Cleaner and Responsible Consumption 22 (2026) 100456

Contents lists available at ScienceDirect

Cleaner and Responsible Consumption

journal homepage: www.journals.elsevier.com/cleaner-and-responsible-consumption

Forces pushing forward or holding back? Drivers of cultured meat transition in Southern Africa up to 2070 through a Real-Time Delphi study

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ARTICLE INFO

Keywords:
Cultured meat
Force field analysis
Drivers of change
Real-time Delphi
Southern Africa

ABSTRACT

Cultured meat, or lab-grown meat, is an emerging alternative protein gaining increasing attention in food sustainability discussions. However, its transition dynamics in developing regions such as Southern Africa remain underexplored. While futures studies commonly identify drivers of change, it often gives limited methodological attention to how these drivers are assessed. This study addresses this gap by integrating Real-Time Delphi (RTD) and Force Field Analysis (FFA) to evaluate the relative influence of drivers shaping the cultured meat transition in Southern Africa over 45 years, covering 2025 to 2070. Data was collected from 30 experts (n = 30), from 10 countries using the 4CF Halynx 2.0 platform. Four driver categories emerged i.e., production, consumption, mrga-blueprints, and 4th Industrial Revolution Technologies & their higher version (4IRTs+). The findings indicate that all driver categories exhibit a positive net force, suggesting an overall directional momentum towards transition. However, high levels of expert divergence highlight significant complexity and uncertainty regarding the feasibility, pace of transition, and socio-cultural acceptance. Key enabling drivers include population growth, urbanisation, climate change, food insecurity, and 4IRTs+. Socio-cultural dynamics, regulatory complexities, and higher comparative prices of cultured meat to conventional meat were identified as inhibitors. The study advances futures studies methodology by demonstrating how the combination of RTD and FFA enables clearer quantification and qualification of driver directionality, though with reservations concerning potential over mathematisation of uncertain futures. Theoretically, the study moves beyond descriptive mapping of change drivers by embedding transition analytic theories. Policy implications point to adaptive and transparent regulatory frameworks, investment in culturally grounded innovations, assimilation of 4IRTs+, investment in biotechnological and bioprocessing infrastructure if transition is to be attained.

1. Introduction

The demand for sustainable proteins has generated significant interest in novel food innovations, such as cultured meat (Bisht et al., 2025a; Kamalapuram et al., 2021; Ye et al., 2022). Pioneered as a sustainability innovation, cultured meat promises scalable, nutritious, environmentally sustainable, and ethical proteins for the burgeoning global population (Bisht et al., 2025a; Soleymani et al., 2024). Its emergence is propelled by population growth amid sustainability challenges in the incumbent protein value chain, which is dominated by conventional livestock farming. Currently, agricultural activities occupy about 50% of the world's habitable land, generate approximately 1.3 billion tons of waste annually, and consume 70% of the available freshwater (Mazzamuto et al., 2025; Smith et al., 2024). Livestock farming alone uses approximately 70% of agricultural land and accounts for about 18% of the world's greenhouse gas (GHG) emissions (O'Mara, 2011). In total, livestock provides 40% of humanity's protein requirements (Smith et al., 2024; Terpou et al., 2025), while the remainder comes from plants. Despite the sustainability concerns of environmental degradation, biodiversity loss, socio-economic challenges, and ethical issues associated with livestock farming, the sector is expected to grow beyond planetary boundaries (Lumsden et al., 2024),

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https://doi.org/10.1016/j.clrc.2026.100456
Received 18 December 2025; Received in revised form 9 June 2026; Accepted 20 June 2026
Available online 23 June 2026

to meet the rising demand for protein (Liu et al., 2023) The 2050 economic and population growth projections anticipate a 21% increase in meat consumption per capita, which will lead to a 63% increase in GHG emissions (Henchion et al., 2021; Lumsden et al., 2024). It is against this backdrop that cultured meat, together with other alternative proteins such as insect-, fungi-, and algae-based proteins, has emerged at the forefront of protein sustainability transitions (Ahmad et al., 2025; Gallen et al., 2022; Yu et al., 2025) (see Fig. 1).

In Southern Africa, protein deficiency persists despite the dominance of livestock rearing. The region records the lowest protein intake per capita, after Central Africa, West Africa, and Southeast Asia (Vissamsetti et al., 2024), with 67 g per capita per day, compared to the global average of 84 g per capita per day. Meat is an important source of proteins, iron, zinc, Vitamin B12, and other nutrients; yet it remains inaccessible in some regions, such as Southern Africa. The Southern African Development Community (SADC) reported food insecurity and protein deficiency, highlighted by cases of stunted growth among infants in its member states (SADC, 2022). Since the year 2000, the Southern African population has grown by 37% to 363 million by 2020. About 30% of the SADC population is severely food insecure, 8% is malnourished, while about 50% live on less than $1 per day (Mapiye et al., 2020). As the population of Africa is expected to more than double to 3.2 billion by 2070, the population of Southern Africa is only expected to grow significantly (UN, 2024). In the context of projected population growth, protein deficiency, food insecurity, climate vulnerability, and resource constraints, this study seeks to explore the drivers that may promote or inhibit the transition to cultured meat in the region. The peculiar Southern African socio-economic profile suggests that drivers to alternative protein transition identified in the Global North (Warner, 2019) could behave differently in the region, thus making a context-specific analysis crucial.

While contemporary and novel food research positions cultured meat as a future protein with sustainability benefits (Bisht et al., 2025b; Fernandes et al., 2024; Gu et al., 2025; Pawar et al., 2023), local realities, such as cultural perceptions, food regulation, technological readiness and economic conditions, influence its long-term adoption (Jafarzadeh et al., 2024 Jafarzadeh et al., 2024; Lin et al., 2025; Proi et al., 2025). The socio-technical conditions vary spatially across the globe; thus, it is imperative to take a country- or regional-level approach in analysing the drivers that could influence the future of cultured meat. For instance, the production of cultured meat requires sophisticated bioprocessing infrastructure, a consistent energy supply, clean water, an efficient transportation system, a reliable regulatory framework, and intense scientific research, among other factors (Choi et al., 2025; Garrison et al., 2022; Hossain et al., 2025; Saraswat et al., 2025). These enablers are currently weak in most Southern African countries, as many countries lag in providing basics such as reliable energy (Carson et al., 2018). Despite these obtaining limitations, investments in renewable energy are shaping up (Alex-Oke et al., 2025; Breyer et al., 2023). Cellular Agriculture start-ups are emerging and research on cultured meat is accelerating, (Tobias-Mamina et al., 2025; Tsvakirai et al., 2023). Due to this emergent nature, a foresight approach to forces that could promote and inhibit the cultured meat transition is timely and necessary. Based on the long-run principles of economics, both production and consumption are elastic, it would be overly deterministic to discount Southern Africa basing on current challenges. The study adopts a 45-year horizon (2025 to 2070), which aligns with the long-term continental blueprints such as the Africa Agenda 2063 and the SADC Industrialisation Strategy and Roadmap 2063. Extending the horizon to 2070 enables a full-cycle assessment of cultured meat under these long-term blueprints which we referred to as mega-blueprints in this study. Uniquely, this study conceptualises mega-blueprints as drivers of change themselves, capable of influencing transition pathways. Furthermore, the 45-year horizon is methodologically appropriate given that food transition, particularly those involving deep traditional shifts, unfolds more slowly than other technological innovations such as Artificial Intelligence. Thus, the chosen timeframe enhances robustness by reflecting experts' anticipation of structural and socio-cultural transformations over a long time.

Despite growing global scholarship on protein alternatives such as cultured meat, the literature remains heavily skewed towards Global North contexts (Benussi and Samoggia, 2025), with limited attention to how transition drivers may manifest in Global South regions such as Southern Africa. This current study is perfectly located in Southern Africa within Global South, a region where scholarship of this kind is still emerging and relatively scarce. Moreover, while futures studies and transitional studies commonly identify "drivers of change or forces of change", they often stop short of systematically evaluating their relative strength and direction (i.e., whether these drivers are driving forward as promoters or in resistance as inhibitors) (Dearing, 2000; Hommels et al., 2025; Ketelings et al., 2021; Rad and Sonesson, 2024). This creates methodological and empirical bottlenecks in understanding the competing forces that interact to shape long-term transition, particularly in under-researched regions like Southern Africa. This research is a humble attempt to bridge that gap by adopting Force Field Analysis as a tool to quantify and qualify drivers of change.

