The potential impact of cultured meat on the meat industry and the environment

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Dissertation written under the supervision of professor Peter V. Rajsingh PhD

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Abstract

The meat industry is facing transformation. Besides already existing plant-based substitutes, a new alternative from the laboratory is moving increasingly closer to the market. Cultured meat has emerged as a game-changing technology for the global food business, with the potential to address severe environmental, climate, global public health, and animal welfare issues.

The dissertation examines the potential of cultured meat being a substitution threat for conventionally produced meat. In addition, a scenario analysis highlights the environmental impact of cultured meat in the meat industry. To answer the research questions, a qualitative study methodology is applied in the form of semi-structured expert interviews and an examination of the secondary literature.

The results indicate that cultured meat poses a significant substitution threat for conventionally produced meat starting in 2030. Although cultured meat is a sustaining innovation, the impact on the meat industry is powerful since the phenomenon exploits its characteristics by addressing the world's driving concerns about the environment, health, and food security. Before cultured meat becomes reality, it still must surmount several challenges, such as regulatory barriers, technological progress, and the associated price parity. Nevertheless, the scenario analysis points out that cultured meat could substantially enhance the environmental footprint of the meat sector.

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Sumário

A indústria da carne está a enfrentar transformação. Para além dos substitutos à base de plantas já existentes, uma nova alternativa do laboratório está a aproximar-se cada vez mais do mercado. A carne cultivada surgiu como uma tecnologia revolucionária para a indústria alimentar global, com potencial para abordar graves questões ambientais, de sustentabilidade, de saúde pública global, e de bem-estar animal.

A dissertação examina o potencial de a carne cultivada ser uma ameaça de substituição da carne produzida convencionalmente. Além disso, uma análise de cenário destaca o impacto ambiental da carne cultivada na indústria da carne. Para responder às questões base da investigação, é aplicada uma metodologia de estudo qualitativo sob a forma de entrevistas semi-estruturadas de peritos e uma análise da literatura secundária.

Os resultados indicam que a carne cultivada representa uma ameaça significativa de substituição da carne produzida convencionalmente a partir de 2030. Embora a carne cultivada seja uma "sustaining innovation", o impacto na indústria da carne é poderoso, uma vez que o fenómeno explora as suas características ao abordar as preocupações mundiais sobre o meio ambiente, a saúde e a segurança alimentar. Até que a carne cultivada se torne realidade, tem ainda de superar vários desafios, tais como barreiras regulamentares, progresso tecnológico, e a paridade de preços associada. No entanto, a análise de cenários salienta que a carne cultivada pode melhorar substancialmente a pegada ambiental do sector da carne.

Título: O impacto potencial da carne cultivada na indústria da carne e no meio ambiente

Autor: Marte Wieling

Palavras-chave: Substituição, inovação, sustaining innovation, meio ambiente, análise de cenários, carne cultivada, carne baseada em células, substitutos de carne, indústria pecuária

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List of Abbreviations

b	Billion
BCG	The Boston Consulting Group
CO_2eq	Carbon dioxide equivalent
EU	European Union
GHG	Greenhouse gases
m	Million
m^2a crop-eq	Land use equivalent ratio
OECD-FAO	Organisation for Economic Co-operation and Development and Food and Agriculture Organization of the United Nations

1. Introduction

The world population continues to grow. In 2019, 7.7b people lived on earth while in 2030 the world population is projected to reach 8.5b people (United Nations, 2019). The amount of food required to sustain all these people is enormous. The Organisation for Economic Co-operation and Development and Food and Agriculture Organization of the United Nations (OECD-FAO) identified the growing population as the main driver of demand growth for agricultural commodities. During the next decade, the global demand for agricultural products is projected to grow by 1.2% annually (OECD-FAO, 2021).

As shown in Figure 1, in 2020, 3.3b metric tons of cereals and seeds were harvested worldwide (Figure 1). However, only 43% of the grown crops remain for human food consumption while another 38% of the harvest is dedicated to feeding livestock (OECD, 2022). This is due to the huge livestock populations that make up a major part of the world's animal population. While 60% of all mammals on earth are livestock, only 4% represent wild animals (Bar-On, Phillips, & Milo, 2018). Looking at the biomass of the birds, 70% of all birds are chickens and other poultry and only 30% of the birds live in the wild (Bar-On et al., 2018).

In addition, the OECD-FAO forecasts that feed consumption will increase even faster (1.2% p.a.) than human food consumption (1.0% p.a.) over the next decade. This development is the result of the ongoing expansion of livestock farming and the increasing demand for meat (OECD-FAO, 2021). Global livestock output reached 337m metric tons in 2019, a 44 percent increase since 2000 (FAO, 2021c).

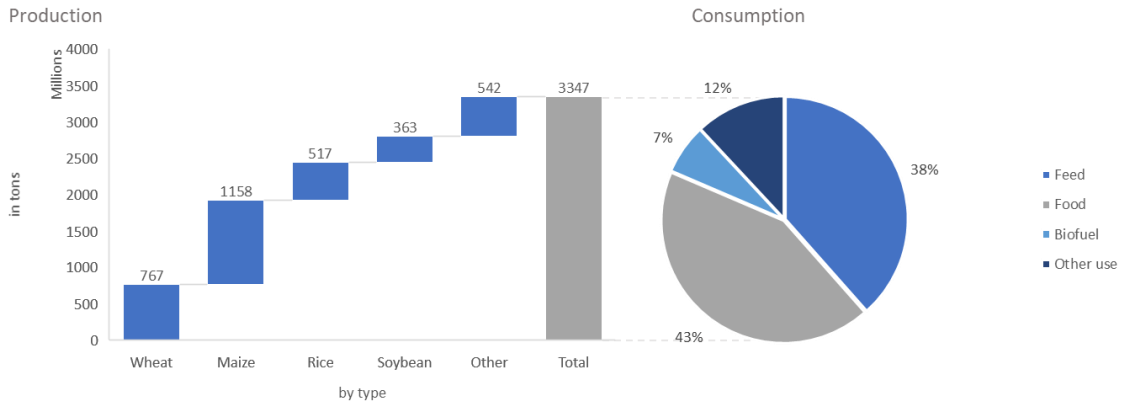

Figure 1: Worldwide crops harvest by type and consumption by use in 2020 (OECD, 2022)

Due to its high concentration of nutrients, meat and in particular animal proteins, are perceived as a superior source of energy for humans (Godfray et al., 2018). Despite the ever-rising consumption of meat, increasing consumer awareness in developed countries and

interest in meat substitutes mainly driven by health and sustainability concerns have led to a shift in the consumption of animal proteins (Bashi, McCullough, Ong, & Ramirez, 2019). Consequently, the market landscape has changed and several companies with alternative meat products replacing conventional meat products have entered the market. These meat alternatives are diverse and range from plant-based and insect-based to cultured meat products. The terminology “cultured meat” refers to meat created in a bioreactor with muscle tissues from animal stem cells (Zhang et al., 2020). While plant-based products already represent a significant market share, cultured meat is still in its early stages (Alexander et al., 2017). This thesis explores the potential impact of cultured meat as a significant substitution threat for conventionally produced meat and the livestock industry.

1.1.Problem statement

The food industry and therefore the agricultural sector is facing many major economic, ecological, and social challenges. The most recent UNICEF report highlights the overconsumption and tremendous ecological footprint of humanity (UNICEF, 2022). If the world would live like the average people in countries of the OECD and the European Union (EU), 3.3 earths would be needed (UNICEF, 2022).

The universal and legally binding Paris Agreement adopted by 191 countries and the EU in December 2015 is the global answer to combat overconsumption and climate change (Paris Agreement to the United Nations Framework Convention on Climate Change, 2015). The agreement's central aim is to limit the rise in global temperatures to well below 2 degrees in this century and reach the peak of greenhouse gas (GHG) emissions as soon as possible (Art. 2 and Art. 4).

Agriculture holds a very special position in climate change because it is particularly affected by climate change and is also a major contributor to GHG emissions. The agricultural sector was the second-largest emitter in 2010 and GHG emissions from livestock are expected to grow by over 70% by 2050 compared to 2005 levels (FAO, 2013; IPCC, 2014). Furthermore, studies show that high meat consumption may lead to an increased risk of chronic diseases (Godfray et al., 2018). In addition, industrial livestock production significantly compromises the welfare of farmed animals (Lymbery & Oakeshott, 2014).

The foregoing reasons are driving the health and sustainability concerns of consumers. In turn, these concerns lead to changing consumer preferences accelerating the market development for alternative meat products (Bashi et al., 2019). However, global meat

consumption is still rising. Current meat alternatives such as plant-based proteins, which have been on the market for years, do not seem to be stopping the rising global trend of meat-eating. Cultured meat does not only have the same texture and taste as genuine meat, but it also creates just a fraction of the adverse impact on the climate (Coggin, 2021; Sinke & Odegard, 2021). Hence, cultured meat could not only be a viable alternative to traditional meat and plant-based products but may also be the answer to the multifaceted challenges of the livestock industry.

1.2. Academic and managerial relevance

The agricultural industry faces growing demand for meat while being under pressure to transform into a more sustainable business. Instead of advancing the characteristics of meat with those of plants, cultured meat attempts to replicate conventionally produced meat without animal husbandry (Goodwin & Shoulders, 2013). Therefore, cultured meat might be a significant substitute for meat products in the future (Bashi et al., 2019).

Since the beginning of this century, research in cultured meat has intensified and major breakthroughs have been made in recent years (Goodwin & Shoulders, 2013). However, there is still a long way to go before cultured meat can be produced in large quantities and marketed to end consumers. Cultured meat has the potential to become a reality and transform the meat industry, addressing pressuring challenges of the agricultural sector. McKinsey Senior Partner Christer Tryggestad (2022) pointed out that he sees cultured meat as a viable solution for the agricultural sector to transform into a net-zero business: “If we want to continue eating genuine meat, then cultured meat is the only solution for the agriculture sector to reach net-zero” (Tryggestad, 2022).

Besides cultured meat, other solutions have the potential to disrupt the meat industry. Plant-based or insect-based meat alternatives imitating meat are solutions that already have attained market scale and are transforming the meat industry. However, due to the novelty of cultured meat, the present dissertation focuses solely on cultured meat and its potential impact on the meat industry.

1.3. Research questions

The meat industry is confronted with an unprecedented transformation. New meat alternatives and trends lead to a disruption in the industry. Cultured meat as a futuristic meat alternative could not only replace traditionally produced meat and transform the meat industry, but it may also pave the way to a more sustainable industry. This thesis will evaluate the

potential impact of cultured meat on the meat industry and the environment. The research questions examined are:

- RQ1: Will cultured meat be a significant substitution threat for traditionally produced meat?
- RQ2: Assuming cultured meat partly replaces traditionally produced meat, how would this development affect the environmental impact of the meat industry?

2. Literature review

The first part of the literature review examines the current state of the meat industry to provide a comprehensive understanding of the challenges the industry is facing and the megatrends that are driving change in the meat sector. Subsequently, cultured meat is discussed in detail, being a possible disruptor and substitute for genuine meat in the future. In addition, an overview of the theoretical background of innovation and the industry's competitive structure forms the last part of the literature review.

2.1. The challenges of livestock farming

The conventional meat industry is a multi-billion-dollar industry valued at over 830b US-dollar in 2020 (Shahbandeh, 2021). Looking at the generic meat value chain, livestock farming represents a fundamental part of the meat-producing industry (Figure 2).

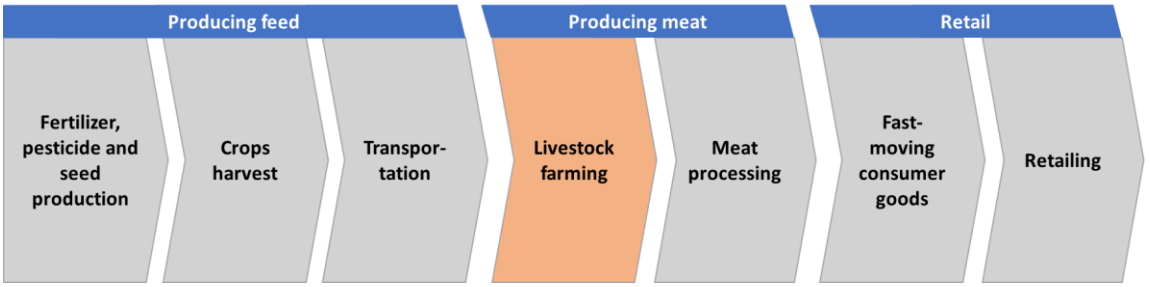

Figure 2: Generic meat value chain (Marcy Lowe & Gary Gereffi, 2009; Novaković, Grujić, & Vujadinović, 2015)

The OECD-FAO forecasts an increase of almost 44m metric tons in global meat production by 2030 (OECD-FAO, 2021). The enormous expansion of the industry is mainly based on two drivers, the growing world population and the growing income and living standard in emerging developing countries (OECD-FAO, 2021).

