast geographical areas such as the United States, Australia and Brazil.

Some States are historically bolder in pushing for innovations in the United States, as epitomized by Silicon Valley in California. By 2023, two startups had the approval from the US Department of Agriculture (USDA) to market cell-based products. Good Meat, a subsidiary of Eat Just and Upside Foods got the approval to produce and commercialize cell-cultivated chicken, and their products are first going to be served in specific locations in Washington DC and San Francisco (CA).

Subnational planning is also emerging in Brazil, an important player in food-producing activities worldwide. Regarding funding, two States in Southern Brazil were pioneers in using public money to fund cellular agriculture projects: Rio Grande do Sul and Paraná, the latter being more recent and more substantial. State government support in Paraná allowed for the establishment of a network of research groups called the New Arrangement for Research and Innovation in Alternative Proteins (NAPI PA). This project, funded by the Fundação Araucária, the Paraná State agency that supports scientific research, technology and innovation, aims to strengthen the state of Paraná as a food producer and to promote cell-based products with added value by using local breeds of cattle and pigs.

Federal public policies may tend to the subnational level of planning if they foster regionally customized actions. In addition, state-level public policies may be more dynamic and agile, even if they are less robust in funding capacity, especially when state funding agencies are present. Regional policies may provide an interesting aid to the development of cellular agriculture, as they are inherently tailored to the local pre-existing strengths as well as specific bottlenecks. Their efficiency is likely highest when they are embedded in well-designed national policies.

6 Public Policy and Governance Actions

The public policy plans are, in general, guidelines for future actions, which in the case under consideration here concern alternative proteins. In addition, more specific governance actions may also be taken. Based on Biscarra-Bellio et al. (2023), fifteen distinct actions have been classified within three main domains: societal dialogue, changes in policies and regulations, and the design of market initiatives. We highlight four of such actions for their especially relevant role in the development of cellular agriculture. These are: the support of dialogue between university and industry, transparency, education and training, and support for conventional producers willing to transition.

6.1 Support for Dialogue Between University and Industry

The innovation development process is recognized as complex and non-linear, with the participation of several actors (Carayannis and Campbell 2009, Etzkowitz and Leydesdorff 2000). Despite this traditional understanding, several barriers still hinder collaboration between actors to develop innovations (Bruneel et al. 2010). We will especially highlight the difficulties and the potential for collaboration between industry and university, as they are at the frontier of developing products based on cultured meat. According to Wilkinson (2023), until recently the industry used to incorporate small changes to adapt to demands from society, frequently as alterations in the final stages of production such as labels with renewed terminology, a process known as delayed innovation. However, industries perceive benefits in embracing more radical innovation (Wilkinson 2023). This is followed by impressive private research funding, which tends to be more efficient when collaborating with academia; otherwise, the chances of publicizing results are much lower. If this is so, why is there a need to support the dialogue between university and industry?

On one hand, companies traditionally focus on capturing relevant knowledge to gain a competitive advantage in the market (Dasgupta and David 1994). For these organizations, the knowledge created is primarily hidden within the organization or disclosed superficially, mainly for patent registration and, consequently, market monopoly for some time (Dasgupta and David 1994). On the other hand, universities are more focused on general social welfare and knowledge sharing. Even though they are immersed in a system that is unfavorable to frontier information sharing, as the current scientific publication system adopts a posture that hampers the wide dissemination of new knowledge, including high costs to access scientific articles and the inability to access raw research data (Budzinski et al. 2020; Molloy 2011), academic institutions remain the stronghold of knowledge sharing. As more research data and articles are made freely available, the degree of transparency of the scientific process and the overall social benefit will increase (Molloy 2011).

Accordingly, attention has been drawn to the partnership between industry and university since this collaboration's potential contribution to innovation is recognized (Nsanzumuhire and Groot 2020). In the case of cultured meat as a radical innovation in food systems, there remain many challenges to be overcome through scientific research, mainly concerning technological development, costs, and ingredients. The literature has highlighted, for example, that the use of fetal bovine serum, something ethically controversial and costly, is one of the great challenges to overcome (Soccol et al. 2023). However, the company Eat Just recently announced that it had received approval from the Singapore Food Agency to use fetal bovine serum-free culture media (The Straits Time 2023). Therefore, the collaboration between the two groups of actors may evolve beneficially for all.