This study employs a Real-Time Delphi (RTD) approach, engaging a multidisciplinary expert panel on the 4CF Halnyx 2.0 platform, and integrates Force Field Analysis (FFA) to assess the direction and magnitude of change drivers. The RTD allowed dynamic interaction, capturing experts' assessments in real time, their consensus and dissensus. At the same time, the FFA tool provides a structural framework for evaluating the balance between drivers that promote and those that inhibit transition This methodological integration contributes to foresight practice by moving beyond descriptive identification of drivers towards a comparative evaluation in terms of directional influence and magnitude.

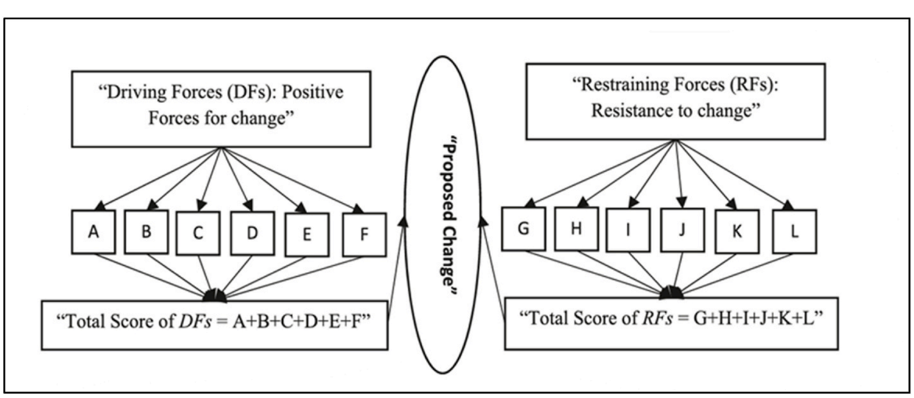

Fig. 1. Driving forces and restraining forces in FFA.
Source: (Erol et al., 2024)

Accordingly, this study is guided by the following research questions: (i) What are the key drivers influencing the transition towards cultured meat in Southern Africa towards year 2070?, (ii) Are these drivers functioning as promoting or inhibiting forces and what are their perceived strengths over the 2025-2070 horizon?, and (iii) Can the FFA tool be adopted to enhance methodological rigour in assessing drivers of change in transitional and futures studies?

By classifying and analysing production, consumption, 4IRTs+, and mega-blueprint drivers, this study contributes more context-specific understanding of cultured meat futures in Southern Africa. This article proceeds by outlining the theoretical framework, methodology, and results analysis. It then offers a discussion of findings through the lens of transitional theories, before quizzing the essence of FFA as a foresight tool, followed by policy recommendations and concluding remarks.

2. Theoretical framework

This article adopted Force Field Analysis (FFA) as a tool for understanding the dynamics of change related to cultured meat in Southern Africa. In the theoretical application of FFA, this study utilises the terms 'forces of change' and 'drivers of change' interchangeably. Kreibich et al. (2011) defined drivers as forces, factors and uncertainties that create or drive change in a business or institutional environment. The term 'drivers of change' is commonly used in foresight and transition studies more often than 'forces of change' (Hommels et al., 2025; Rad and Sonesson, 2024; Vecchiato and Roveda, 2010), though they essentially have the same meaning (Erol et al., 2024). The term forces of change is closely related to the fundamental laws of change in Physics where the FFA has its roots. Peck (2009) highlighted that futurists have much to learn from the Natural Sciences, such as Physics and Chemistry, in their quest to understand the dynamics of social change. This current study offers such a learning opportunity. Originally developed by Kurt Lewin in the 1940S (Erol et al., 2024) FFA has been traditionally applied in organisational and strategic management contexts to conceptualise change as an outcome of driving and restraining forces in each system. The tool gives a structured approach to analysing the balance of forces that sustain or disrupt the status quo. In its classical formulation concept, change occurs when enabling forces outweigh the restraining forces, shifting the entire system towards a new equilibrium.

While FFA has been widely applied in strategic and change management (Hussain et al., 2018), its application in futures studies remains limited and under-theorised. Our study positions FFA not as a predictive tool, but as an analytic lens for structuring and interpreting drivers of change. In futures and foresight science, we understand that all plausible, possible, probable and preferable futures are fundamentally outcomes of interacting drivers of change. From this perspective, FFA offers a simplified mechanism for examining how such drivers may combine, compete or reinforce one another over time to bring new futures, not overlooking the complexity of change dynamics.

The study acknowledges sustainability transition theories (discussed in detail below) and we duly based our analysis and discussion on them. These frameworks provide rich, multilayered explanations of socio-technical transition across niches, regimes and landscapes. We adopt a complementary stance by positioning FFA at a strategic abstraction tool that foregrounds the directional strength of drivers without attempting to fully conceptualise systemic complexities. In this sense, the FFA aligns with the broader transitional literature in its fundamental concern with change processes, albeit at a different level of abstraction, focusing on the net balance of forces in a system. When integrated with established anticipatory methods, such as the Delphi method, FFA becomes a complementary tool for assessing the relative momentum of change drivers shaping futures. Unlike in physical systems, the futures and transitional dynamics of cultured meat are inherently non-linear and deeply embedded in cultural and institutional contexts (Brooks and Place, 2019). The non-linearity underscores the limitations of FFA, particularly its tendency towards reductionism and inherent assumption of equilibrium. The tool tends to mathematise and oversimplify the complexities of drivers' interaction by aggregating them towards net forces. Acknowledging these limitations, this study does not treat FFA as a stand-alone explanatory framework but rather as a heuristic device that complements broader foresight methodologies, in this case the Delphi method.

2.1. Revisiting sustainability transition frameworks

By examining the drivers of cultured meat transition in Southern Africa up to the year 2070, this study is theoretically positioned at the intersection of sustainability transitions and futures studies. Research has demonstrated strong conceptual and empirical linkages between sustainability transition theories and futures studies (Friedrich and Hendriks, 2024; Vähäkari et al., 2020; Zolfagharian et al., 2019) in the pursuit of more sustainable and anticipatory socio-technical futures. The transition towards cultured meat represents one such complex socio-technical transformation, which can be fruitfully examined through the Multi-Level Perspective (MLP), Transition Management (TM), Technological Innovation Systems (TIS), and Social Practice Theory (SPT). This section reviews these frameworks in relation to potential cultured meat futures. Collectively, these frameworks provide a robust analytical foundation for interpreting the RTD and FFA findings concerning possible cultured meat futures in Southern Africa by the year 2070.

The Multi-Level Perspective (MLP), first developed in 2002 by Frank W. Geels, conceptualises socio-technical transitions as long-term, co-evolutionary processes emerging from interactions and tensions between three analytical levels: niches, socio-technical regimes, and the socio-technical landscape (Geels, 2011, 2020; Schot and Geels, 2008). Regimes refer to the dominant structures, institutions, policies, infrastructures, markets, and socio-cultural norms that stabilise existing systems, while landscapes encompass broader exogenous developments such as climate change, geopolitical shifts, and demographic pressures (Schot and Geels, 2008). Niches represent micro-level spaces of innovation where alternatives to incumbent regimes are developed, nurtured, and protected. Within the MLP, transitions occur when landscape pressures destabilise incumbent regimes, thereby creating "windows of opportunity" for niche innovations to break through and gradually reconfigure dominant systems. Cellular agriculture, and particularly cultured meat, has been conceptualised as a niche innovation, while conventional livestock meat production constitutes a historically dominant socio-technical regime (Warner, 2019), increasingly subjected to mounting landscape pressures such as global population growth, climate change, biodiversity loss, technological disruption, and resource scarcity, among others (Bisht et al., 2025; Crawshaw and Piazza, 2023; Jafarzadeh et al., 2024 Jafarzadeh et al., 2024; Mylan et al., 2023; Zhu and Begho, 2022). Learning from the Global North, several sustainability transition studies have explored cultured meat as a disruptive innovation with the potential to destabilise the conventional livestock system. Using the MLP, Moritz and colleagues (Moritz et al., 2022, 2023) examined transition pathways in Germany and Finland, providing comprehensive insights into possible trajectories of cultured meat development. Although the socio-economic contexts of the Global North differ significantly from those of the Global South, these studies nonetheless provide valuable analytical insights that justify the use of the MLP as a relevant framework for analysing drivers of cultured meat transitions in Southern Africa.