Across the globe, there are many different animal species raised for meat consumption. However, three species account for almost 90% of meat production. While poultry meat was the most produced type accounting for 35% of the global meat production in 2019, pork made up 33% and beef represented the smallest part of the three types with 20% (FAO, 2021c).

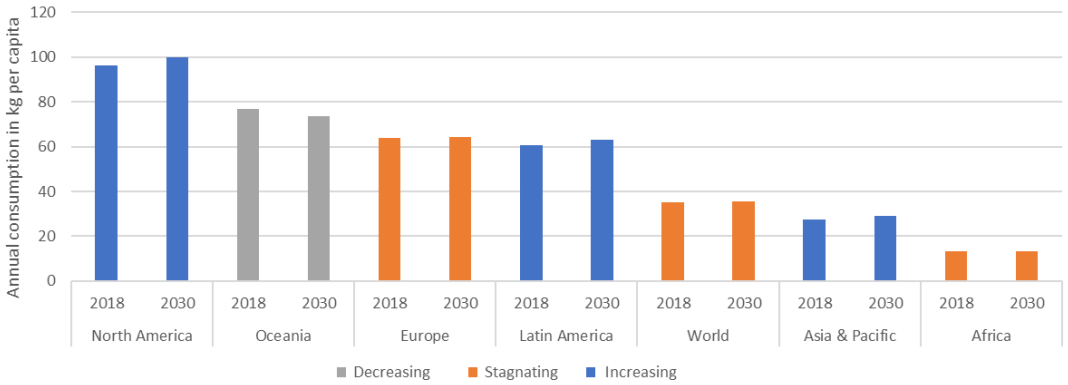

Figure 3: Meat consumption per capita (OECD, 2022)

Although overall consumption will continue to rise, Figure 3 shows that worldwide per capita consumption will stagnate until 2030 (Figure 3) (OECD, 2022). This global development underlies the stagnation in Europe and Africa and even the declining per capita consumption in Oceania (OECD-FAO, 2021).

Notwithstanding, the factors and variables affecting meat consumption are complex and diverse. The determinants can range from rational factors like meat prices or incomes to irrational factors such as tradition, religious beliefs, cultural norms, environmental awareness, or ethical beliefs (OECD-FAO, 2021). The meat industry in particular experiences a variety of market dynamics changing the industry landscape (Bashi et al., 2019). The reasons for the dynamics are megatrends affecting the buying behavior and diet preferences of consumers over time. Megatrends are long-term shifts, irreversible, and therefore a powerful, transformative force changing businesses, industries, or whole economies (BlackRock, 2018). In the following subchapters, the megatrends health, climate change, and resource scarcity and their impact on the meat industry are explored in more detail.

2.1.1. Health

A large number of studies show that higher consumption of unprocessed and processed red meat but also pork and chicken meat can lead to increased risk of heart disease, cancers, diabetes, and premature death (Bouvard et al., 2015; Papier et al., 2021). In addition, a study highlighted that due to intensive large-scale livestock farming practices, from 2010 to 2030 the global use of antibiotics in farm animals is forecast to rise by 67% (van Boeckel et al., 2015). Extensive use of antibiotics can contribute to antibiotic resistance for both animals and humans (CDC, 2021). Consequently, developed drugs no longer have any effect on these bacteria, putting public health at risk (CDC, 2018).

These studies are being widely discussed in society and lead to increased awareness of the negative impact of meat consumption. Consequently, consumer concerns about livestock farming are rising. Health plays an increasingly significant role in food shopping for consumers (Günday, Karabon, Kooij, Moulton, & Omeñaca, 2020). Looking at stagnating meat consumption per capita in Europe, people are changing their diets. Consumer health consciousness is affecting the consumption of meat and hence the livestock industry.

2.1.2. Climate change

In this century, climate change is one of the major challenges mankind is facing. Scientists from all over the world agree that the earth's climatic system, and thus the environment and biodiversity are influenced by human activities (Pachauri & Mayer, 2015). The agriculture sector and in particular the livestock industry have a significant impact on climate change due to GHG emissions. Likewise, it negatively affects the environment in multiple ways such as land use, water use, soil erosion, biodiversity loss, and animal welfare (FAO, 2021c; IPCC, 2014; Lymbery & Oakeshott, 2014; OECD-FAO, 2021).

The agricultural sector, including forestry and other land, accounts for almost a quarter of total GHG emissions worldwide in 2010 (Figure 4). GHG emissions generated by farming activities represented approximately two-thirds of the sector in the same year (IPCC, 2014), while the FAO estimates that a major part (55%) of all farming activities derived from livestock-related activities (FAO, 2021c) (Figure 4). In absolute terms, the total agricultural emissions in 2018 amounted to more than 9.3b tons of CO_2eq, of which more than 3b tons of CO_2eq were generated by livestock-related production processes (FAO, 2021a).

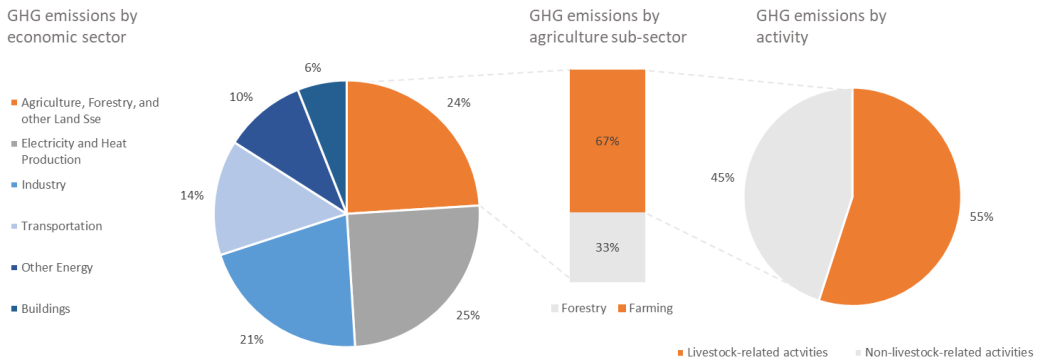

Figure 4: GHG emissions by economic sector, agricultural sub-sector, and activity (FAO, 2021c; IPCC, 2014)

Due to enteric fermentation, manure left on pasture, and synthetic fertilizers, meat has a very high CO_2 intensity. Carbon dioxide and methane account for 80% of the GHG emissions in livestock farming (FAO, 2021c). Methane is a highly powerful GHG and 80 times more

warming than carbon dioxide over 20 years (FAO, 2021c; United Nations, 2021). As a result, cattle meat is the most CO_2-intensive commodity (~30kg CO_2eq/kg) in agriculture (Sinke & Odegard, 2021). In comparison to beef, producing one kilogram of cereals is equal to 0.2kg of CO_2 (FAO, 2021c). The differences in emissions highlight the severe impact of livestock farming on the climate.

Additionally, more than one-quarter of ice-free land is used for livestock grazing while one-third of the cropland is used for the production of feed for livestock (FAO, 2012b). Livestock is one of the major drivers of deforestation which not only causes soil compaction and erosion but also negatively affects CO_2 emissions from deforestation. (FAO, 2021b; IPCC, 2014).

While agriculture is the most vulnerable to water scarcity of any sector of the economy, it is also the largest consumer being responsible for 70% of worldwide freshwater withdrawals (FAO, 2012a). Furthermore, agriculture including livestock farming is dominantly polluting the water with fertilizer and pesticides in many regions all over the world which is in turn directly affecting human health and food security (FAO, 2021b).

While other sectors such as electricity and transportation already found viable sustainable substitutes such as wind power, solar power, green hydrogen, or battery electric vehicles, the agriculture industry still struggles to find an appropriate substitute for meat. Plant-based products are a solution, but do not lead to a complete replacement of meat and thus do not lead to a sector-wide reduction in environmental impact.

2.1.3. Food security

Looking at the growing population reaching almost 10b in 2050 (United Nations, 2019), agriculture and livestock farming pose not only an increasing threat to the climate and environment but also to food security. Natural resources, such as fresh water in areas with less rainfall and arable land all over the world are limited. Moreover, the industrialization of livestock and agriculture is facing their efficiency limits. Due to these circumstances, meat production will be affected by competition between food and feed. Although adult obesity is strongly growing in Northern America, Europe, and Oceania, the global number of undernourished people rises sharply (FAO, 2021c). From 2019 to 2020 the world experienced a rise of over 160 million people to 770 million undernourished people, accounting for approximately 10% of the global population (FAO, 2021c). With limited natural resources, an increasing number of people living on the planet, and only a stagnating consumption of meat

per capita, food security is a serious challenge not only for the livestock industry but also for humanity.

2.2. Market disruptor – cultured meat

The market has responded to these megatrends with various alternatives to existing animal-based meat products. While vegetarian, vegan, insect-based, or microorganism-based meat replacements are already established in the market, cultured meat is a novel technology and had its first market debut in 2013 (Bashi et al., 2019; The Good Food Institute, 2021a).

Although the texturization of the meat alternatives is continuously improving the taste and feel of these products, it seems impossible to fully mimic genuine meat. The reason for this hurdle is the raw material meat alternatives are made off. All of them are based on soy, milk proteins, wheat proteins, mycoprotein, or insect proteins and hence are mainly used for processed meat substitutions such as minced meat (Post, 2012). However, cultured meat is now trying to close this gap.

2.2.1. Meat from the laboratory

Cultured meat also described as cell-based, cultivated, in vitro, synthetic, or lab-grown meat is the use of tissue engineering to create muscle for food consumption (Stephens et al., 2018; Zhang et al., 2020). As a result, the production, as well as the whole value chain of cultured meat, differs significantly from the production of traditional meat (Figures 2 & 5). According to Figure 5, in comparison to conventional livestock farming, cultured meat skips the step of feed harvest.

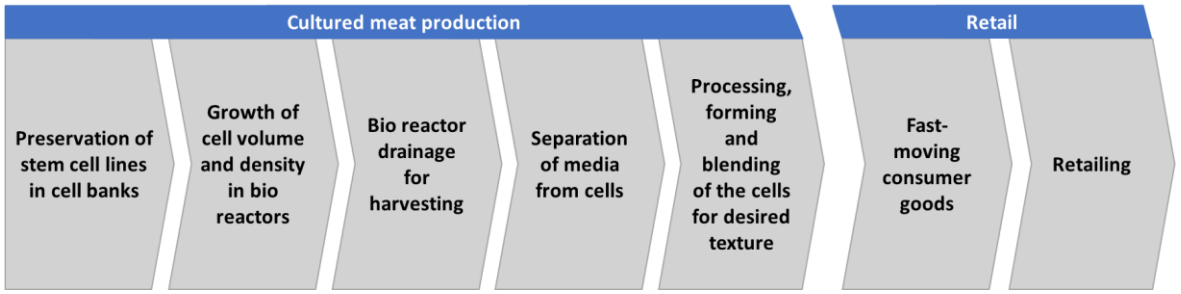

Figure 5: Simplified value chain of cultured meat (The Good Food Institute, 2021a; van der Weele & Tramper, 2014; Zhang et al., 2020)

The base material of cultured meat is a stem cell obtained from the muscle tissue of a donor animal through a biopsy. The stem cell can be taken from all animal species including fish. Another key material for the production is the culture media. This media contains essential nutrients binding proteins, vitamins, enzymes, and mineral trace elements and ensures the

proliferation and differentiation of the cells into muscles. For the growing process, the media and the cells are merged in a bioreactor (Figure 5). During this process, the size of the bioreactor is constantly increased until the tissue formation has reached a desired size and density. As the last production step, a centrifuge separates the tissue formation/scaffold and the media allowing harvesting of the meat and the extrusion of consumer-size portions. (Datar & Betti, 2010; van der Weele & Tramper, 2014; Zhang et al., 2020)

The production process illustrates the capabilities of biotechnology for food production and the fact that no slaughter of animals is involved (Figure 5). In addition, due to the use of an animal stem cell, the texture and taste of the meat are similar or comparable to genuine meat (Bashi et al., 2019).