A major advantage is that current challenges in food production technology via cell cultivation may be more quickly resolved if university and industry collaboration were prioritized. Universities offer distinct scientific expertise, experience with cutting-edge research, already established laboratories and legitimacy in relation to research results, interpretation and conclusions. The industries offer real challenges that they have been facing in their development structures, in addition to support in the financing of collaborative research. Through specific public policies for this type of collaborative research, the government may provide its share of the necessary resources. In this way, all actors win and scientific progress in the field moves faster and more efficiently, as harmonized efforts build a solid pillar for this evolution.

6.2 Transparency

Cellular agriculture technology has been mobilizing promises and expectations over the past decades. However, incipient and modest efforts to provide adequate information to the general public, capable of fostering science-based debate, make it difficult for an educated conversation on cultivated meat by society. Amoore (2020) pointed to the problem of the "black box" when constructing a public debate around the societal impacts and implications of technology. According to the same author, transparency and accountability are made difficult to access, reflect and discuss by the wider public due to the opacity of information given by technology developers. Also, according to Beumer and Edelenbosch (2019), when assessing potentially disruptive innovation, the research and the expectations are commonly articulated within the walls of individual organizations, making it difficult to have an informed societal debate.

An additional important factor to consider is that a significant portion of the entrepreneurs in the field of cellular agriculture either are or used to be scientists in the field. Thus, attention to the claims made by such actors benefits from considering both positionalities and the interests involved when the same individual is concomitantly a scientist and a capitalist entrepreneur. "When wearing a public entrepreneurial hat, they might make strident claims about the promise of their research, but when among research peers, they will be much more cautious and equivocal, though publicly still committed to the promises associated with their field" (Borup et al. 2006). One major challenge of the field regarding transparency is the unequally distributed access to knowledge, where information is contested and strategically used according to the different actors and interests that play unequal roles in the debate (Brown and Michael 2003). Finally, language is a bottleneck to be overcome as it can hinder transparency and fruitful debate. It is important to translate scientific language to comprehensible information for everyday conversational use. In addition, because English has become the official language in research and science, essential terms that are required to refer to aspects of new technologies are invariably in English. Thus, for countries where English is not the first language, there is a fundamental need to establish specific terminology in the local language, as this is a matter of local accessibility to the discussion (Garbin et al. 2024).

The importance of transparency and the pitfalls to avoid may be better understood by considering the lack of transparency in conventional animal farming. In part, the intensive animal farming sector has responded to the growing criticism it receives by hiding their practices and problems. The most symbolic example of this strategy is the passage of ag-gag laws in some American states, which contain provisions prohibiting taking or possessing photographs, video, or audio recordings from an animal farm without the farm owner's consent. Robbins et al. (2016) have studied how awareness of ag-gag laws eroded trust in farmers and demonstrated that even the intention to restrict access to information could undermine trust. A proactive stance fostering transparency is likely the best approach to a sound relationship between the food industry and society, allowing consumers full access to knowledge and understanding of all aspects of their food choices.

Therefore, we believe that efforts to provide full access to definitions, opportunities and challenges, as well as scientific advances related to alternative proteins, are warranted. As with any field, the essential knowledge to make informed decisions must be within the reach of public debate. This seems even more relevant because cellular agriculture involves human nutrition and deep-rooted cultural aspects.

6.3 Education and Training

In addition to the relevant role of universities in knowledge sharing, they are the place where professionals get the needed qualifications and abilities for adequate performance in their jobs. In the special case of developing a completely new and worldwide food industry, a spate of new jobs requiring new education will likely involve all stages of the cell-based food production chain. Although novelty touches all stages, it is estimated that the biggest transformations occur upstream in the production chain, as cell-cultivation processes aim to substitute animal raising and slaughter processes. We take Brazil as a concrete case to discuss the challenges that seem to lie ahead in terms of education and training, for reasons related to the country's sizeable meat industry, the availability of scientific papers discussing the potential social impacts of cellular agriculture for Brazil, and our more direct knowledge regarding the context of this country.

The low qualification of the Brazilian workforce, especially in the initial stage of conventional animal food production, i.e., farms and slaughterhouses, may be a relevant bottleneck for the development of cellular agriculture. The arrival of alternative proteins may help raise worker qualifications since most job opportunities in the new production chains will be for workers with higher qualifications (Morais-da-Silva et al. 2022). It remains open to debate whether the necessary efforts, including public policies and governance, will be made to convert this bottleneck into an opportunity. This highlights the immeasurable importance of appropriate policies.