Complementing the MLP is Transition Management (TM), focuses on the governance dimension of sustainability transitions, particularly the deliberate influencing and facilitation of long-term systemic change. Developed by Derk Loorbach and colleagues, TM similarly conceptualises transitions as complex, non-linear, and inherently uncertain processes that cannot be fully controlled, but can be guided through participatory visioning, experimentation, learning, and adaptive governance (Loorbach & Rotmans, 2010; Loorbach and Van Raak, 2006). The TM framework operates across strategic, tactical, operational, and reflexive levels, with activities progressing from long-term envisioning towards short-term implementation and iterative learning (Loorbach & Rotmans, 2010). As in the case of the MLP, TM has been widely applied and analysed through foresight lens, particularly in the Global North. For instance, Loorbach and colleagues examined case studies in sectors such as healthcare, roofing materials, and resource utilisation in countries including Belgium and the Netherlands (Loorbach & Rotmans, 2010). In the context of cultured meat, the TM framework provides a valuable lens for understanding how governance actors such as governments, institutions, industry stakeholders, and consumers may collectively shape the future of the meat system through coordinated visioning, policy experimentation, and institutional adaptation.

In contrast to both the MLP and TM, the Technological Innovation Systems (TIS) approach focuses more explicitly on the processes that enable or constrain the emergence, development, and diffusion of new technologies such as cultured meat. Developed by Anna Bergek and colleagues, the TIS framework conceptualises innovation systems as networks of actors, institutions, knowledge, infrastructure, and market structures that collectively shape technological change (Eichhorst et al., 2025; Köhler et al., 2019). The TIS approach is commonly operationalised through seven key system functions: entrepreneurial experimentation, knowledge development, knowledge diffusion, guidance of the search, market formation, resource mobilisation, and legitimation. The drivers of cultured meat transition (Warner, 2019) span a wide spectrum of forces that strongly overlap with these TIS functions. In the Netherlands, Droog (2023) analysed the cultured meat innovation system and identified persistent negative feedback loops among key actors, despite the technology's transformative potential. Similarly, Fornstedt et al. (2025) applied the TIS framework to plant-based meat alternatives in Sweden, with particular attention to the legitimation function. They argue that policymakers should prioritise targeted regulatory legitimacy to accelerate sustainability transitions. Empirical evidence of this nature suggests that the TIS framework provides a nuanced approach of evaluating whether prevailing drivers reinforce or constrain key system functions within the cultured meat innovation trajectory in Southern Africa towards year 2070.

The Social Practice Theory (SPT) departs from system- and governance-centric perspectives by arguing that transitions in consumption and production patterns are embedded within socially shared practices rather than solely individual choices or institutional structures (Venkatraman et al., 2023). Propounded by scholars such as Elizabeth Shove, SPT conceptualises social practices as configurations of three interconnected elements: materials (technologies and infrastructures), competencies (skills and knowledges), and meanings (social norms, values, and cultural interpretations). Socio-technical transitions occur when these elements are reconfigured, displaced, or stabilised in new configurations (Hansen et al., 2021; Shove et al., 2012; Tomiyama et al., 2020).Within the context of our study, the SPT framework extends across the four identified cultured meat driver clusters, making it a particularly useful lens for interpreting RTD findings related to behavioural, cultural, and consumption-oriented dimensions of cultured meat futures in Southern Africa.

Overall, the sustainability transition theories reviewed here provide a robust and complementary analytical foundation for understanding the drivers that may shape the trajectory of cultured meat transition in Southern Africa over the 45-year horizon.

3. Materials and methods

3.1. *Curating the drivers for the cultured meat transition in Southern Africa*

The study filtered drivers shaping cultured meat in Southern Africa through a multi-step process. First, we conducted a targeted literature review, drawing especially from the recent grey literature of FAO, Foresight for Food and Southern Africa regional studies, gleaning drivers shaping the broader food systems (Berkum et al., 2017; FAO, 2023, 2024; Gupta et al., 2025; Jayne et al., 2014). This process gathered a long list of change drivers ranging from population dynamics, climate change, economic growth, innovation and science, epidemic and political dynamics. Second, driver validation process, involving regional experts was implemented to ensure regional relevance. This step was critical in futures studies, where the objective is not merely to identify empirically observable drivers or trends but to incorporate expert judgement on emerging and uncertain drivers (Vecchiato & Roveda, 2010). The drivers were then refined and consolidated into a Delphi instrument that fit a single Delphi study.

Drivers were categorised into four groups: Production drivers (supply-side), Consumption drivers (demand-side), Industrial Revolution technologies based on the 4th Industrial Revolution Technologies (4IRT+), and mega-blueprints. Unlike the conventional classification frameworks such as PESTEL (Political, Economic, Social, Technological, Ecological and Legal factors), this categorisation reflects futures-oriented logic that separates supply side, demand side, technological revolutions and long-term policy blueprints to better capture their differentiated roles in shaping transition. Mega-blueprints included UNSDGs and their successors, the AU Agenda 2063; SADC Industrial Strategy and Roadmap 2063 which are treated as drivers of change due to their agenda setting and anticipatory governance roles. The 4th Industrial Revolution Technologies and their higher versions, hence the + sign, represent possible 5th, 6th, up to the K^{th} Industrial Revolution, within a 45-year horizon (2025-2070) (Grinin et al., 2017). These higher version of 4IRTs are expected to co-develop and influence cultured meat evolution (Idamokoro, 2025; Saraswat et al., 2025).Refer to Table 2 for the final list of drives that appeared on the RTD instrument.

3.2. *Real-time Delphi (RTD) method and instrument*

The study utilised a Real-Time Delphi method to collect data from the regional experts. Unlike the traditional, round-based Delphi (Calleo and Pilla, 2025), RTD allows for more dynamic conversation and iterations within a single continuous discussion. Experts could view anonymised group responses and revise their answers iteratively without enforcing consensus. This aligns with the contemporary application of the Delphi method in futures studies, where dissensus is recognised as an important indicator of uncertainty and contested trajectories rather than a methodological weakness (Rikkonen et al., 2021; Tapio, 2002). It is important to emphasise that a foresight-oriented Delphi study differs fundamentally from conventional survey research. While traditional surveys aim for statistical generalizability through probabilistic sampling and rigorous quantitative research protocols, a foresight-oriented Delphi is a structured experts' elicitation method designed to explore uncertainty, generate informed judgment and support anticipatory thinking where empirical data is very limited or non-existent (Calleo and Pilla, 2023; Fink-Hafner et al., 2019; T. Gordon and Pease, 2006; Marchais-Roubelat and Roubelat, 2011). The focus is not on measuring population parameters but on capturing informed reasoning, divergent perspectives and conditions under which different futures may emerge (Giannarou and Zervas, 2014; Hill and Fowles, 1975; Renzi and Freitas, 2015). Ontologically, just as the outputs of other foresight methods, foresight-oriented Delphi results should not be treated as predictions or empirical realities but as constructed representations of possible futures.

The Real-Time Delphi instrument was administered on the 4CF Halynx 2.0 platform, a premium Real-Time Delphi platform. The instrument consisted of a quantitative component in which experts rated the forces of change on a scale from −3 (inhibiting) to 0 (no influence) to +3 (promoting). The qualitative feature allowed experts to provide the rationale behind their ratings. The comments and perspectives evolve as experts engage in continuous discussion, agreeing and disagreeing in the process.

With prior engagements and pre-survey research ethics protocols completed, data collection commenced on 9/9/2025 and continued until 07/10/2025. Experts were constantly reminded to complete the survey and return to the platform for possible iterations.

3.2.1. Validity and reliability

The study aligned with the onto-epistemological approaches of futures studies to ensure validity and reliability. Essentially, validity and reliability in foresight differ from the rudimentary experimental science research because it does not test fixed truths in the present but explores uncertain and not-yet-existing futures (Piirainen et al., 2012). That being the case, we would rather reinterpret validity and reliability concepts than abandon them. Validity typically asks truthfulness, accuracy, and appropriateness (Peeters and Harpe, 2020), which is difficult to test in futures studies. Rather, in futures studies validity pertains to plausibility, internal consistency, and usefulness in decision making (Piirainen et al., 2012).