2.2.2. Current stage of development

Since the early 2000s, the National Aeronautics and Space Administration has conducted research on cultured meat to establish a sustainable food supply chain for long-term flights in space. However, these investigations were still early laboratory studies (Zhang et al., 2020). In 2013, the Dutch scientist Mark Post presented the first cultured meat hamburger patty. Although it took more than three months and cost $330,000 to produce the cultured meat patty, the presentation attracted a lot of media attention (Zhang et al., 2020). At this time, cultured meat was in the very early stages and, the technology was still in its infancy (Post, 2012).

Today, biotechnology and cultured meat have made enormous progress (Figure 6). Figure 6 illustrates the market maturity of cultured meat divided into 5 phases. During the phase of conceptualization in 2013, the costs for cultured meat were exorbitantly high (Figure 6). Within the next few years, an increasing number of startups developed bench-scale prototypes of cultured meat. After proof of concept, in 2019 the commercial era with pilot-scale facilities producing the first wave of salable products has begun (The Good Food Institute, 2021a). Already in 2021, Future Meat Technologies announced to bring down the costs for 110 grams of chicken below $4 (Terazono, 2021). Besides Future Technologies there are 70 other startups such as Aleph Farms, BlueNalu, or Lab Farm Foods trying to win the race for future market share (Aleph Farms, 2022; BlueNalu, 2022; Lab Farm Foods; The Good Food Institute, 2021a). In 2022, the industry is forecasted to slowly transit into the demonstration-scale phase (The Good Food Institute, 2021a) (Figure 6). This stage of development underlines significantly the novelty of cultured meat and that cultured meat is still in the middle of an evolution.

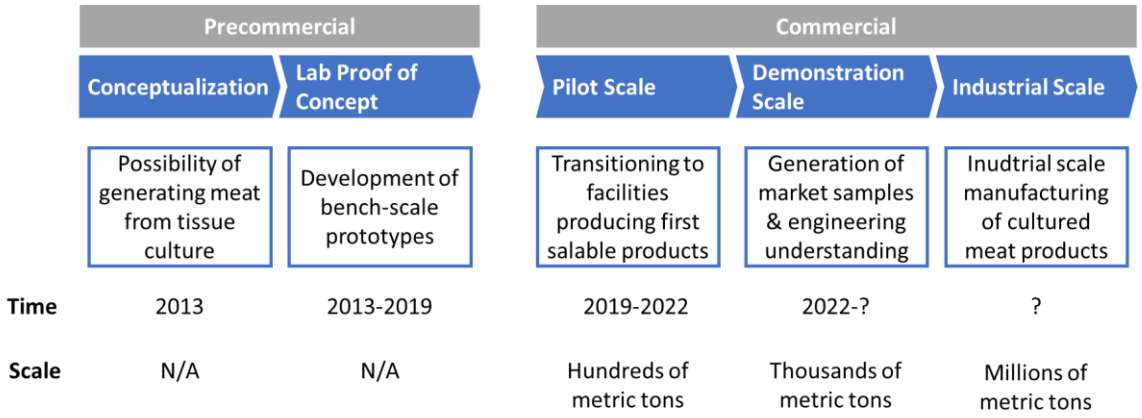

Figure 6: Market maturity of cultured meat in phases (The Good Food Institute, 2021a)

Increasing market activity is also reflected by the volume of invested capital. While in 2016 investment totaled only $6m, by 2020 this number had risen to $366m accounting for 14% of the overall annual private-sector investment within the alternative protein sector (The Good Food Institute, 2021a). Thus, the cumulative invested capital raised from 2016 to 2020 reached almost $500m (The Good Food Institute, 2021a). In 2021, Future Meat Technologies raised $347m, the largest-ever funding for cultured meat, to build a large-scale production facility for cultured meat products (Paris, 2021). Financial capital and engagement are also emerging from established multinationals such as Tyson Foods and Merck KGaA (Merck Science & Technology Office, 2021; Servino, 2018). Additional public governmental funding is boosting the ramp-up of the cultured meat market and its ecosystem. Singapore, the first and only country that approved lab-grown meat in 2020, is pushing further into cultured meat (The Good Food Institute, 2021a). Its state-backed investment institution Temasek has invested $8bn in agriculture technology and cultured meat to create a domestic food supply chain (Ruehl, 2021). Looking at the demand side, a McKinsey analysis highlights rising consumer interest in alternative proteins. Cultured meat had a 16% CAGR of internet queries from 2004 to 2019 (Bashi et al., 2019).

Although there is no efficient production of cultured meat yet since products are not fully market-ready, there are already various assumptions about the future size of the market. McKinsey predicts a huge market opportunity and estimates the market volume in 2030 at about 2.1m metric tons worldwide, while The Boston Consulting Group (BCG) forecasts the market volume in 2035 at 6m metric tons (Brennan, Katz, Quint, & Spencer, 2021; Witte et al., 2021). How cultured meat affects the meat industry will be examined in more detail in section 5 of the dissertation given its anticipated growth.

2.3. An industry faces disruption

With the increasing speed of change affecting the world, new business models or emerging technologies likely occur within an industry. Those innovations can lead to massive changes or even to disruption in the industry landscape.

2.3.1. Innovation

Innovation is associated with value creation, but it is not a one-size-fits-all proposition; it can be achieved in a variety of ways. In the mid of the ’90s, Clayton Christensen coined and conceptualized the idea of disruptive innovation (2013). However, the term disruptive innovation has been widely misunderstood and co-opted by the business world (Christensen, Raynor, & McDonald, 2015) Therefore, it is essential to carefully examine and correctly understand the concept in order to determine the influence innovation has on an industry and its incumbents. Innovation is not a product, but a process, or more precisely, an evolution of a product over time (Christensen et al., 2015).

There are different types of innovation. Sustaining innovation is described by Christensen as “better products that you could sell for better profits to your best customers” (Christensen, 2013). Hence, sustaining innovation is a performance improvement of an established product targeting the most profitable customers.

In contrast, disruptive innovation is the process in which a smaller company climbs upward the market and takes on larger, more established companies (Christensen, 2013). This process is further divided into two sub-types. Low-end disruption takes place when a disruptor is focused on low-end customers and serves them with a “good enough” product at a lower price while incumbents only give attention to the most profitable customers (Christensen et al., 2015). As a result, the new disrupter gains market share over time and captures the incumbent’s customers in the end. New market disruption is when a disruptor creates a new market where none existed before (Christensen, 2013). This means non-consumers are converted into consumers (Christensen et al., 2015).

Comparing both types of innovation, the differences in the market diffusion are more evident when looking at the encroachment framework (Schmidt & Druehl, 2008). The framework maps the type of innovation to the type of diffusion and suggests that sustaining innovation is a high-end encroachment while disruptive innovation is a low-end encroachment (Schmidt & Druehl, 2008). The encroachment implies that the new product is cannibalizing sales of the existing product. While a low-end encroachment can be overlooked easily since

the potential is delayed, a high-end encroachment has an immediate and striking impact on the market (Schmidt & Druehl, 2008). Consequently, a disruptive innovation's diffusion process can be less disruptive to an incumbent than a sustaining innovation due to the immediate high cannibalization of sales that leads to a fight for market share.

2.3.2. Competitive forces in an industry

The intensity of the fight for market share is rooted in the competitive nature of an industry. Michael E. Porter highlighted that competition is not only based on other players, rather it is anchored in its underlying competitive forces (1979). The state of competition in an industry is reflected by the Five Forces Framework (Porter, 1979) (Figure 7).

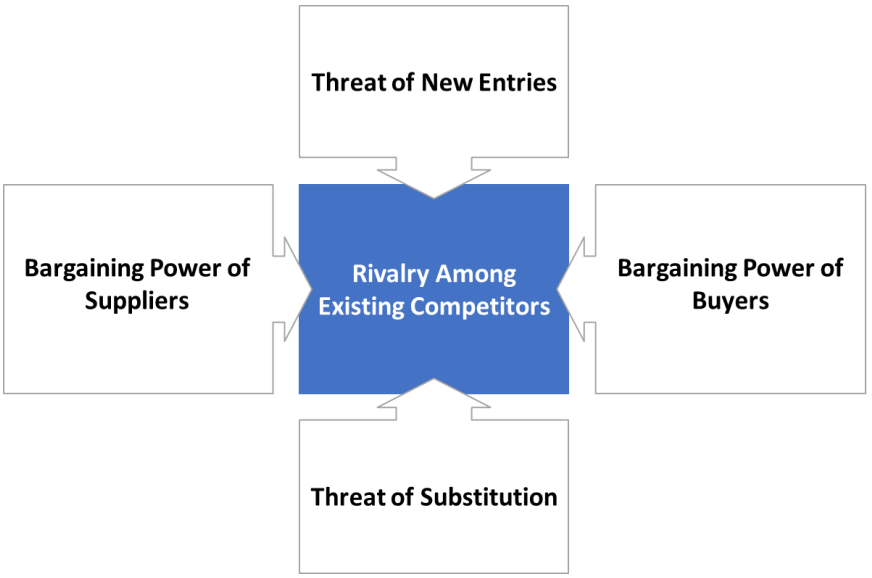

Figure 7: Porter's Five Forces Framework (Porter, 1979)

Using the outside-in perspective, the structure is a straightforward approach to identifying certain powers in accordance with a certain business situation (Johnson, Scholes, & Whittington, 2009). The collective strengths of the forces not only determine an organization's ability to make a profit but also call attention to the places where industry trends and dynamics have the greatest importance (Porter, 1979). Trends may affect the competitive forces and therefore the industry structure (Porter, 1979). When an industry structure including the level of rivalry alters, incumbents or new players can exploit this industry change strategically. Hence, new, and potential competitive positions may emerge. Changes in the industry's structure create new demands and new tactics to meet current ones (Porter, 2008).

Shifts in the industry's structure can occur for several reasons such as changes in technology or changes in customer needs and preferences. For example, a shift in the threat of substitution can emerge due to technological advancements (Porter, 2008). Advances in

technology create new substitutes and can lead to shifts in price-performance comparisons (Porter, 2008).

Even if an industry is usually considered relatively stable, it can undergo change affected by competitive forces. This, in turn, alters the attractiveness of the industry and the profitability of incumbents. This phenomenon will be thoroughly examined in the next chapters.

3. Methodology

In order to study a complex phenomenon in its context, a qualitative study methodology is appropriate (Baxter & Jack, 2015). While quantitative research seeks to explain a certain phenomenon by emphasizing quantification in the data collection and analysis, a qualitative approach seeks to understand the phenomenon (Hollis, 2011).

3.1. Research design

Qualitative research is concerned with "deepening of understanding a given problem" (André Queirós, Daniel Faria, & Fernando Almeida, 2017). Hence, for this dissertation, a qualitative approach is applied to understand the evolving phenomenon of cultured meat and its impact on the meat industry. This also ensures that "the issue is not explored through one lens, but rather a variety of lenses which allows for multiple facets of the phenomenon to be revealed" (Baxter & Jack, 2015). Due to the novelty of the research topic and the limited available data, an exploratory case study design was conducted aiming to reveal initial research "to tackle new problems on which little or no previous research has been done" (Brown, 2006).

3.2. Data collection

To gather primary data in the form of qualitative information, expert interviews were conducted. The interviews were semi-structured meaning only a part of the questions is predefined. This interview design offers structure but establishes also a certain degree of freedom "to explore one of the questions in greater depth" (André Queirós et al., 2017). In addition, the experts can elaborate on their points of view, opinions and experiences in more detail contributing to the data collection.

The interview guide consisted of 14 structured questions of which some can be classified as open-ended questions, and some were closed-ended questions with a ranking assessment (Appendix A). Combining both types of questions in the questionnaire provided the opportunity both to quantitatively compare responses and to obtain additional information that

is not anticipated. The first 5 questions aimed to understand the cultured meat phenomenon fundamentally, meaning how it differs from other protein alternatives, for which applications, and in which regions there is a particular potential (Appendix A). The questions 6 to 11 were designed to evaluate the potential of cultured meat including opportunities and risks while the questions 12 to 14 aimed to answer the second research question of how a substitution would affect the environmental impact of the meat industry (Appendix A).