In alignment with research initiatives, Brazilian universities are gaining momentum in teaching and training activities. The Federal University of Paraná (UFPR), Brazil, in partnership with the GFI, offered three editions of the course "Introduction to cellular animal science" in the postgraduate Program in Veterinary Sciences, starting in 2020, and an optional course was approved in 2023 for undergraduate programs in veterinary medicine and animal sciences. The State University of Campinas (UNICAMP), in the State of São Paulo, offered the course "Alternative Proteins: Made of Plants, Fermentation and Cultured Meat," in the postgraduate program of the Faculty of Food Engineering in 2022. In other universities where cultivated-meat research is conducted, there is evidence of a ripple effect in education, as students get involved and the discussions ignite on campus, in a sort of teaching through the grapevine. For instance, the Federal University of Minas Gerais recently released its cell-based chicken proof of concept, as their students organized their participation in a network of students interested in cellular agriculture maintained by the GFI, regardless of the absence of an organized undergraduate course in this university so far.

Additional initiatives around education and training have been taken in Brazil by the GFI. For instance, the GFI offers an open-access online course "The Science of Alternative Proteins," in Portuguese. Thus, it is evident that there are increasing opportunities to learn about cellular agriculture in Brazil, including formal initiatives that can evolve to contribute to fulfilling the demand for new professionals in the nascent alternative protein industry.

Many countries have also initiated relevant initiatives. In the United States, The Cellular Agriculture & Bio Fabricated Foods, organized by Tufts University, is a permanent course in the Biomedical Engineering Department. In the Cellular Agriculture & Cultured Meat Lab, students designed and taught the first undergraduate lab course for cellular agriculture techniques through the Tufts Experimental College. The University of North Carolina (UNC) launched one of the first classes focused exclusively on cellular agriculture. The course was developed in partnership with students from the Chapel Hill Alt Protein Project, a student organization developed with support from the Good Food Institute. In Australia, the association "The Cellular Agriculture Australia (CAA)" launched the country's first online course on cellular farming in conjunction with industry, academia, and regulatory organizations.

In Singapore, Nanyang Technological University (NTU) launched the first university course on alternative protein. The undergraduate course "Future Foods—Introduction to Advanced Meat Alternatives" was developed in partnership with The Good Food Institute.

In the Netherlands, a proposal led by Wageningen University & Research, in collaboration with Maastricht University and Delft University of Technology, has been put forward to develop three courses about precision fermentation, cultured meat, and the societal and sustainability aspects of cellular agriculture.

In Israel, Technion (Israel Institute of Technology) announced the establishment of the "Sustainable Protein Research Center." Addressing the global challenges of climate change, human health, and nutrition. Technion launched a multidisciplinary research center for sustainable proteins, which will function as a hub for fundamental and applied research in alternative proteins, commercialization, entrepreneurship, and research support for the industry and education. In Canada, the University of the Fraser Valley has also been presenting some initiatives around training.

Besides new courses on cellular agriculture, a more transversal approach seems also warranted. In Brazil, according to Biscarra-Bellio et al. (in preparation) there are some mandatory courses in veterinary medicine, animal science, bioengineering and food engineering programs that, despite their focus on conventional animal protein production or research, can be adapted and expanded to relate to different stages of the cell-based meat chain. Additionally, there are courses present in some programs that have more specific content directly related to the new technology of cell-based meat production, which can serve as a basis for creating new courses to be implemented in the curricula of all interested programs. The structuring of syllabi, courses and programs will be necessary for the preparation of qualified labor in order to mitigate the challenges and foster the opportunities of this new labor market.

6.4 Support for Producers

The agribusiness sector is vital for certain countries and relevant to global food security. Therefore, any alteration in this sector can trigger numerous consequences for different stakeholders and perhaps higher risks for producers. Thus, it is common for public policies to support farmers. Created in 2003, the Brazilian "Plano Safra" is a successful example of a public policy that supports producers regarding financing. However, such policies must adapt to the increasingly prevalent new reality: producers who need to diversify or transition from animal production. For example, in 2022 the Dutch government established a policy of acquiring properties to reduce the emission of environmentally harmful gases banned by the European Union (Boztas 2022).