Instrument validity was ensured through a multi-step process. Content validity was established through a structured expert review involving futures studies experts, particularly experienced experts at 4CF, and other multidisciplinary academics, who assessed the adequacy of the driver items in representing the domain of cultured meat transition in Southern Africa. Experts were engaged in developing the RTD instrument to ensure construct, content, and criterion validity. Second, random pre-tests of the instrument were conducted, ensuring that it enlists what it is supposed to. Most importantly, a primer was included in the pre-survey to ensure maximum reflexivity and reduce expert presentist biases (details about the primer is beyond the scope of this article). Reliability is about replicability and accuracy of research (Peeters and Harpe, 2020). Unlike in conventional research, replication is unrealistic in foresight, as contexts change, participants differ, and the truth is conjectural (Adams et al., 2026). Thus, process robustness and traceability become key to reliability. The study addressed reliability through consistent method application and transparency in documenting data sources and analytical steps.

Table 2
Drivers promoting/inhibiting cultured meat transition up to 2070.

Drivers promoting/inhibiting cultured meat transition up to 2070	Mean score	Standard Dev	Enabler/ inhibitor Ally/Foe
Production drivers up to 2070			
Human capital development in Biotech and related fields	+1.67	1.83	enabler
Power and Energy development	+1.37	1.67	enabler
Financial architecture	+0.88	2.67	enabler
Tech -infrastructure and Bioprocessing equipment	+0.65	2.11	enabler
Politics and governance rhetoric	+0.20	2.08	enabler
Regulatory framework, licensing and competition laws	−0.42	2.08	inhibitor
Consumption drivers up to 2070			
Population and urbanisation trends in SADC	+2.04	0.99	enabler
Responsive to marketing and branding	+1.86	1.03	enabler
Net effect if cultured meat is priced lower than conventional meat.	+1.74	0.85	enabler
Net effect if cultured meat is priced higher than conventional meat	−0.55	0.88	inhibitor
Food security dynamics in Southern Africa	+1.23	2.22	enabler
Climate change and ecological dynamics in Southern Africa	+0.87	2.21	enabler
Socio-cultural dynamics in Southern Africa	−0.88	2.29	inhibitor
4th Industrial Revolution Technologies (4IRTs+)			
Green energy transition	+2.06	1.21	enabler
Artificial Intelligence and Machine Learning	+1.92	1.32	enabler
Biomanufacturing and Genetic Engineering	+1.90	0.77	enabler
Advanced Robotics and Automation	+1.85	0.89	enabler
Additive manufacturing, Blockchain technologies, etc	+1.53	1.40	enabler
Mega-blueprints as drivers			
Is cultured meat an ally or foe to the SADC 2063 industrialisation agenda	+0.78	1.89	ally
Is cultured meat an ally or foe to the AU Africa Agenda 2063	+1.05	1.67	ally
Is cultured meat an ally or a foe to SDGs	+1.43	1.34	ally

3.3. Participant selection and data collection

A Delphi expert is someone with substantial knowledge and experience in the subject or its complementary fields (Devaney and Henchion, 2018). Like in the conventional meat industry, the cultured meat industry value chain could be diverse and intertwined with cultural, economic, and political systems. Cognizant of this reality, the study drew on experts from Biotechnology, Genetic Engineering, Food Science, Agriculture, Energy, and Culture, among others, with at least 5 years of experience (see Table 1). Experts were identified through publications, LinkedIn profiles, and referrals by fellow experts. A total of 90 experts were invited, and 35 responded. After excluding incomplete submissions, 30 valid responses from 10 countries were retained. In contrast to conventional research, foresight-oriented Delphi studies value experts' diversity, engagement of participation over statistical representation and probabilistic representativeness, though these elements remain important. (Gordon and Glenn, 1999; Meijering et al., 2013).

Table 1
The Delphi expert panel.

SADC Country	Biotech & GE	Food Science	Economics	Food Systems & Ecology	Energy	Culture	Health	Research	Other fields	Total
Zimbabwe	2B, 1M	2M, 1L	1M	1PhD, 1M				1PHD		10
Zambia				1M				1PhD, 1M	1M	4
South Africa	1M	1M								2
Lesotho			1M		2M			1M		4
Namibia						1 PhD				1
Botswana		1M							1L	2
Mozambique							1B			1
Malawi	1B									1
Africa outside SADC										
1. Rwanda				1PhD		1M		1PhD		3
2. Kenya				1PhD				1M		2
Total	5	5	2	5	2	2	1	6	2	30

Qualification key.
1. PhD-Doctoral Degree holders.
2. M-Master's Degree holders.
3. B-Bachelor's degree holders.
4. L-Lower than a bachelor's degree, e.g., Higher National Diploma.

3.4. Dealing with uneven samples

Although there is no universally agreed-upon size for a Delphi panel, the literature suggests that an optimal panel size falls between 8 and 30 experts (Beiderbeck et al., 2021; Hasson et al., 2025; Rowe and Wright, 1999), though a larger, more representative panel is preferable. Whilst sampling was conducted with an average target of 6 Experts per SADC country, the response rate was low in many countries. Nevertheless, the study recorded an uneven distribution of experts across the region. To empirically assess the potential bias arising from the over-representation of Zimbabwe, an internal robustness test was conducted. Zimbabwe responses ($n = 10$) were aggregated separately and compared with the full dataset ($n = 30$) across all 21 drivers. The similarities in mean scores and standard deviations across drivers indicate that the overall distribution and directional trends were not materially influenced by the imbalance. Based on this observation maintained the sample because the iterative nature of the RTD thrived on the strength of arguments and collective reasoning rather than participant distribution.

3.5. Data analysis

Data presentation and analysis followed the driver's categorisation and the FFA tool. The use of the mean was appropriate in this context because the objective was to derive a directional assessment of each driver consistent with the logic of FFA. The symmetric scale (−3 to +3) allowed the mean scores to serve as a clear, interpretable indicator of whether the driver promotes or inhibits the transition to cultured meat. The analysis also relied on reporting standard deviations to flag consensus and dissensus. This was essential in a foresight-oriented Delphi, where divergence of opinion is often as informative as convergence (Tapio, 2002), especially in this study, where outcomes would proceed to scenario generation. Qualitative justifications were also considered as reasoning behind the ratings.

4. Results

This section presents results from expert assessments. The mean score and standard deviation of each driver are reported to indicate the

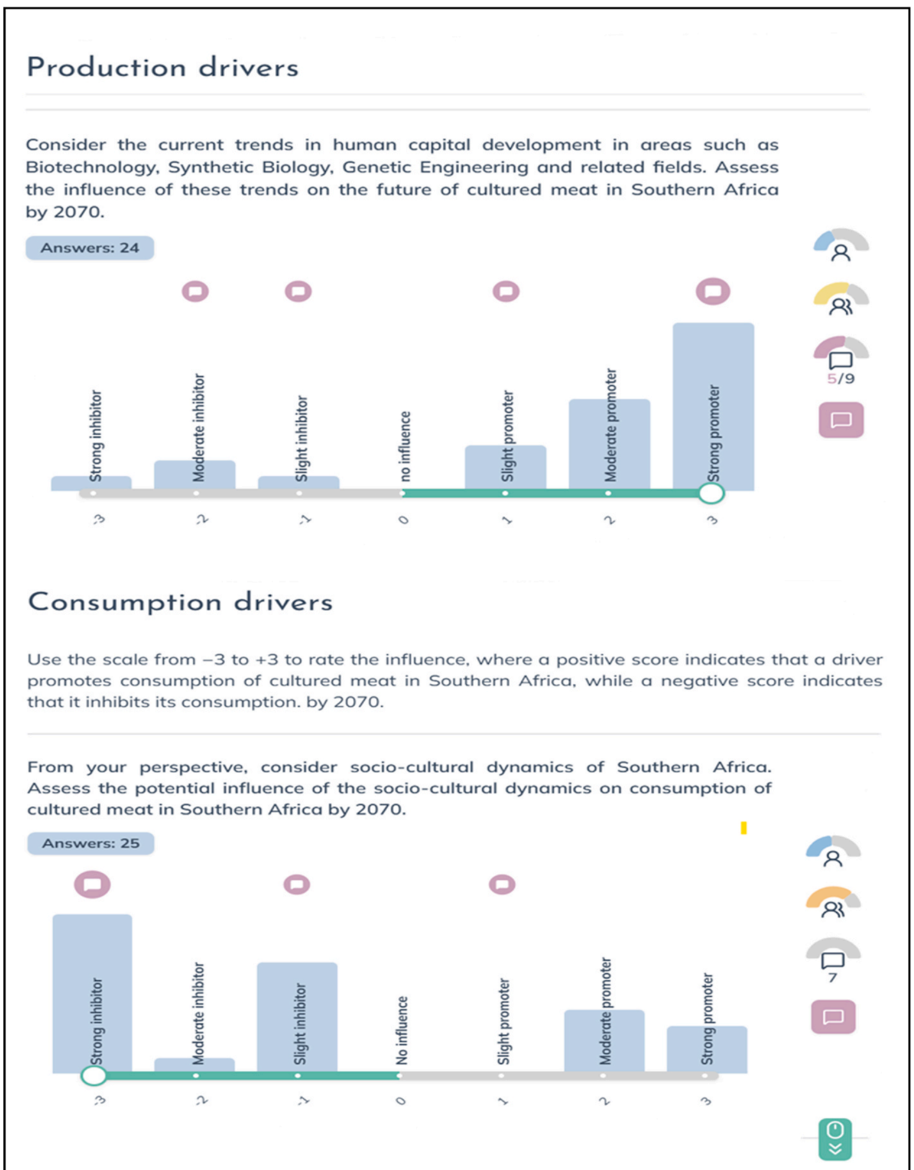

Fig. 2. Screenshots of the Cultured 2070 survey on the 4CF Halynx 2.0 platform.
Source: Authors