ID	ROLE IN COMPANY	ORGANIZATION TYPE
EXPERT 1	Chief Executive Officer, Cultured Meat Start-up in Israel (Funding > $130m)	**Start-up**
EXPERT 2	Manager, Cultured Seafood Start-up in the U.S. (Funding > $80m)	**Start-up**
EXPERT 3	Chief Operating Officer, Cultured Meat Start-up in the U.S. (Funding ~ $2.5m)	**Start-up**
EXPERT 4	Chief Sustainability Officer, Cultured Meat Start-up for Petfood in the United Kingdom	**Start-up**
EXPERT 5	Managing Partner, Alternative Proteins Venture Capital Firm in Switzerland	**Venture Capital Firm**
EXPERT 6	Chief Investment Officer, Alternative Proteins Venture Capital Firm in the U.S. & Singapore	**Venture Capital Firm**
EXPERT 7	Global Agribusiness Lead, Top Tier Consultancy in the U.S.	**Consulting Firm**
EXPERT 8	Director of Responsible Research and Innovation, Nonprofit Research Institute for Cultured Meat in the U.S.	**Non-profit Organization**
EXPERT 9	Scientist, Academic Research Institution at a well-known University in Germany	**Non-profit Organization**

Table 1: Expert roles and organization types

Overall, 9 interviews were conducted with a wide range of cultured meat experts across different geographies to ensure a holistic and comprehensive examination of the cultured meat phenomenon (Table 1). The interviewees represented different types of organizations and therefore different stakeholders with divergent perspectives (Table 1). Furthermore, the

respondents were chosen based on their professional expertise and engagement with cultured meat.

Besides primary data collection, secondary research was conducted based on the literature review. The secondary data analysis was a comparative element in the data collection and completed the view of the phenomenon with high-quality data (Bryman & Bell, 2011). Moreover, secondary data was condensed into analyses to confirm the statements of the interview partners.

3.3. Data analysis

Two methods were used for data analysis. First, the content analysis was applied to analyze the qualitative information from open-ended questions of the interviews. Content analysis is a research technique for drawing reproducible and meaningful conclusions from texts and transcriptions of the open-ended interview data (Krippendorff, 2004). Responses were transformed into an organized conceptual structure. The interviews were transcribed verbatim, then paraphrased to condense statements and to ensure comparability (Appendix A).

Subsequently, the data obtained was processed into a scenario analysis to answer the second research question. Different scenarios were used to create a direction for future developments by observing key variables (Kosow & Gaßner, 2008). Hence, based on the answers and the secondary data such as lifecycle assessment studies, different hypothetical constructs of possible future were constructed serving as orientational knowledge.

4. Findings

The first closed question was designed to determine the extent to which the available protein alternatives pose a threat to the substitution of conventionally produced meat (Figure 8). In a second step, the interviewees were asked to provide reasons for their answers to understand their reasoning. Microorganism-based proteins have only 5 answers overall since not all experts had expertise in this area (Figure 8). Looking at the diagram, the answers showed a slightly higher potential for animal-cell-based proteins (Figure 8). The 6 interviewees representing different organizations (startups and non-profit research organizations) believed in higher potential for animal cell-based proteins. They justified their views based on superior taste and texture as well as “limitless opportunities” to substitute the whole animal-protein market (Expert 1, 2, 3, 4, 8 & 9). By contrast, the 3 interviewees forecasting higher potential

for plant-based products argued that plant-based products are market mature, approved, and price competitive (Expert 5, 6 & 7).

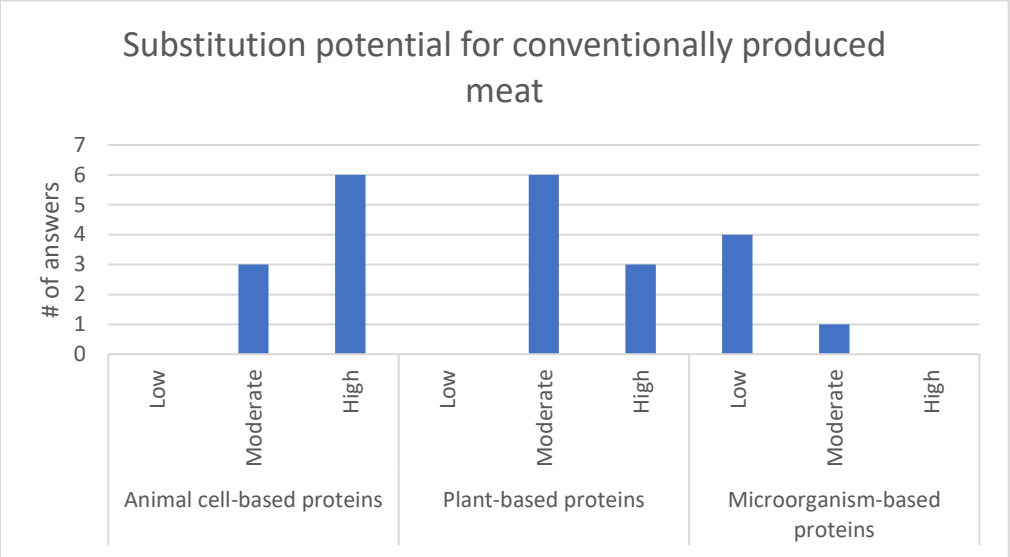

Figure 8: Interview question 1 (Appendix A)

The subsequent question was if cultured meat is a substitution threat for conventionally produced meat and if it is a fundamental gamechanger or rather a temporary trend in the meat industry. This question focused solely on cultured meat and its distinctive features to assess the impact of the phenomenon. The results were unambiguous, and all experts stated that cultured meat is a fundamental gamechanger for the meat industry and provided a wide range of reasons ranging from food security to environmental and health benefits (Appendix A).

Due to the novelty of the technology, question 3 aimed to determine the current state of technological development by determining whether a dominant production process already exists. All answers explicitly state the absence of a dominant production process (Appendix A). Moreover, the answers confirmed that producing meat with the help of animal cells is still in its infancy and all organizations are still exploring proper manufacturing methods. While most experts are pursuing the more popular approach of producing meat in a bioreactor (Figure 5), there are also alternative production methods such as 3D printing technology (Expert 9).

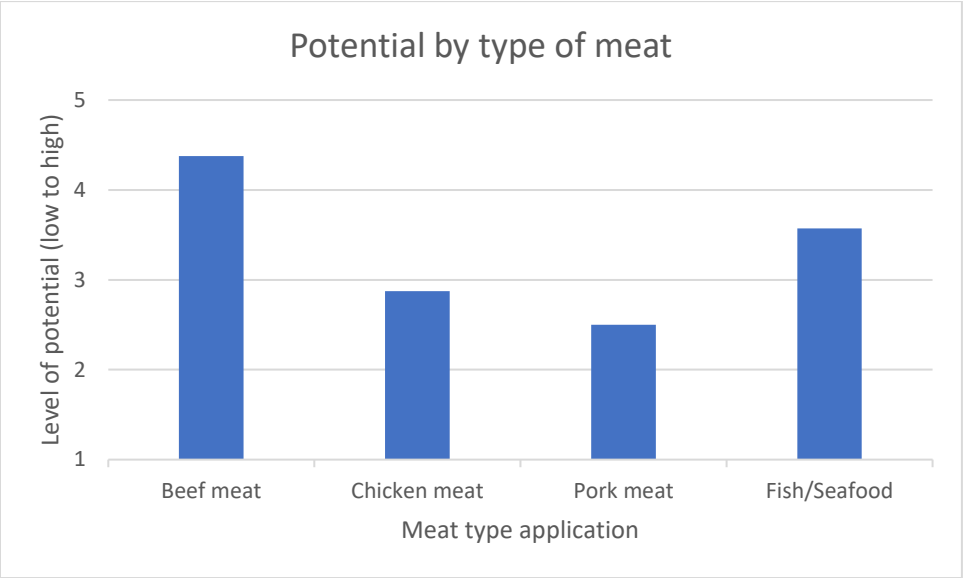

Figure 9: Interview question 4 (Appendix A)

The fourth question was closed and aimed to identify the meat application with the highest potential for substitution success (Figure 9). The question also provided insight into the different properties of meat types and rationales for substitution suitability. On average (potential on a scale of 1-5), beef and fish/seafood are the most suitable substitution applications (Figure 9). Beef has the highest environmental impact and is the most expensive product making it easier to reach price parity (Expert 1, 3, 4, 5, 6, 7 & 9). Fish/seafood instead has the second-highest potential since it is the only species that is wildly hunted leading to increasing environmental concerns of consumers (Figure 9; Expert 1, 2, 3 & 5). Furthermore, fish/seafood has technological advantages in the natural growth process (Expert 4 & 8). Although chicken meat is easier to grow (Expert 4, 5, 6, 7 & 8), the overall substitution potential is classified as low. It is the cheapest meat type and is already produced highly efficiently making it hard to reach price parity (Expert 1, 3, 4, 5, 6, 7 & 9). Cells from pork are similarly difficult to grow as cells from beef, but the price of pork is only moderately high, preventing it from being attractive as a substitute (Expert 3, 4, 5, 8 & 9). In the long term, however, the growing Asian population with a growing middle class will consume relatively large amounts of pork resulting in greater attractiveness of pork as a substitute product (Expert 6 & 7).

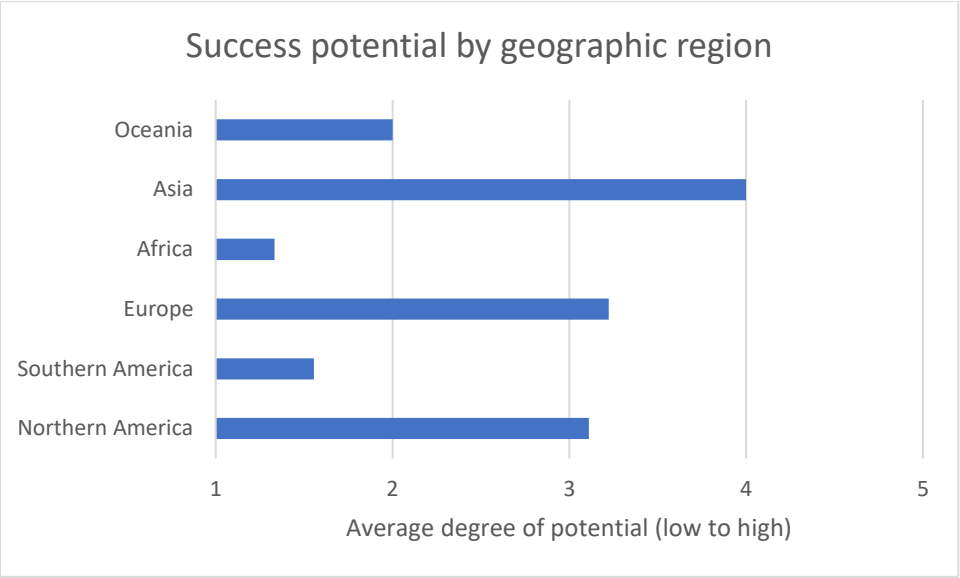

Figure 10: Interview question 5 (Appendix A)

While question 4 identified which type of meat is most attractive, the fifth question explored where substitution has the greatest potential for success (Figure 10). The geographic comparison is straightforward and indicates that Asia has the highest potential for a successful substitution of conventionally produced meat (Figure 10). According to the experts, Europe and the USA show moderate potential, while Southern America and Africa indicate low potential (Figure 10). 8 out of 9 experts mentioned food dependency as the regional key factor tremendously increasing the potential for cultured meat as a substitute (Appendix A). However, a strong agricultural lobby and the resulting protectionism of livestock could restrict the potential (Expert 1, 3 & 7).