If cellular agriculture takes a prominent position in the total protein market, leading to progressive decreases in the market share of conventional producers, the most affected producers may be those on small farms due to the lack of scale and consequently less competitive advantage (Morais-da-Silva et al. 2022). Research conducted in 2022 and 2023 with cattle and broiler producers in Australia and Brazil, two of the main producers and exporters of animal protein, revealed that some producers are seeking alternatives to animal production. However, they reported a lack of knowledge on choosing a new business model and the absence of structured demand. In addition, there is no government support or policies to assist them in making this decision and economically surviving the risks of transitioning. As such, some farmers reported feeling at a loss and prone to failure, with no financially viable alternative business (Bogueva et al. 2023).

Public policies can be developed to assist producers in capitalizing on the opportunities of alternative proteins within the emerging market. As outlined in Bogueva et al. (2023), some key points were identified by the producers to mitigate risks in diversification. They are (1) identifying new demands for primary products considering liquidity, financial return, and suitability for the region's soil and climate, (2) sharing information and success stories in a manner accessible to producers, and (3) establishing the market and supply chain for cellular meat.

For identifying the primary products considering demand, liquidity, financial return, and suitability for the region's soil and climate, policies encouraging research and projects in collaboration with public institutions and a multidisciplinary team of professionals—economists, agronomists, and veterinarians—are necessary. Ideally, such a collaboration can identify market needs and assess the product's viability in the specific production region. As for sharing information and success stories in a manner accessible to producers, traditional outreach programs may be launched. Research findings can be disseminated to producers through pamphlets and local events, enabling them to access information on how best to address eventual challenges they may face. Likewise, promoting best practices is always welcome, fostering a virtuous cycle of success.

Finally, producers need some level of risk control to feel safe in diversifying their activities, and the establishment of the market and supply chain for cellular meat can aid risk reduction. The alternative protein sector is in its developmental stages, and policies that encourage this market, ensuring producers some demand, are essential. For instance, traditional agricultural products are promoted in the media and the stability of a strong alternative protein industry depends also on a similar level of promotion to consumers. This approach tends to increase information, exposition and awareness among consumers, thereby reducing potential neophobia. Additionally, the supply chain and other aspects of the alternative protein sector need further development. The collaboration among the government, market stakeholders, and producers to determine the optimal model for each stage of the chain is crucial for the scalability of this market.

6.5 A Broader View

The establishment of new production chains for alternative proteins to feed humans and animals is based on biotechnological advances that have been considered the second domestication, which is the domestication of cells (Tubb and Seba 2019). This points to the enormity of the transformation that has just started, a major movement in the way humans produce food, only comparable with the domestication of animals 10,000 years ago. With this magnitude, the recruitment of a complex range of public policies and additional governance actions is required. Thus, a dynamic

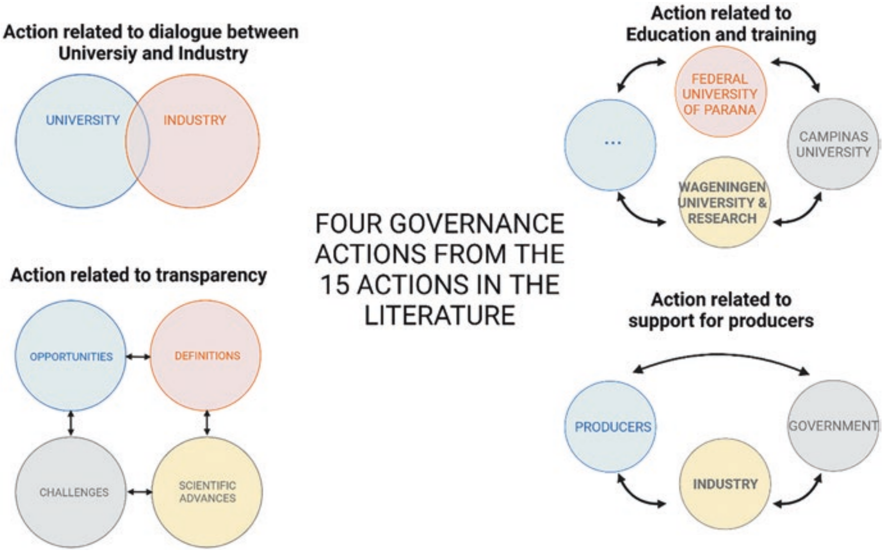

Fig. 4 Summary of four governance actions selected from the 15 actions presented by Biscarra-Bellio et al. (2023). Created with BioRender.com

process of maturing the fifteen actions such as research and teaching, dialogue, transparency, awareness, inclusion, basic education, differentiate strategies, differentiate countries, inclusions as private goals, policies for transition, funding programs, marketing regulation, the inclusion of externalities, tax benefits and market incentives, proposed by Biscarra-Bellio et al. (2023) is to be expected. Investments in additional research on the fundamentals of governance seem strategically sound for this radical innovation to achieve its full disruptive potential in an equitable and just manner, which leaves no one behind. For the actions described, collaboration and developing a network that facilitates understanding gaps and needs are essential. It is not reasonable to expect that the incredible advances provided by biotechnology suffice to advance in relation to the many social needs involved; a proportional movement must be enacted in public policies and governance (Fig. 4).