perceived direction (i.e., promoting or inhibiting) and the variability, respectively). The FFA diagrams are presented in thematic clusters: production, consumption, industrial revolution technologies, and mega-blueprints. Results presented are descriptions of expert perceptions rather than predictions of future outcomes. The Net Force values represent aggregated directional tendencies for each cluster and should be interpreted as heuristic indicators rather than deterministic forecasts. Across all clusters, the results show mixed mean scores ranging from negative to positive, with high standard deviations (see Table 2), indicating substantial disagreement among experts. The recorded divergence reflects the higher level of uncertainty and contested nature of the cultured meat transition, which should not be mistaken for a lack of analytical coherence.

4.1. Drivers for cultured meat production

Overall, the production cluster recorded a positive Net Force of +4.35 (see Fig. 3) (see Fig. 2). Mean scores ranged from −0.42 to 1.67 albeit with high standard deviation ranging from 1.67 to 2.08. Human capital development in biotechnology and related fields (+1.67) recorded the highest positive rating followed by power and energy development (+1.37), financial architecture (+0.88), technological infrastructure and bioprocessing equipment (+0.65) and politics and governance rhetoric (+0.20).

The regulatory frameworks, licensing and competition laws were identified as an inhibitor among production drivers (−0.42). with a large standard deviation (SD = 2.08).

4.2. Drivers for cultured meat consumption

The consumption drivers show a stronger positive effect than the production drivers, with an overall Net Force of +6.34 (see Fig. 4). Mean scores ranged from −0.88 to +2.04.

Population and urbanisation trends recorded the highest positive rating (+2.04), followed by responsiveness to marketing and branding (+1.86) and lower prices of cultured meat compared to conventional meat (+1.74). Food security dynamics (+1.23) and climate change &ecological dynamics (+0.87) were also rated as enablers. Socio-cultural dynamics (−0.88) and higher prices of cultured meat relative to conventional meat prices (−0.55) were identified as inhibitors with contrasting variations in expert ratings (SD = 2.29 and 0.88 respectively)

4.3. 4th industrial revolution technologies and their higher versions (4IRTs+)

The IRTs + cluster recorded the highest Net Force value (+9.28) among all the cluster (see Fig. 5). All the drivers in this cluster were rated positively with mean scores ranging from +1.53 to +2.06. Green energy transition recorded the highest mean score (+2.06), followed by Artificial Intelligence and Machine Learning (+1.92), biomanufacturing and genetic engineering (+0.90), advanced robotics and automation (+1.85) and additive manufacturing & blockchain technologies (+1.53).

Standard deviation ranged from 0.77 to 1,40 representing lower variation in expert assessment when compared with the other three clusters, production, consumption and mega-blueprints.

4.4. Mega-blueprints and cultured meat

The mega-blueprints cluster recorded a positive Net Force value of +3.26 (see Fig. 6). The mean scores ranged from +0.78 to +1.43, indicating positive assessments across the three blue-print categories.

The United Nations Sustainable Development Goals (UNSDGs) received the highest mean score (+143), followed by African Union Agenda 2063 (+1.05) and the SADC Industrial Strategy and road mapping (+0.78). Standard deviation ranged from 1.34 to 1,89 indicating moderate variation among experts' assessments. Notably, the three mega-blueprints were identified as allies to cultured meat transition.

5. Analysis

The results depict a directionally positive yet structurally contested landscape for cultured meat transition in Southern Africa. Although all four driver clusters (production, consumption, 4IRTs+, and Mega-blueprints) reported positive net forces, the relatively high standard deviations indicate substantial uncertainty regarding pace, and trajectory of the transition. Rather than reflecting a linear transition pathway, the findings suggest an emerging socio-technical system characterised by competing expectations, uneven capabilities and contested visions of the future. From a transition perspective, the findings can be interpreted through the lens of transition frameworks.

5.1. Supply-side niche formation under structural constraints

The production drivers exhibit a moderate positive Net Force of (+4.35), suggesting a perceived niche development potential within the regional bioeconomy (Tobias-Mamina et al., 2025b). Human capital development (1.67 ± 1.83) and energy systems (1.37 ± 1.67) emerged as key enabling forces; however, both are characterised by high dispersion, indicating uncertainty in the niche-stabilisation conditions in Southern Africa. Analysing through the MLP lens, the findings reflect cultured meat as an emerging technological niche whose development depends on capability accumulation through biotechnology skills, green

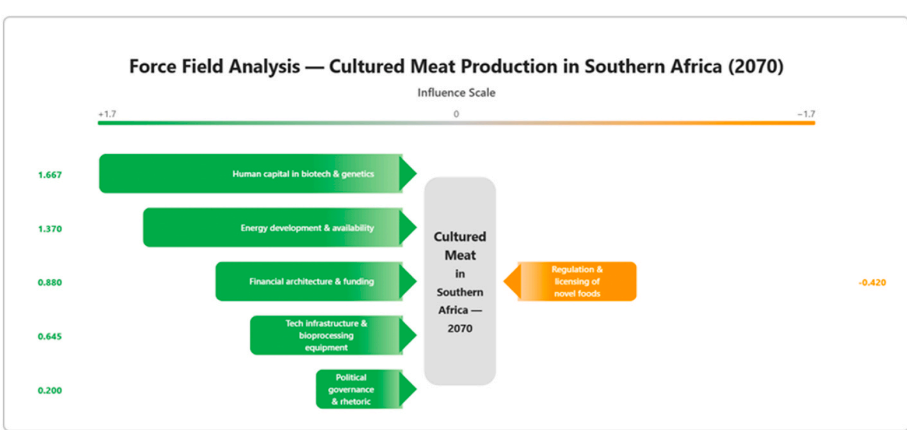

Fig. 3. Production drivers. Net Force (4.77 -0,42 = +4.35).
Source: Authors

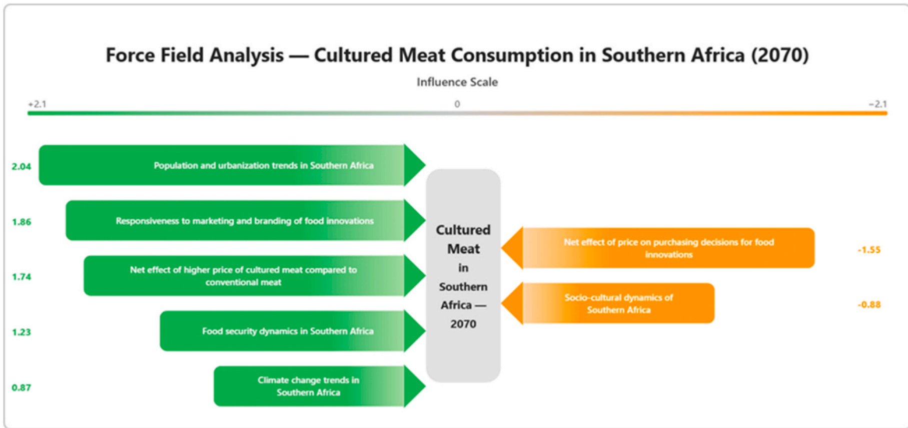

Fig. 4. Consumption drivers. Net Force (7.77-0.88-0.55 = +6.34).
Source: Authors

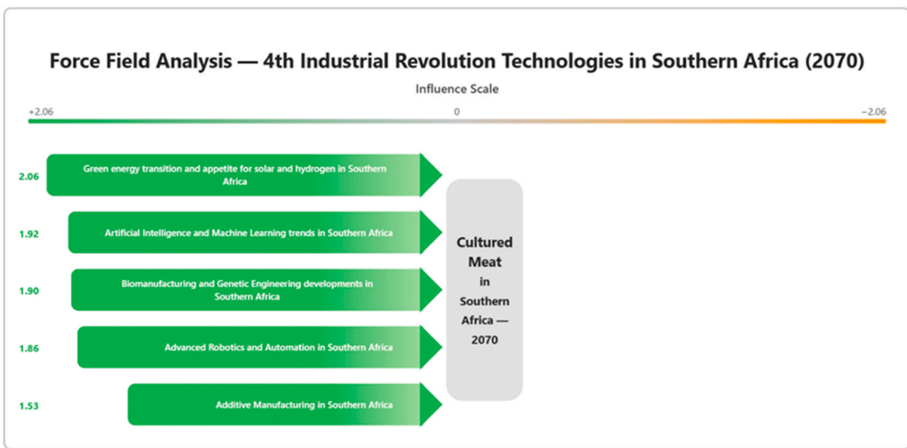

Fig. 5. 4IRTs + drivers. Net Force (+9,28).
Source: Authors.