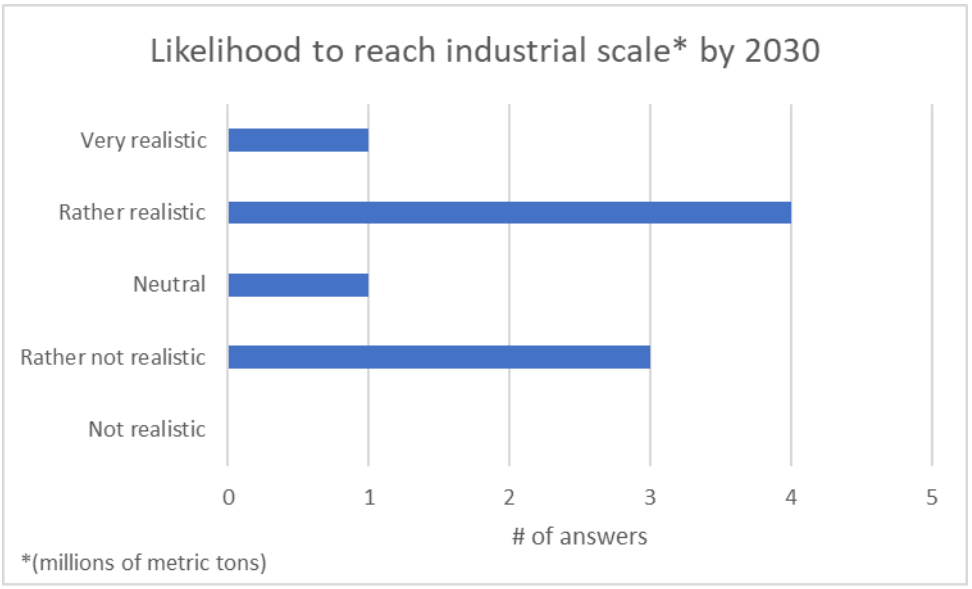

Figure 11: Interview question 6 (Appendix A)

Despite all concerns about the novelty of the technology, most experts (5) consider it realistic or very realistic to reach an industrial scale in production by 2030 (Figure 11). Nonetheless, 3 experts from research and industry (Venture Capital Firm and Startup) also doubt the feasibility of achieving production volumes in millions of tons by 2030 (Figure 11). In theory, large-scale production is feasible, but in practice, the industry is still a long way off (Expert 3, 6 & 8).

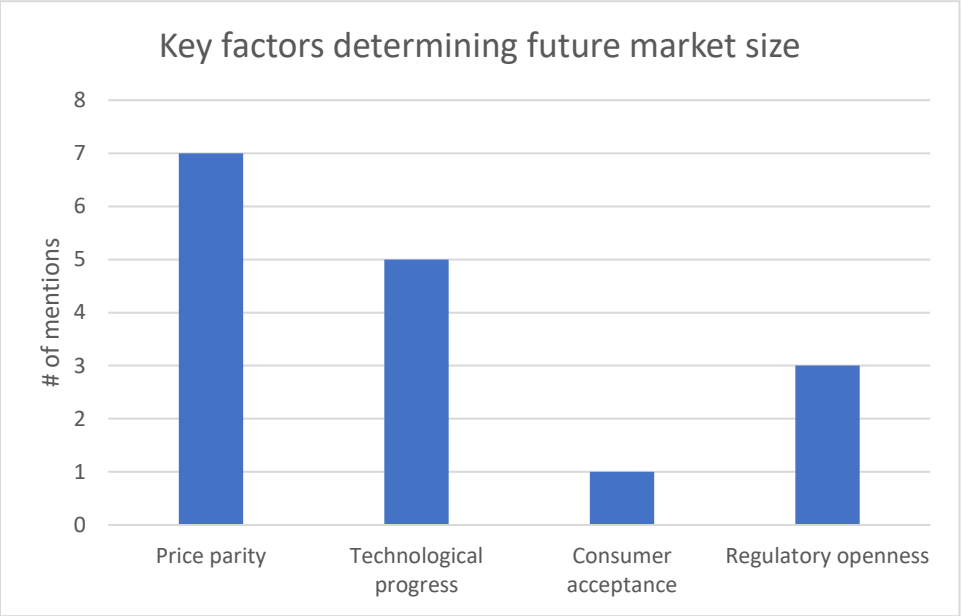

Figure 12: Interview question 7 (Appendix A)

Question 7 was an open-ended question to find out general major factors influencing market adoption and the future market size. Seven out of 9 experts mentioned price parity as the key to gaining traction in the animal protein market (Figure 12). Moreover, 5 interviewees consider technological progress a crucial factor that is simultaneously influencing price parity, while regulatory openness and consumer acceptance play a minor role (Figure 12).

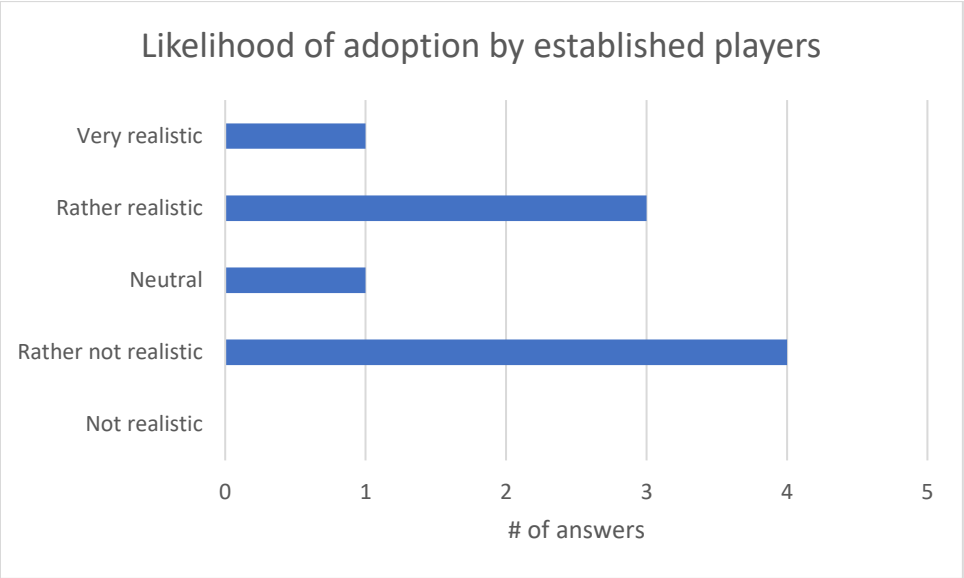

Figure 13: Interview question 8 (Appendix A)

Due to the novelty of the phenomenon, it was assumed that established companies in the food industry such as Fast-Moving Consumer Goods companies, food chains, or food processors might play an important role in accelerating the substitution development by adopting products in the portfolio. While 4 interviews confirm the assumption, 4 experts consider it rather unrealistic that established companies adopt cultured meat products (Figure 13). However, there is evidence that companies already cooperate with cultured meat startups (Expert 1 & 2) and invest in animal-cell-based proteins (Expert 3), but the technology is too novel to be adopted soon by a high number of established players (Expert 5, 6 & 9). Once the industry has matured to the point that firms consider it a profitable industry, the number of investments and collaborations will skyrocket (Expert 9).

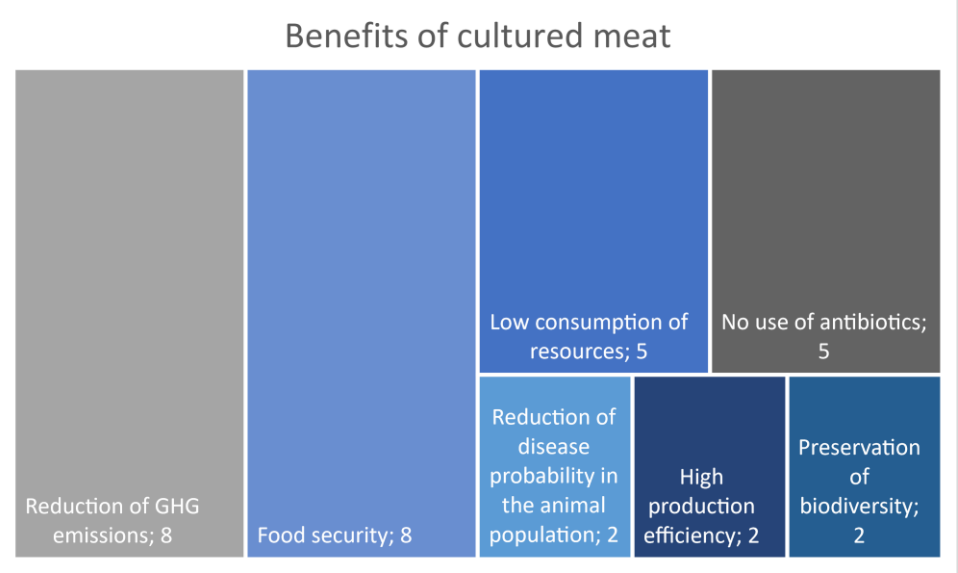

Figure 14: Interview question 9 (Appendix A)

The experts were asked an open-ended question to provide the major benefits of cultured meat to assess the superior value and performance cultured meat is creating. 8 out of 9 interviewees mentioned the reduction of GHG emissions and food security (Figure 14). Additionally, more than half of the experts (5) considered cultured meat beneficial in the lower consumption of land or water resources and the absence of antibiotics (Figure 14). The treemap indicates that reduction of disease probability in the animal population, high production efficiency, and preservation of biodiversity are considered advantageous by 2 experts respectively.

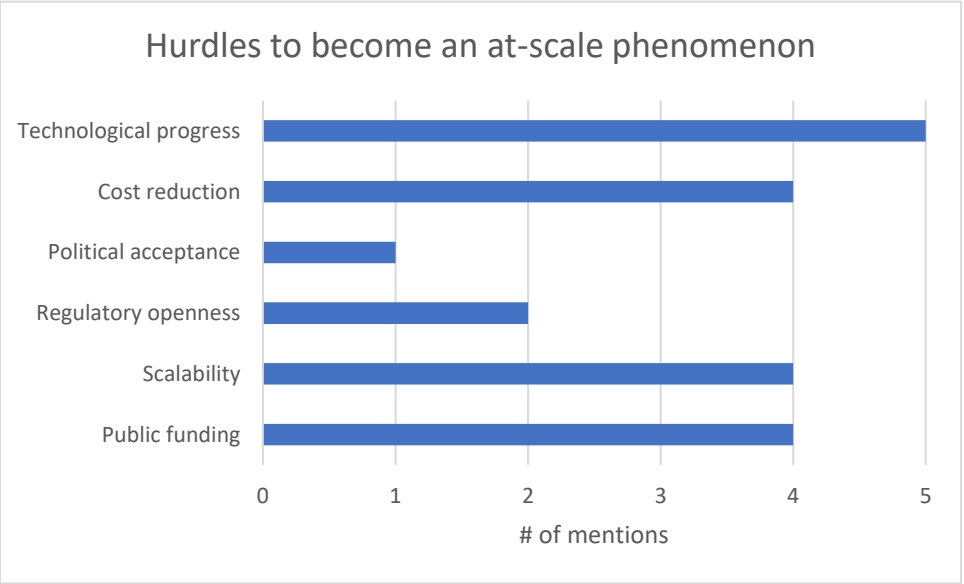

Figure 15: Interview question 10 (Appendix A)

To obtain a holistic perspective on the phenomenon, in addition to the benefits, the challenges of becoming an at-scale phenomenon were asked (Figure 10). The major challenges for cultured meat to be an at-scale phenomenon are limited access to public funding, scalability of production, an enormous cost reduction, and technological progress in bioreactor manufacturing, cell-line, culture media, and scaffold materials development (Appendix A; Figure 15). Further identified hurdles are regulatory openness and political acceptance (Figure 15).

In the subsequent question, the experts provided solutions for the challenges. Due to the open question, the interviewees had the opportunity to propose a broad variety of solutions. Several experts mentioned the inclusion of governmental authorities to tackle the regulatory openness, governmental acceptance, and access to public funding (Expert 2, 3, 4, 6, 8 & 9). In addition, experts consider established companies as a solution to reach scalability and simultaneously reach price parity by reducing costs (Expert 2, 5, & 6). Finally, accelerating technological progress can be solved by startups specializing in certain value chain steps to

deepen knowledge in key areas such as bioreactor production, cell line, media, or scaffold material development (Expert 3, 4, 5, 8 & 9).