7 Challenges and Future Developments

Forecasts indicate that a significant portion of the protein market will come from alternative proteins in 10–15 years. Some of these projections suggest that 22% of the market will be alternative proteins by 2035 (Witte et al. 2021), while others indicate 60% by 2040, with cultivated meat responsible for 35%, as stated by Gerhardt et al. (2020). Several variables can affect these predictions, including consumer acceptance, market supply and development, regulatory advancements, and levels of investment and public policies. Regarding public policies, they seem to require reforms to change the current food systems, as current public policies primarily focus on the existing production system, maintaining the status quo. Therefore, a natural first task is to identify the changes required to encourage alternative proteins through public policies and governance.

In Herrero et al. (2020), actions are proposed to accelerate the development of a more sustainable food system. The speed of innovation depends on appropriate incentives, regulations, and social license, which, in turn, are related to constructive dialogue with stakeholders and transparency regarding the paths to follow. Some actions are suggested to accelerate the transformation. To build trust among the stakeholders in the food system is a key point in this process. For systemic changes to occur, industries must identify the opportunity; governments must recognize the need for change to achieve prosperity and well-being; a dialogue with citizens must be conducted to change attitudes; and public policies and investments that encourage such changes must be implemented. Considering those points, governments can lead in facilitating and communicating why and how to innovate, and a high-level agreement on new directions seems fundamental (Herrero et al. 2020).

Despite the benefits, alternative proteins also pose challenges, frequently mentioning social issues. In Morais-da-Silva et al. (2022), both social opportunities and challenges were identified. Among the opportunities are the provision of inputs to the new sector, new jobs and better conditions and wages for workers, the possibility of reducing food insecurity, and a greater ethical consideration for both human and non-human animals. Among the challenges are the reduced demand for conventional animal protein and reduced employment in the first stages of the conventional chain (Morais-da-Silva et al. 2022), which may be felt in the long term. However, if planning is not carried out in time, the challenges may have a significant impact, as conventional animal production is currently of great importance to the income of numerous families and the economy of some countries, including Brazil. The study concludes that the threats will occur regardless of engagement with the new sector because the scenario depicts an imminent change in the global consumption pattern. In contrast, the opportunities will be seized only by the countries that invested and developed the alternative protein chain. Thus, public policy and governance for the development of cellular agriculture seem extremely important to reduce potential negative social impacts and create social opportunities.

8 Conclusion

Our study sought to clarify how public policies may be better addressed to support the transition to cell-based foods as more sustainable means of protein production and consumption. Our discussions led to a series of cases of supranational, national, and local agents developing medium and long-term planning actions and more specific ones.

The development of public policy and other aspects of governance are essential to guide public investments and highlight the alternative protein sector in social, investment, and technological development discussions. The public sector may also take specific actions in partnership with institutions of other dimensions, such as support for collaborative research and transparency about all aspects of cellular agriculture. We also argue that there is a need for significant advances in education and training so that people may seek jobs in the emerging sector. Finally, we emphasize that conventional farmers, primarily linked to family animal farming, need support to adapt and diversify their production to seize the possible opportunities. Thus, the role of public policies remains central in the transition to alternative proteins, even considering a partial transition. Governments worldwide have taken both general and more specific actions, but many countries have not yet presented decisive actions regarding the issue. As this is a complex path, it is likely that the sooner each country discusses and implements the best public policies and actions, the better prepared it will be for this emerging sector and all the accompanying opportunities.

As technology advances faster with increasing levels of financing or funding, it may become harder for inactive countries to jump in. This wave of technological development may represent numerous benefits in terms of sustainability, animal ethics, and food production capacity, but it also means new global economic arrangements. Countries that prefer to stay out of this new technology in food production may suffer the negative consequences of this potential transition without reaping part of the benefits due to the technological and implementation delays they will face. Therefore, it is highly recommended that a transformative innovation policy capable of directing technological development towards a level of collective well-being be designed to foster alternative proteins, along with proper governance actions.

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