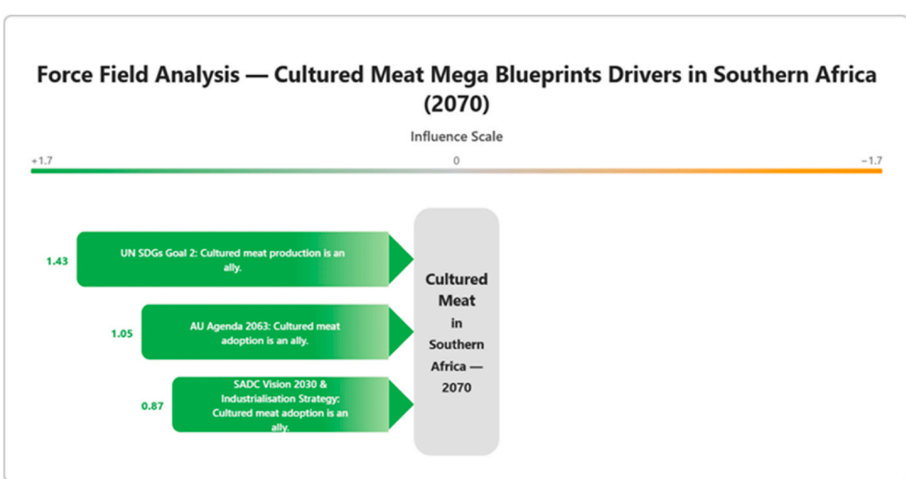

Fig. 6. Mega blueprints. Net Force (3.26).
Source. Authors 2025

energy development, and financial injection enabling bioprocessing infrastructure. However, the high variation among experts' assessments suggests that niche stabilisation remains vulnerable to broader socio-economic and institutional conditions. From the TIS perspective, the Human capital development driver contributes directly to functions of knowledge development and knowledge diffusion, while biotechnology infrastructure, energy systems and financial architecture strengthen entrepreneurial experimentation. However, the functions appear only partial through persistent brain drain and infrastructural limitations (Nelson and Nelson, 2002; Williams and Crush, 2005). The financial architecture emerges as a tying node linking up Biotech infrastructure, human capital and energy. The negative ratings assigned to regulation and governance (−0.42) are significantly when analysed from the MLP and TM. Within the MLP framework, regulatory systems constitute part of the technical regime that governs licensing, market participation and production standards. Negative ratings on regulation represent regime-level constraints that may inhibit niche expansion. Within the TIS framework, it points to a weakness in the function of legitimation. The absence of a clear regulatory pathway reduces investor confidence, reduce entrepreneurial experimentation, thus weakening expectations of future market formation.

Overall, the production cluster of drivers reflects a potential cultured meat that is structurally dependent on regime transformation and landscape-level support.

5.2. *Demand-side potential under social-cultural uncertainty*

Consumption drivers record a firmer Net Force of +6.54, indicating a perceived positive directional trajectory in the demand-side evolution of cultured meat relative to production systems. The results suggest that demand -side conditions may evolve more rapidly than production capacity creating the possibility of future imbalances between demand and regional supply. Within the MLP framework, population growth, urbanisation, food security issues, and climate change are interpreted as landscape pressures acting upon the conventional livestock regime. The pressure originates outside the immediate control of actors within the incumbent meat production system but create conditions that may destabilise the existing meat production system thereby opening opportunities for alternatives such as cultured meat. The positive ratings assigned to these drivers indicate experts perceive increasing structural pressures to the traditional livestock production. Population growth and uncontrolled urbanisation particularly received strong expert support. However, the transition is not linear or automatic as opportunities created by landscape pressures do not guarantee regime transformation. There are other conditions that mediate in the transitional matrix for example price parity. From a TIS perspective, the ability of cultured meat to establish a viable market niche depends not only on technological feasibility but also on economic competitiveness and socio-cultural acceptability. The variations reflect competing interpretations of the landscape pressures therefore uncertainty regarding magnitude and timing of landscape induced regime destabilisation. Socio-cultural dynamics emerged as the strongest inhibiting force within the consumption cluster, therefore, suggest uncertainty regarding the magnitude and timing of landscape-induced regime destabilisation. Socio-cultural dynamics emerged as the strongest inhibiting force within the consumption cluster. From the Social Practice Theory perspective, the socio-cultural dynamics mean shows that meat is not merely a food commodity but a cultural product whose consumption is rooted in practices involving meanings, traditions, values and identities. Consequently, reservations on cultured meat reflects forms of cultural lock-ins (MLP) rooted in cultural reproduction rather than purely economic and technological consideration. However, the high variation associated with the driver indicates that cultural resistance is neither uniform nor universal within Southern Africa. Overall, the consumption cluster suggests that while landscape pressures points to alternative proteins, regime-level cultural dynamics could constrain the pace and direction of transition.

5.3. *4th industrial revolution Technologies+ (4IRTs+) as transitional accelerators*

The 4th Industrial Revolution Technologies+ (4IRTs+) cluster recorded the highest Net Force value (+9.28), indicating the strongest perceived influence among all driver clusters. Green energy, Artificial Intelligence, biomanufacturing, advanced robotics and related technologies were viewed as the positive potential contributors to the cultured meat transition towards the year 2070. Analysing through the TIS perspective, these technologies can rapidly strengthen multiple innovation functions at once, such as knowledge development, entrepreneurial experimentation, resource mobilisation and market formation. The relatively high mean scores and lower dispersion among experts indicate a higher degree of consensus regarding 4IRT's + influence on accelerating the transition. Within the MLP, 4IRTs + can be understood as a mechanism that expedites activities within the innovation niches and facilitates interactions with broader socio-technical transformation processes. The technologies could contribute towards reconfiguration of production systems, supply chains, business models and consumer engagement mechanisms, thus seamlessly promoting niche expansion towards transition. The findings resonate with the SPT as 4IRTs + could reshape material elements, enhance the actors' competencies and modify the meanings associated with meat consumption. Nevertheless, uncertainty remains regarding the speed of innovation, adoption, adaptation, scale and equitable distribution of these technologies. Overall, the 4IRTs + emerged as powerful transition drivers, but their impact remains contingent upon their assimilation into the future meat industry.

5.4. *Mega-blueprints interpretive ambiguity*

The mega-blueprints cluster recorded a positive Net Force (+3.26), reflecting the general compatibility of cultured meat to long-term development agendas. However, the relatively modest scores and high standard deviations suggest that such alignments remain contested and open to interpretation. From a Transition Management perspective, these mega-blueprints such as UNSDGs, AU Agenda 2063; SADC Industrial Strategy 2063 serve as strategic visions intended to motivate and coordinate shared goals, expectation on food innovations. The findings indicate a perceived alignment between cultured meat and UNSDGs than the continental and regional blueprints. From an MLP, mega-blueprints can be understood as landscape level institutions that shape the broader expectations regarding desirable futures. For example, SDG number 2 on Zero Hunger and goals number 2, 3 and 4 of the AU Agenda 2063 are relatable to the cultured meat transition. The influence is indirect but significant since these blueprints affect policy priorities, regulatory frameworks and funding allocation at regional and government level. Overall, the findings suggests that mega-blueprints, in their quest for sustainability indirectly supports cultured meat transition. The variance points to a significant policy gap, particularly around issues of meat independence, meat democracy and sovereignty.