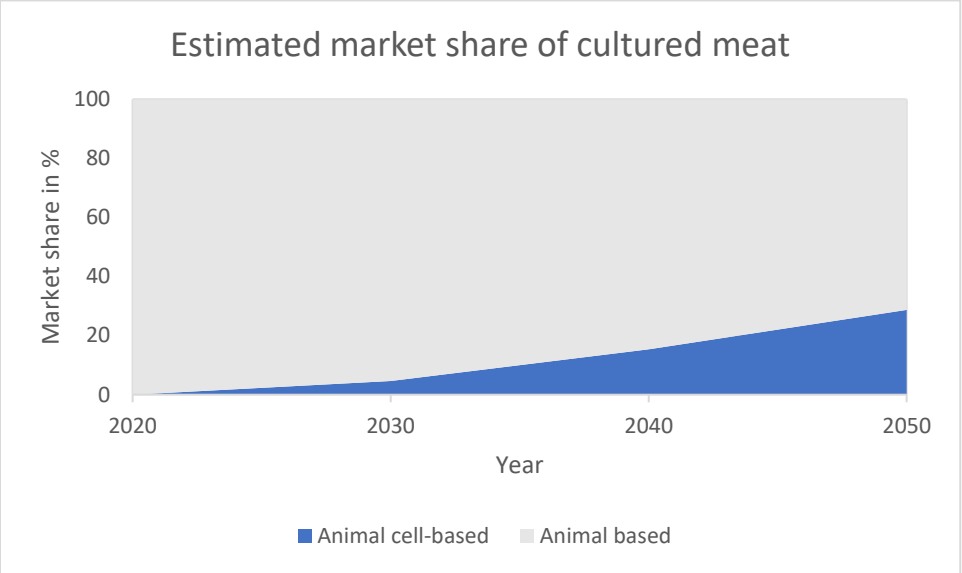

Figure 16: Interview question 12 (Appendix A)

Question 12 was a closed question to quantify the estimated market share animal cell-based proteins can gain in 2030, 2040, and 2050. One of 9 experts was not able to answer the question due to uncertainty surrounding these estimations (Expert 8). By 2030, cultured meat is estimated to account for almost 5% of the meat market. The share is expected to reach 15% by 2040 and 29% by 2050 (Figure 16).

All experts agreed that cultured meat products will not compete with plant-based products. 3 experts predicted a minimal overlap between the markets, while 6 experts forecasted no competition between the product types (Appendix A). Cultured meat will be barely or entirely indistinguishable from conventional meat, and therefore primarily cater to carnivores (Expert 1, 2, 7, & 8). In addition, the future protein market will be divided into a hybrid protein offering (Expert 3, 4, 5 & 6). Besides conventionally produced meat, plant-based and animal cell-based proteins will coexist in the market.

Finally, all interviewees strongly agreed that cultured meat can be a viable solution to reduce the carbon footprint of the agricultural sector (Appendix A). However, 8 experts pointed out that the transition is only possible if the production process is powered by renewable energies. In addition, the decision on a decentralized or centralized production system is essential since a centralized one could lead to significant additional emissions in logistics (Expert 7 & 8). Expert 6 also warns that food security is a dramatic problem for humanity making the sustainability of food supply a non-priority at present which results in the neglect of renewable energy.

5. Discussion and interpretation

The discussion and interpretation are divided into three parts. Based on the interview data and management theory, the first subchapter classifies cultured meat as innovation and thus determines the place and pattern of market diffusion. To ultimately answer the first research question, the second part elaborates on the first sub-chapter and outlines the reasons, drivers, and barriers to cultured meat being a substitution threat. The last subchapter addresses the second research question and builds scenarios based on the findings from the previous subchapters, the interviews, and secondary market data.

5.1. Innovation in the meat industry

Due to the use of a new production method by growing meat in the laboratory (Figure 5) instead of using conventional livestock (Figure 2), cultured meat can be considered an innovation that causes economic change and "creative destruction" in the meat industry (J. A. Schumpeter, 2006; J. Schumpeter & Backhaus, 2003).

In order to explore where and how cultured meat has an impact on the meat industry, one must understand the type of innovation the meat industry is facing. Although the novelty and breakthrough of cultured meat could be perceived as a disruption, cultured meat is classified as sustaining innovation. This classification is based on three key differentiators.

Firstly, the product performance relative to existing products in the market differs between sustaining and disruptive innovation. While disruptive innovations seek to create "good enough" products, sustaining innovations create products that outperform existing products on the quality and performance dimensions (Christensen et al., 2015). Cultured meat is not only healthier due to the absence of antibiotics and manure from the food system, but it is also less harmful to the environment and animal welfare (The Good Food Institute, 2021b) (Expert 1 & 3).

The second differentiator is the target audience which is also closely related to the product performance. The "good enough" product for disruptive innovation targets the lower end of the market which is associated with a lower willingness to pay and inferior performance expectations of the product. Sustaining innovation, in contrast, targets customers with a high willingness to pay for high-quality products (Christensen et al., 2015). Due to the high production costs of cultured meat, and the low production quantities, the target group is in the upper end of the market with a high willingness to pay (Expert 4 & 9). Hence, in the short term, the highest potential for market entry is high-end beef products (Figure 9; Expert 3).

Reciprocally, as of now, cultured meat startups are not able to target the least profitable portion of the market due to the high production cost.

Thirdly, the business model differs between disruptive and sustaining innovation. Disruptive innovation is based on low costs to come in at the bottom of the market, whereas sustaining innovation depends on profitable business models (Christensen et al., 2015). For this reason, a potential market entry option for cultured meat can be also a retail value-added product with a high margin to reach price parity (Expert 6).

Although the new entrants are small startups that challenge incumbents such as food processors by leveraging emerging biotechnology, the innovation process is not disruptive.

The characterization of the phenomenon as sustaining innovation provides the place for market encroachment. Sustaining innovation "encroaches on the high end of the existing market, and then diffuses downward" (Schmidt & Druehl, 2008). Hence, in the short-term, cultured meat encroaches on the market from the high end by serving the most profitable customers with beef (Figure 9). When hurdles such as technological progress, scalability, and the associated cost reduction are solved (Figure 15), cultured meat in form of fish, pork, or even low-priced chicken can move steadily down the market capturing the share of customers with a lower willingness to pay.

5.2. From the lab to the consumer's plate

After identifying the place of the encroachment and diffusion, the second step is to measure and assess the threat of substitution for conventionally produced meat to answer the first research question.

5.2.1. Cultured meat – a serious substitution threat

Porter pointed out in the 5-Forces Framework that one major force shaping the industry's competition is the threat of substitute products (Figure 7). Furthermore, he emphasized that substitute products should be given very particular attention, which are subject to trends that improve their price-performance ratio with the current products of the industry (Porter, 1979). In concrete terms, the substitution threat is particularly high when the price-performance trade-off becomes more attractive to the current product (Porter, 2008).

On the performance dimension, cultured meat exploits its characteristics and puts itself in a superior position. Looking at the megatrends, health, climate change, and food security, cultured meat addresses all of them (Figure 14). In comparison to conventional meat, cultured

meat is not only healthier but also less harmful to the environment (Expert 1 & 3). Considering the continuously growing world population, land and water resources are limited making food security a serious problem. The food security conundrum can be also tackled by cultured meat. Studies show that cultured meat would use the soil 60-300% more efficiently for chicken, while for beef the efficiency increase reaches 2,000-4,000% (The Good Food Institute, 2021b). Those efficiencies can be utilized to free up land for growing crops and vegetables for a rapidly growing world population (Figure 14; Expert 2, 4, & 5). In addition, the actual product characteristics such as taste, and texture remain the same and are indistinguishable from genuine meat (Expert 3, 4, 6 & 8). Given the megatrends that are significantly influencing consumer purchasing behavior, the perceived performance of cultured meat far exceeds that of conventional meat (Bryant & Barnett, 2018). As a result, cultured meat is a significant substitution threat for conventional meat confirming the consensus among experts that it will be a fundamental gamechanger for the meat industry (Appendix A; Figure 8).

While cultured meat is superior on the performance dimension, on the price dimension it is lagging. In line with Porter, the experts consider price parity to be a key factor in gaining market share (Figure 12). Although the technology is developing rapidly leading to significant production cost reductions, the current production costs are still 100-10,000 higher than the benchmark costs of comparable conventional meat products (Vergeer, Sinke, & Odegard, 2021). The cost differential occurs because cultured meat is at the onset of commercialization (Figure 6). Likewise, all experts agree that an ideal production process does not yet exist, and companies are just starting to build their first pilot-scale productions (Figure 6; Expert 3). The majority of experts (Figure 11) and the literature state that an industrial scale is feasible by 2030 resulting in price parity with conventionally produced meat (Vergeer et al., 2021; Witte et al., 2021).

In addition, the threat of substitutes is also high if the buyer's cost of switching is low (Porter, 2008). Once production can be scaled up and cultured meat is available in supermarkets or food chains, the cost of switching is low.

Looking at the first research question (*Will cultured meat be a significant substitution threat for traditionally produced meat in the future?*), cultured meat poses a significant substitution threat to conventional meat since it offers a perceived superior performance and can reach price parity by 2030. While in the short-term more expensive beef might be a successful application, in the long term all types including fish/seafood are attractive application options. In the long term, the experts foresee an even higher substitution potential

through animal cell-based proteins since plant-based proteins are considered a "stepping stone" in the alternative protein movement (Figure 8; Expert 2). However, on the way to getting traction in the meat market, cultured meat still needs to reduce costs enormously by further advancing scalability and technology. Therefore, in the beginning, there will be a hybrid product offering consisting of conventional meat, plant-based, cell-based, and hybrid protein products (Expert 3, 4, 5, 6 & 8).

5.2.2. Barriers to overcome

On the path to a successful substitution threat for meat, several challenges still need to be overcome. Looking at the key factors determining the future market size and the hurdles, there is an overlap and key factors for success potential currently also represent a part of the hurdles of the phenomenon (Figures 12 & 15). Conversely, solving a hurdle also implies that the substitution potential of cultured meat increases at the same time.

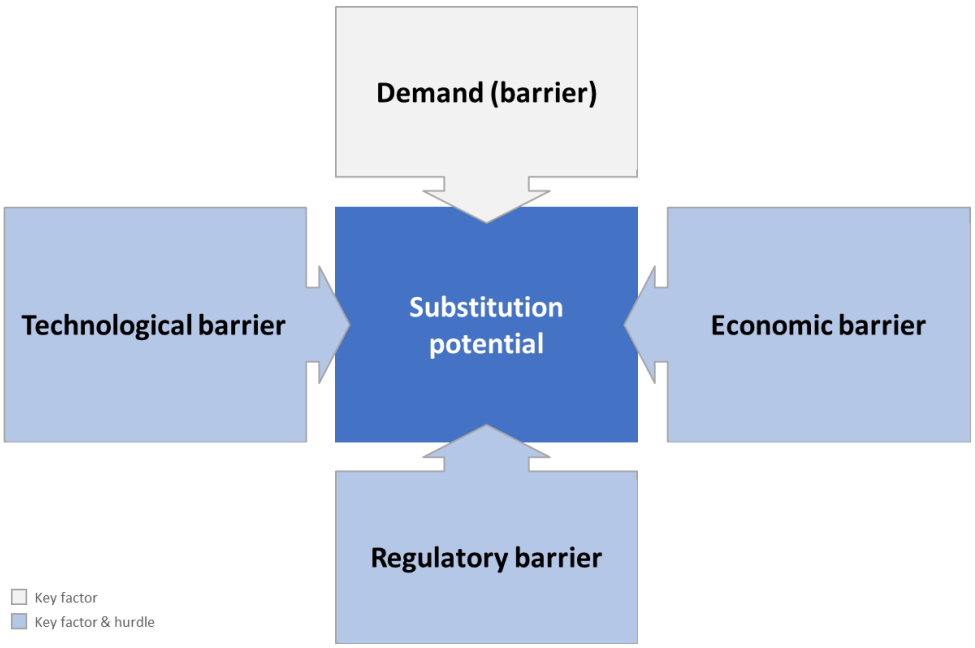

Figure 17: Categorized barriers for cultured meat (Appendix A)

Consequently, the key factors and hurdles have been categorized by topic into four types of barriers (Figure 17). The demand barrier, including consumer acceptance, is considered by the experts to be only a key factor and not a hurdle to substitution potential. Studies show that a large proportion of consumers accept cultured meat, so demand is not a barrier. (Bryant & Barnett, 2018). However, studies also suggest that the consumer's knowledge, familiarity with cultured meat, and the wording around cultured meat would likely affect consumer acceptance (Post et al., 2020). According to a US consumer survey about acceptance conducted by one expert up to 40% of the animal protein market could be covered (Expert 1). Although

consumer acceptance is not a hurdle, it remains a determining factor for the success of cultured meat.