6. Discussion

Cultured meat futures in Southern Africa remain largely unpredictable and open to debate. The study results should not be interpreted as predictive outcomes but as grounded representations of expert judgments under uncertainty, a case typical of foresight-oriented Delphi studies (Rowe and Wright, 1999). This discussion moves beyond the descriptive presentation of the expert rankings in Section 4 to provide analytical interpretation of the findings through the lenses of Multi-Level Perspective, Technological Innovation Systems, Transition Management and Social Practice Theory. It critically examines how the observed patterns of driver strength and discrepancy shape the prospects for cultured meat transition in Southern Africa.

Contrary to current realities, the results unexpectedly position production drivers in a positive momentum, which is uncharacteristic of a region grappling with energy deficits, water scarcity, and other supply-side limitations (Apraku et al., 2023; Ndubuisi and Avenyo, 2024; UN, 2018). The results aligned with potential futures shaped by incremental socio-economic progress and policy shifts (Boamah, 2020; Mujeeb et al., 2025). From the MLP angle, these developments represent strengthening niche conditions that could support the emergence of cultured meat as an alternative socio-technical configuration. The anticipated improvements in biotechnology capacity and renewable energy systems indicate niche building that could gradually challenge the incumbent livestock-based meat regime. Similarly, the TIS view these as strengthening functions of knowledge development. Knowledge diffusion and resource mobilisation are necessary for technology maturation and commercialisation. These optimistic production driver results are consistent with the literature, which positions Africa as emerging industrial hub after India and China (African Development Bank, 2019; Giallourakis, 2021; UN, 2025). In line with the findings, nascent developments in regional research have gained prominence in fields such as biotechnology and tissue engineering (Parawira and Khosa, 2009). Local universities are introducing new degree programs in fields aligned with cellular agriculture, confirming the development of human capital coupled with the green energy transition (Mirzania et al., 2023; Olanrewaju-Elufowoju et al., 2026). While experts project potential development in biotechnology capacity and green energy systems, expectations are strongly moderated by dissensus, particularly regarding infrastructure readiness and institutional capabilities by 2070. The uncertainty is not only about technological progress but also about the ability of regional systems to retain, integrate and scale up knowledge capabilities (Williams and Crush, 2005). Within the MLP framework, the finding suggests that though niche innovations may be emerging, they may not achieve sufficient stability to exert the transformative pressure on the incumbent regime (Geels, 2019a, 2020).

On the other hand, regulation and governance appear as typical regime-level constraints (Geels, 2011, 2020; Pay and Gianoli, 2024), suggesting potential institutional inertia, policy ambiguity, and governance systems opposed to cultured meat. More importantly, the data suggest that production drivers are not independent variables but part of the incumbent system. From a TIS perspective, the regulatory uncertainty erodes the legitimation and guidance search functions. The findings therefore suggest that governance is not merely an external factor but a mechanism for shaping the performance of an innovation system. For example, regulatory uncertainty may influence financial flows, which in turn affect human capital retention and infrastructure development. This understanding reinforces the systemic nature of transitional dynamics, which cannot be fully captured by force field analysis alone but by models such as Technology Innovation Systems and Transitional Management (Edsand, 2019; Nelson and Nelson, 2002; Pay and Gianoli, 2024).

Findings on consumption drivers show greater consensus on demand-side pressures than on production conditions. Population growth and urbanisation emerged as the major promoting drivers, a position supported by population projections for Southern Africa which is expected to double by 2070 (Smith et al., 2024). While the demographic pressures are empirically grounded, their straightforward translation into transitional pathways remains uncertain. Food security and climate change drivers reinforce the demand for alternative proteins, as they exert pressure on the incumbent regime of traditional livestock farming. Consistent with our findings, literature on cultured meat often references MLP landscape pressures such as population growth, food insecurity, climate change and biodiversity loss as the foundational basis for sustainable food innovations such as cultured meat (Bisht et al., 2025b, 2025a; Doraiswamy Iyer and Krishnan Iyer, 2020; Nyika et al., 2021; Pay and Gianoli, 2024; Treich, 2021). However, dissenting panel opinions downplayed the projected impact of climate change on livestock production, citing climate adaptation practices such as climate-smart livestock rearing (Fushai et al., 2025).

The findings amplify price parity not only as a driver but also as a regime-switching condition, a position widely supported in cultured meat innovation literature (Doraiswamy Iyer and Krishnan Iyer, 2020). Within the TIS, price parity can be interpreted as a market formation function that determines whether cultured meat can move beyond protected niche spaces into the mainstream market. However, uncertainty persists even if price parity is met because food switching is not merely a rational economic challenge, but a complex decision mediated by multiple factors (Pay and Gianoli, 2024).

As widely reported in the literature, socio-cultural dynamics emerged as a lock-in and an inhibitor of the cultured meat transition (Dzvukamanja et al., 2025; Tobias-Mamina et al., 2025c; Ye et al., 2022). Within the MLP framework, these dynamics constitute some important regime elements because dietary practices, cultural identities and food traditions may contribute to stability and reproduction of the existing livestock systems. In the same vein, the socio-cultural aspects are linked to the legitimation function. Transforming worldviews, myths, and metaphors of cultured meat takes time and may never align with certain socio-cultural profiles. However, the present study shows that resistance is not uniform; it is fragmented and context-dependent, reflecting heterogeneous cultural logics across the region.

The 4IRTs+' cluster indicate expert consensus on the potential technological enablement of cultured meat systems. Technologies such as AI, biomanufacturing, big data, green energy, and blockchain were perceived as cross-cutting enablers, a position already supported in the cultured meat literature (Ahmadi Kaliji et al., 2025; Choudhary et al., 2024; Soleymani et al., 2024a). From a transition perspective, these technologies can expedite Technology Innovation Systems, invigorate the niches of innovation under MLP, and reconfigure the materials, meanings, and practices under the Social Practice Theory. The broad structural enablement reshapes the feasibility conditions for the transition to cultured meat. However, the impact is not automatic. The findings indicate uncertainty regarding the speed and equity of technological diffusion, in Southern Africa itself and in comparison, with other regions.

Mega-blueprints (UNSDGs and their successors, AU Agenda 2063; SADC Industrialisation Strategy 2063) indicate symbolic and normative alignment rather than operational integration of the cultured meat industry. The overall alignment of cultured meat with broader global sustainability goals cannot be disputed, evidenced by the participation of UN special organs such as the FAO and WHO in creating enabling frameworks for adoption (FAO, 2022). While cultured meat is broadly perceived as compatible with food security and sustainability goals, its alignment with mega-blueprints remains weak and contested. This suggests that mega-blueprints function as interpretive policy regimes that shape how innovations are framed rather than how they are operationalised.

6.1. Critiquing FFA as a prospective foresight tool

The study adopted the FFA as a prospective foresight tool based on its capabilities as a powerful change management tool. Futures studies are essentially a study of potential change packaged as possible, plausible, desirable, and undesirable futures (Niiniluoto, 2001; Sardar, 2010); thus, FFA remains in its familiar use, but the focus has changed from present change to possible and unknown futures. Whilst FFA is excellent at presenting and quantifying the forces of change, it is compromised as a foresight tool for several reasons. First, weighting drivers of change and calculating the net force concept, plucked from physics, fails to recognise the complex nature of the intertwining forces of change and the multiple feedback loops (Tuominen et al., 2025). Futures are not deduced from adding and subtracting forces but rather through the interplay of complex systems (F. Geels, 2020; F. W. Geels, 2011). Moreover, the futures are not merely a game of numbers; one stronger driver can counteract multiple drivers to jolt the whole system. For example, despite a positive net force in the production cluster, a single restrictive regulation can successfully inhibit the entire transition. As for the consumption drivers, despite a host of drivers promoting transition, resistant socio-cultural practices may curtail it. The driving forces differ in their influence, a phenomenon that is understood through futures-scenario generation by identifying critical uncertainties (van den Berg et al., 2021).

Second, while the FFA presents drivers of change abstractly, it simultaneously obscures their political nature, power dynamics, and contestations involved. In sustainability transition studies, these power struggles are important in shaping the transition (Geels, 2020). Third, the FFA provides a static snapshot of drivers, limiting its ability to capture temporal evolution and pathway dynamics. Unlike futures scenarios, futures personas and horizon scanning, the FFA does not inherently model change over time.

To address these limitations, this study integrates FAA with Real-Time Delphi and anchors the analysis within a long-term foresight horizon of 2070. In this configuration, the FFA functions as a heuristic tool for structuring and elicitation rather than a predictive tool.