The technological barrier is a key factor but also a hurdle and includes technological progress and scalability. Still in its infancy, four key technological areas (cell line development, cell culture media, scaffold materials, and bioreactors) have been identified that require further innovation (Expert 3, 4, 6, 8 & 9). The base material -- cell line development -- needs to be driven forward, to ensure better growth properties (Expert 4 & 9). Secondly, as another critical growth resource, the cell culture media requires advancement. So far, the culture media usually contains animal sera that are not viable for cultured meat since it is misaligned with animal welfare (Expert 4 & 9). Culture media that are free of any animal-derived material do exist but are still very expensive leading to even higher production costs (Schwartz, 2019). However, Merck KGaA as a technology enabler and one of the only active established companies, is accelerating this emerging field by providing animal-free media (Merck, 2021). Thirdly, the scaffold materials for providing the texture and mouthfeel of cultured meat face a similar issue and need to be produced without animals (Expert 6). Nevertheless, these materials are also very expensive and require further development (Post et al., 2020). In order to push the production on an industrial scale and provide market readiness, bioreactors require enormous research and development efforts (Expert 4, 5, 6 & 8). Expert 8 emphasized the importance of collaboration between all stakeholders (startups, incumbents, academia, and regulatory) including an open-access research approach to accelerate the technological progress of cultured meat.

The scalability hurdle is closely related to hurdles of the economic barrier. While price parity and the associated production cost reduction are addressed in the previous subchapter 5.2.1, the access to public funding still poses challenges for the industry (Expert 2, 3, 8 & 9). Bioreactors require significant capital (Humbird, 2020). The experts claim that private funds provided by venture capital firms or a few industry incumbents such as Tyson Food or Cargill are insufficient and access to debt capital is capped due to the limited liability of startups (Expert 6). Hence, access to public funds must be expanded to drive overall progress. Investments are not limited to the private sector, but public funding still occurs relatively rarely (Expert 8 & 9). However, a positive trend is apparent and in April 2022, the Dutch government announced €60m funding for the creation of an ecosystem around cellular agriculture representing the world's largest-ever public investment in this area (The Good Food Institute, 2022).

Lastly, to become an at-scale phenomenon cultured meat needs to overcome regulatory barriers. The regulatory framework for food differs across regions and countries. Without going into detail about individual regulations, Expert 7 pointed out that the European Union has an overall stringent food safety framework, making it more difficult for food innovations to enter the market (Expert 7). However, the novelty of the phenomenon and the fact that cultured meat is not yet produced in a standardized process, makes it very unlikely to receive market approval soon (Stephens et al., 2018). Uncertainty in both technology and regulation implies dealing with ambiguity. Looking at the factors increasing the substitution potential in a region, food dependency is a crucial factor (Appendix A; 8/9 Experts). Hence, cultured meat is anticipated to emerge first in countries whose governments are dedicated to the sector's expansion and showing openness towards cultured meat (Figure 12; Expert 7). To properly build efficient regulatory frameworks, companies and regulators are required to collaborate. Singapore's agricultural GDP is below 0.1% making the country dependent on food imports (World Bank, 2020). To tackle the dependency, Singapore's self-sufficiency goal "30 by 30" aims to strengthen food security by building an agricultural industry producing 30% of the nutritional needs locally and sustainably by 2030 (Singapore Food Agency, 2022). The strategy indicates Singapore's high ambition, support, and openness towards new food innovations such as cultured meat. For this reason, Singapore also committed $60 million to the Agri-Food Cluster Transformation Fund (Singapore Food Agency, 2022). Furthermore, the Middle East is geographically, environmentally, and climatically very dependent on food imports (Le Mouël & Schmitt, 2018). Expert 7 points out that the combination of food dependency and high financial resources promotes political as well as regulatory openness toward cultured meat (Expert 7). The Qatar Investment Authority backed the $200 million funding for Eat Just (Business Wire, 2021). Thereupon Est Just announced afterward to build a commercial cultured meat facility in Qatar (Just Food, 2021). Further efforts of the governments in the Middle East are confirmed by the investment ($400m) made by the Abu Dhabi Growth Fund in Upside Foods (Yasmin, 2022).

Thus, regulatory openness also implies a certain degree of political acceptance and support, which are indispensable for cultured meat to achieve commercial scale. Based on the regulatory perspective and due to the higher food independence caused by a stronger agriculture sector, Europe and North America tend to have a lower potential than Asia (Expert 1, 6 & 7).

5.3.Substitution with environmental impact

To answer the second research question (*Assuming cultured meat partly replaces traditionally produced meat, how would this development affect the environmental impact of the meat industry?*), three scenarios are created in 2030, 2040 2050 (Table 2). While scenario 1 is the worst-case assumption, the second one represents a more likely situation. Scenario 3 underlies the assumption of the best possible development.

ID	DESCRIPTION
SCENARIO 1	Cultured meat fails to enter the market and the meat industry remains unchanged resulting in no encroachment.
SCENARIO 2	Cultured meat succeeds in entering the market but is operated with conventional energy.
SCENARIO 3	Cultured meat succeeds in entering the market and is operated with sustainable energy.

Table 2: Scenarios for environmental impact assessment

Energy and market share are the two identified key variables affecting the environmental impact of cultured meat substitution. 8 experts agree that energy is the key factor in the environmental impact of cultured meat as it is the largest contributor(Appendix A) (Alexander et al., 2017; Sinke & Odegard, 2021). Therefore, in Scenarios 2 and 3, the energy mix to produce cultured meat varies. In Scenario 2, power is generated based on a worldwide average policy scenario indicated in the World Energy Outlook for 2030. Whereas, in Scenario 3, the energy is sustainable and is generated using onshore wind turbines and solar modules. To reflect the variation in the second key variable, market share, Scenario 1 assumes that cultured meat does not enter the market, while Scenarios 2 and 3 assume the average value of the answers given by the experts (Appendix B; Figure 16).

Despite the barriers preventing cultured meat from becoming a widespread occurrence (Chapter 5.2.2.), the experts predicted on average a market share of 4.63% (~17m tons) by 2030, 15.38% (~65m tons) by 2040, and 28.72% (~139m tons) by 2050 (Appendix B). Looking at short-term forecasts carried out by BCG (6m tons by 2035) and McKinsey (2.1m tons by 2030), the values are lower than the 2030 result of this dissertation (Brennan et al., 2021; Witte et al., 2021). This can be explained by the following reasons. Firstly, both studies are over a year old, and the area of research is fast-changing leading to different estimations. Secondly, different calculation bases may have been used. For the scenario analysis, the average of all expert answers was taken. One answer for the year 2030 was significantly divergent from the

other answers (Expert 1). The average value is very sensitive to outliers resulting in a positive shift of the average. One could also have taken the median or excluded the outlier. However, since the topic is unexplored and novel, all responses were included in the following scenario analysis.

ID	DESCRIPTION
ASSUMPTION 1	Market share is based on the average values of the interviews and amounts to 4.63% for the year 2030, 15.38% for 2040, and 28.72% for 2050.
ASSUMPTION 2	Market share of cultured meat is evenly distributed among the meat types of beef, chicken, and pork.
ASSUMPTION 3	Cattle, chicken, and pork represent the meat industry, and fish/seafood is not included in the scenario analysis.
ASSUMPTION 4	Based on the growth rate from 2020 to 2030, global meat demand grows in a linear pattern (14% per decade) from 2030 to 2050.
ASSUMPTION 5	The GHG emissions, land use, and water use remain on the 2030 levels for conventional and cultured meat and do not change over time.
ASSUMPTION 6	The energy mixes in Scenarios 2 and 3 remain the same for 2030, 2040, and 2050.

Table 3: Assumptions for the scenario analysis

Regarding the scope of this paper, the scenario is subject to assumptions resulting in a simplification of the model (Table 3). To present data in a robust and comparable way, the values of all meat types are based on the life cycle assessment study of CE Delft (Sinke & Odegard, 2021).

Moreover, three indicators (GHG emissions, land use, and blue water use) were used to assess and illustrate the environmental impact of cultured meat on the meat industry. For conventional meat types, an ambitious benchmark (intensive, West-European, circular agriculture) with comparably low environmental impact was chosen to highlight the minimal benefits of cultured meat.

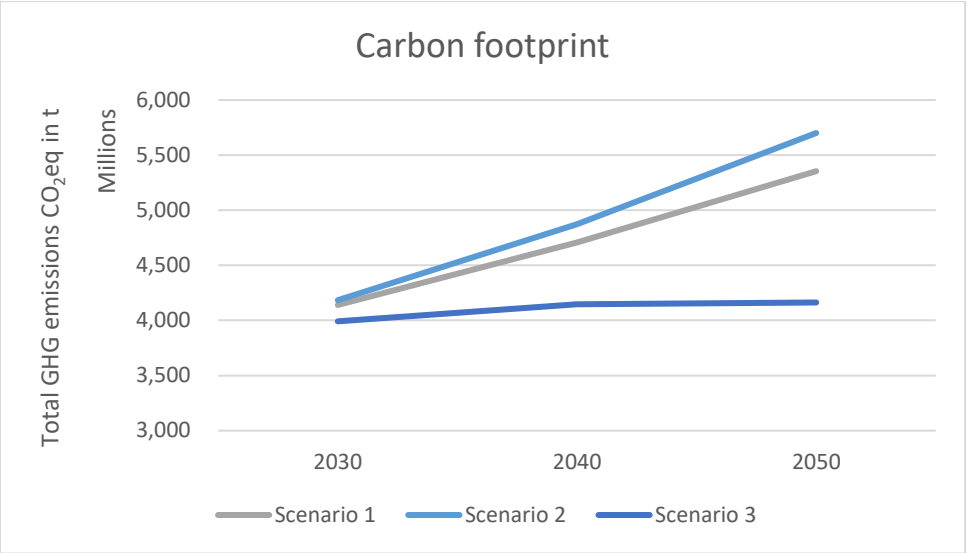

Figure 18: Global carbon footprint of the meat production in 2030, 2040, and 2050 (Appendix B)

Looking at the carbon footprint of Scenario 3, it is unambiguous that cultured meat produced with sustainable electricity strongly reduces carbon emissions of the meat industry (Figure 18). Despite increase in meat consumption, the Scenario even leads to a stagnation of emissions from 2040 to 2050, when 29% of the market share is attained (Figure 18). Compared to Scenario 1, the emission reduction reaches ~1.2b tons of CO_2 per annum in 2050, representing a reduction of more than 22% (Appendix B; Figure 18). Based on a business-as-usual trend with current policy projections, the overall global GHG emissions are predicted to reach 46.59b tons in 2050 (Climate Analytics and New Climate Institute, 2021). Scenario 3 would result in a reduction of 2.6% of total global CO_2 emissions (Figure 18). While in Scenario 1 GHG emissions increase by almost 30% in 20 years, in Scenario 3 the carbon footprint rises by only 4% from 2030 to 2050 despite a continuous increase in total consumption.

Although cultured meat produced with conservative energy in Scenario 2 emits only half as many GHG emissions as beef meat (Appendix B), the scenario performs the worst across all years (GHG growth rate of 36% from 2030 to 2050) since it generates twice as much as pork meat and almost 4 times as much as chicken meat. It confirms the experts' conclusion that cultured meat is highly energy-dependent and does not improve the carbon footprint on its own.