7. Conclusion and policy directions

The study provides a timely, critical, and forward-looking assessment of the drivers shaping the potential transition to cultured meat in Southern Africa by 2070. Therefore, it extends the literature on cultured meat and foresight. By focusing on context-specific realities, constraints, emerging opportunities and applicable mega-blueprints in Southern Africa, the study moves beyond the Global North-centric assumptions.

Methodologically, the integration of RTD and FFA provides a novel hybrid foresight approach for eliciting, structuring and assessing expert perceptions of transition drivers under conditions of uncertainty. This approach particularly enhances the Delphi method, which is specifically a method for long-term anticipation under conditions of uncertainty and scanty information (Dalkey, 2003; Fink-Hafner et al., 2019). This contributes to the foresight methodology, especially when the outcomes are further foresight work such as generation of scenarios, Backcasting or guiding technological road mapping. The framework is transferable to analysis of other emerging technologies and sustainability transitions beyond the cultured meat innovation.

Second, the study contributes to cultured meat transition research by extending analysis beyond the dominant focus on consumer acceptance, techno-economic feasibility and environmental performance. Through integration of Multi-Level Perspectives (MLP), Technological Innovation Systems (TIS), Transition Management (TM) and Social Practice Theory (SPT), the study demonstrates that cultured meat transition in Southern Africa is not merely a techno-economic challenge but a broader socio-technical transformation including multiple interactions such as niches, regimes, landscapes, governance systems and socio-cultural dynamics. Importantly, the study highlighted that transition pathways are not determined by individual drivers but by their collective interaction across the socio-technical systems.

Given the uncertainty and multiplicity of possible futures, policy recommendation emerging from futures studies should not be interpreted as deterministic prescriptions but rather as strategic directions responsible for increasing systems preparedness. Nevertheless, we prioritised policy implications according to the strength of change drivers and Net Force values as well as the systemic role in enabling or inhibiting transition pathways. Based on the empirical findings, socio-cultural dynamics (-0.88 ± 2.29) and regulatory constraints (-0.42 ± 2.08) presented the most crucial policy targets, given their inhibitory direction and relatively high dissensus. These drivers create compound uncertainty. The strongest empirical momentum was observed in 4IRTs (+9.28), affirming that the technological enablement is the most powerful lever, provided the inhibitors are addressed in parallel. Accordingly, six prioritised policy directions emerge from the empirical evidence and are ranked according to their relative driver strength and systemic leverage.

- *Culturally embedded science communication*
  i. Socio-cultural dynamics presented the most significant inhibition (-0.88 ± 2.29) among all drivers. Cultural resistance to cultured meat in Southern Africa is rooted in varied relationships with identity and religion, and, in some cases, with livestock. Policymakers should therefore develop context-sensitive science communication that is grounded in local food narratives. This can be achieved through: Funding community-based programmes focused on food literacy and science communication.
  ii. Designing consumer engagement strategies, including participatory food tasting and storytelling that connect cultured meat to food sovereignty in Africa, rather than foreign technology
  iii. Establishing food innovation dialogues that present a platform for intergenerational debates on the future of meat, including youth participants who are more receptive to novel proteins.

The overall goal is to gradually reframe the current perception of cultured meat from a foreign technology to a locally relevant protein innovation aligned with food security goals.

- *Adaptive, science-based regulatory frameworks for novel foods*

The regulatory framework was the only production driver rated as a net inhibitor (−0.42), and the experts emphasised the GMO regulatory precedent in Southern Africa as a cautionary example of how biotechnology innovation can be obstructed (Muzhinji and Ntuli, 2020). Within both the MLP and TIS frameworks, regulation functions as the regime selection mechanism and source of legitimacy for emerging innovations. Uncertainty in regulatory frameworks does not operate in isolation; it compounds financial risks and undermines human capital retention. This compounding effect makes regulatory modification a high-leverage policy intervention. Policymakers should:

i. Develop transparent, science-based regulatory framework for cultured meat, setting clear approval standards, licensing systems and risk assessment frameworks
ii. Create a regulatory certainty and eliminate ambiguity to attract investment, promoting entrepreneurial experimentation while reducing risk.

- *4IRTs+ and Infrastructural enablement are supreme.*

The strongest empirical momentum (+9.28) was observed in Industrial Revolution Technologies (4IRTs+). Cultured meat, together with other cellular agriculture products, is a 4IRT; hence, it flourishes together among its compatriots (Nhokovedzo et al., 2025). Policy should therefore prioritise:

i. Accelerated investment in green energy such as solar, wind, hydrogen and geothermal, as foundational infrastructure. Development of advanced AI, blockchain technology, big data, and biomanufacturing infrastructure linked to food systems III. Regional and national coordination of digital and cellular agriculture innovation systems.

- *Demand-side transformational strategies*

Consumption dynamics show a positive directional momentum but remain socio-culturally contested. Policy should focus on:

i. Culturally sensitive marketing and consumer trust-building strategies
ii. Price moderation and accessibility strategies, such as subsidies
iii. Enabling food systems resilience, particularly in urban areas

- *Production systems strengthening*

Production systems indicate positive but unstable momentum, suggesting supply-side constraints and fragile production systems. Policy should prioritise:

i. Retention of human capital in biotechnology and synthetic biology through local innovation systems and entrepreneurial opportunities.

ii. Development of Afrocentric bioprocessing infrastructure to reduce technological dependence and improve control of production processes. Creation of enabling regulatory systems, licensing and commercialisation frameworks for novel foods such as cultured meat
iii. Coordinated financial architecture and technology + finance linkages

- *Institutional alignment to mega-blueprints*

Mega-blueprints were broadly perceived as moderate enablers (+3.62). This reflected a well-documented gap between operational implementation and policy framing as these blueprints function as interpretive frameworks that influence legitimacy for sustainable innovations without providing the specific funding or mandates required for cultured meat to enter industrial strategies (Edwards et al., 2024). Cultured meat shows weak but positive alignment to mega-blueprints, indicating that these policy frameworks currently function as interpretive rather than operational drivers. Policy implications should include;

i. Ensuring strategic alignment of local policies to regional, continental, and global frameworks
ii. Translation of high-level policy goals to local innovation roadmaps and vice versa (top-down and bottom-up alignments)
iii. Clarifying regulatory positioning of alternative proteins with regional and national strategies

Despite its highlighted contributions, the study has several limitations. First, the findings are based on experts' judgements rather than empirical behavioural or market-based data. This introduces a degree of interpretive subjectivity, but that is always the case in futures studies, particularly with the Delphi method. The foresight-oriented Delphi method always seeks to elicit experts' judgements about the unknown futures under conditions of uncertainty and limited information. Second, although robustness checks indicated minimal distortion of sample imbalance, the uneven representation of the sample in favour of Zimbabwe may still influence subtle contextual interpretations. Third, the long-term horizon (2025-2070) perpetuates inherent uncertainty, particularly given the non-linear nature of the socio-technical transition. Also, long-term futures thinking is always difficult as experts are often clouded by presentism biases or future discounting. To mitigate this, we introduced a novel, contextually sensitive intergenerational primer that will be explained in the next article emanating from the same data.

We suggest that future research leverage the driver clusters identified in this research, extract critical uncertainties, and generate plausible, internally consistent scenarios for cultured meat in Southern Africa by 2070. More interestingly, these scenarios could be livened up by adopting future personas as hypothetical representations of life in 2070. Further research could encourage food policy actors to discuss the desirable (utopian) meat future for the region. A reasonable further step for this study could be to backcast the desirable futures from 2070 to inform policy formulation, with full inclusion of diverse interest groups, particularly future-generation envoys.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Simbarashe Nhokovedzo: Conceptualization, Data curation, Investigation, Methodology, Software, Writing – original draft. **Petri Tapio:** Methodology, Project administration, Supervision. **Tawanda Prosper Mushayavanhu:** Formal analysis, Investigation, Writing – review & editing. **Emmanuel Ndhlovu:** Formal analysis, Writing – original draft, Writing – review & editing. **Kudakwashe Chiwaya:** Formal analysis, Investigation, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was conducted while the corresponding author was at the Futures Literacy Company (4CF) under a Global Fellowship Agreement, which spanned from August 2025 to January 2026. The authors express their sincere gratitude to 4CF for providing free access to its premium Real-Time Delphi platform, the 4CF Halnyx 2.0, which was instrumental in the execution of this study.

Data availability

Data will be made available on request.

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