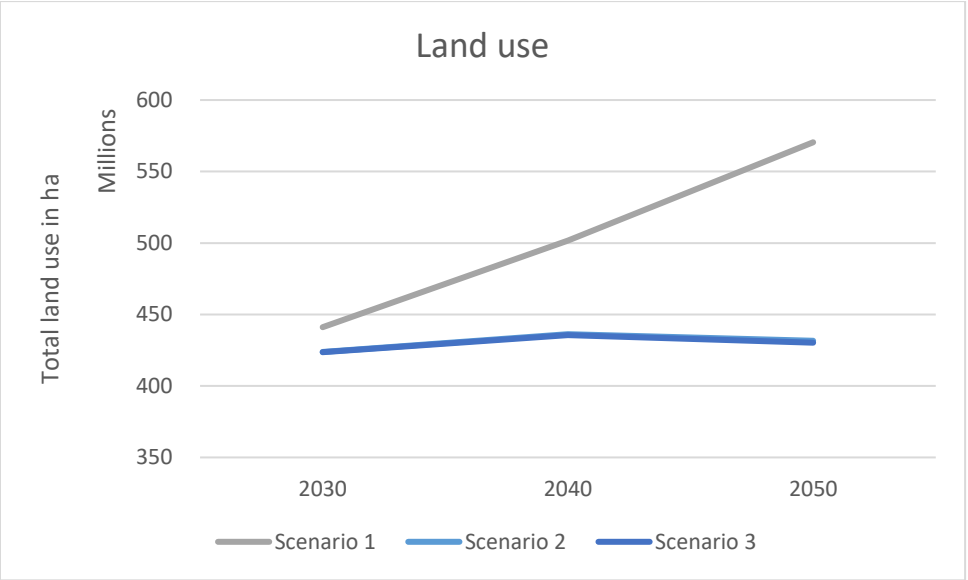

Figure 19: Global land use for the meat production in 2030, 2040, and 2050 (Appendix B)

Due to the significant land use savings of cultured meat per kg (95% reduction compared to beef, 72% reduction compared to pork, and 63% reduction compared to chicken), Scenarios 2 and 3 show enormous potential for improvement through the substitution of cultured meat (Appendix B; Figure 19). If cultured meat attains a market share of 29% in 2050, more than 140 million ha (25%) could be saved annually (Figure 19). This would be more than four times the size of Germany and illustrates the potential land that could be made available for other uses such as human food cultivation. Despite growing demand for meat, in both scenarios, the overall land use can be reduced from 2040 to 2050 (Figure 19).

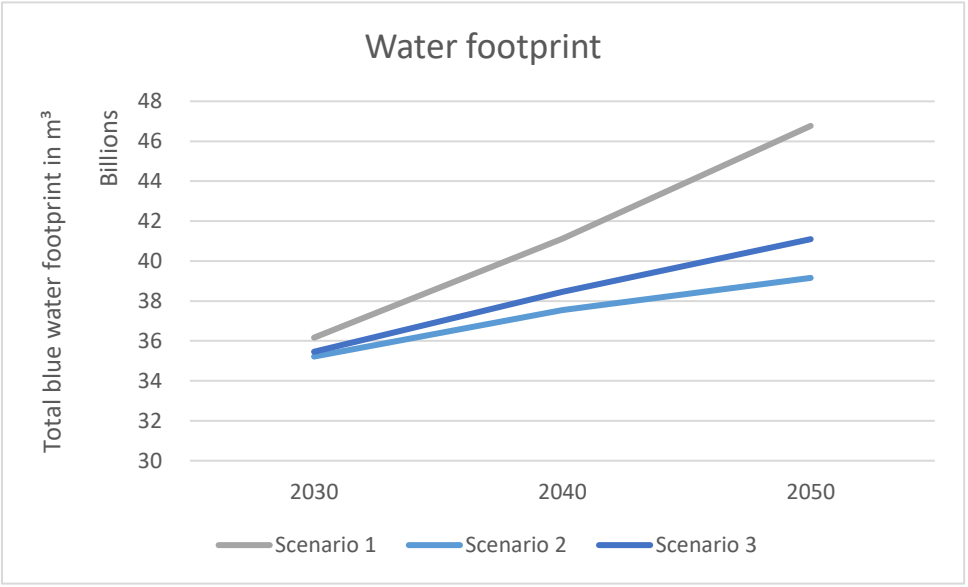

Figure 20: Global blue water use in the meat production in 2030, 2040, and 2050 (Appendix B)

Finally, in the analysis of water consumption, scenarios were enhanced for if cultured meat becomes a substitute for conventionally produced meat (Figure 20). Using a conventional

energy mix results in the lowest use of blue water due to the water-intensive production of solar cells for sustainable electricity production (Sinke & Odegard, 2021). However, the use of renewable energy for cultured meat production could still result in yearly water savings of 5.6b cubic meters (12%) in 2050, which can provide immense relief, especially in highly water-stressed regions (Figure 20). Given increasing scarcity of freshwater worldwide and the fact that agriculture is the sector that consumes the most water, environmental degradation can be significantly mitigated.

Overall, the scenarios prove a significant positive environmental impact of cultured meat on the meat industry. However, using a sustainable energy mix for energy-intensive cultured meat production is crucial to achieving a positive transformation of the meat sector into a more ecologically sustainable business. Especially given the rapidly growing population and the limited natural resources, cultured meat could represent an enormous contribution to improving the efficient use of resources. Additionally, with each kg of cultured meat replacing conventionally produced meat, the livestock population can be reduced, enhancing animal welfare.

6. Conclusion

The last chapter of the dissertation summarizes results answering the research questions as well as critically examines limitations of this work and provides an outlook for further research.

6.1. General conclusion

Cultured meat is at the cusp of transforming the animal protein market. Besides already existing alternative proteins, animal cell-based proteins could become a reality. Public concern about climate change, health, and food security not only drives demand for cultured meat products but also provides further incentives for startups as well as incumbents to advance the technologies.

The dissertation aimed to answer the question of whether cultured meat can pose a significant substitution threat to conventionally produced meat. By analyzing and evaluating the phenomenon in detail, cultured meat is a sustaining innovation with the potential to encroach on the high end of the meat market. The results revealed that cultured meat has great potential to replace a significant share of the animal protein market by 2030. Due to the similarity with genuine meat and the unlimited application possibilities, cultured meat is a substitution without compromise for the consumer. In addition, cultured meat addresses the

adverse effects of livestock farming. The growing population, the increasing demand for protein-rich diets, natural resource scarcity, animal welfare, and environmental problems such as GHG emissions and biodiversity loss could be tackled comprehensively and sustainably.

However, it is a long path with pertinent challenges before cultured meat products are consumer-ready. The most critical hurdle is price parity. In order to pose a real substitution threat, production costs need to be significantly reduced. This goes along with the achievement of industrial-level production and technological progress in product and production development. In the final step, it is imperative that cultured meat receives regulatory approval from the authorities and the necessary support in the form of cross-industry collaboration from incumbents. Only under these conditions, cultured meat can pose a serious substitution threat to conventionally produced meat.

The scenario analysis explicitly indicates that cultured meat can have a substantial positive impact on the environmental footprint of the meat industry. Considering the increasing overall consumption of meat, cultured meat could compensate for additional GHG emissions, land use, or water consumption in the future. However, renewable energy sources for production are crucial to achieving a comprehensive beneficial environmental effect. Finally, the substitution of conventional meat can also simultaneously solve the animal welfare problem of livestock farming and the global food security challenge through the efficient use of resources.

6.2.Limitations

Although the dissertation contributes to its area of study, it faces limitations. First, the sample size of the experts is low which limits generalizability. Even though there is breadth and diversity due to the different organization types, the number of experts is too small (9). Moreover, the organization types are not equally distributed. While 4 out of 9 experts were from startups, 2 others represented venture capital firms, only 2 came from independent research institutions, and one was from a consulting firm. This may result in an overly positive and one-sided assessment of cultured meat as it can be assumed that the entrepreneurs and investors have more opportunistic points of view than scientists or consultants.

Secondly, the scenario analysis has a very limited prognostic value and cannot be used for a precise prediction. The assumptions made for the scenario have greatly simplified the scenario to a thought experiment and can therefore lead to inaccuracies. The scenario aims to direct the attention to both variables, energy mix and market share, and how those interact with one another.

Thirdly, cultured meat is a futuristic and technologically heavy field of study since there is only one regulatory approval worldwide yet. Cutting-edge topics with this degree of novelty may lead to respondents' biased assumptions and replies.

6.3.Further research

The dissertation solely focused on cultured meat and fish for human nourishment, further applications for cultured meat such as pet food were excluded. With lower regulatory hurdles and a less complex approval process for pet food, there could be an opportunity to get to market faster. However, the market for pet food differs significantly from the meat industry resulting in a different substitution potential. Further research is required to assess the substitution potential for cultured meat for pet food.

In addition, cellular agriculture technology can be used for other meat industry by-products, such as leather. An evaluation of the substitution potential can also be carried out in this area, which requires further research.

Likewise, the energy mix plays a crucial role for cultured meat to be an environmental enhancement for the meat industry. However, there is no feasibility study showing that an operation with sustainable energy can be carried out. Further research is needed to determine how and whether this will be possible in the near future.

Finally, the dissertation did not examine the economic implications of substitution in the conventional meat market. Cultured meat could significantly affect the market power and supply chain. Depending on the centralized or decentralized approach, the supply chain of meat could drastically change to a very local production supporting food security in troubled regions or to an even more centralized production resulting in concentrated supply power. Furthermore, it could lead to an increase or mitigation of logistics efforts. The decision and the respective implications require further research.

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Appendix A

Interview questionnaire template

Expert ID: x	**Expert:** xxx					
Q1	**What are the types of products with the highest potential to be a substitution threat for traditionally produced meat in the future?**					
	Type of Alternative	Animal cell-based proteins	Plant-based proteins	Microorganism-based proteins		
	Potential					
	Reason/clarification					
Answer	Further details:					
Q2	**How much potential do you see in cultured meat as a substitution threat? Do you see it as a temporary trend or as a fundamental game-changer?**					
Answer						
Q3	**Are there different manufacturing/production methods for culturing meat? Is there a dominant scientific process?**					
Answer						
Q4	**On a scale from 1-5 (1 lowest; 5 highest), for which type of meat (beef, chicken pork, and fish/seafood) do you see the greatest /lowest potential for cultured meat?**					
	Type of meat	Beef meat	Chicken meat	Pork meat	Fish/Seafood	
	Potential (1 lowest; 5 highest)					
	Reason/clarification					
Answer	Further details:					
Q5	**Do you see a particularly high/low potential for success for cultured meat in certain geographic regions?**					
	Geographical region	Northern America	Southern America	Europe	Africa	Asia	Oceania
	Potential (Very low, low, moderate, high, very high)						
	Key factors						
	Higher potential		Lower potential				
Answer							
Q6	**On a scale from 1-5 (1 lowest; 5 highest), how realistic is it to reach an industrial scale (millions of metric tons) in 2030?**					
	Likability of industrialized scale till 2030 (1 lowest; 5 highest)					
Answer	Further details:					
Q7	**What do you think are the key factors determining the future pace of adoption and market size of cultured meat?**					
Answer						
Q8	**On a scale from 1-5 (1 lowest; 5 highest), how likely is it that established players (FMCG companies, food chains, etc.) integrate cultured meat products into their company/product portfolio?**					
	Likability of adaption of established players					
Answer	Further details:					

Q9	**What are the benefits of producing cultured meat instead of genuine meat?**
Answer	
Q10	**What are the biggest hurdles for the industry to overcome so it can become an at-scale phenomenon?**
Answer	Further details:
Q11	**What needs to happen to overcome these hurdles?**
Answer	Further details:

Q12 **What is your estimate of the share (in %) that cultured meat can substitute in the animal protein market in 2030, 2040, and 2050?**

	Year	2030	2040	2050
	Market share of animal protein market in %			
Answer	Further details:			

Q13	**How will vegetarians and vegans perceive cultivated meat? Do you think plant-based proteins will compete with cultured meat?**
Answer	
Q14	**Do you see cultured meat as a viable solution to reaching net-zero or a low carbon footprint in the agricultural sector?**
Answer	

Paraphrased expert interviews

Expert ID: 1 **Expert:** Chief Executive Officer, Cultured Meat Start-up in Israel

Q1 **What are the types of products with the highest potential to be a substitution threat for traditionally produced meat in the future?**

	Type of Alternative	Animal cell-based proteins	Plant-based proteins	Microorganism-based proteins
	Potential	High	Moderate	-
	Reason/clarification	More advanced product; Rather another meat type than substitution	Unable to reach nutritional properties of genuine meat	-
Answer	Further details:	-		

Q2	**How much potential do you see in cultured meat as a substitution threat? Do you see it as a temporary trend or as a fundamental game-changer?**
Answer	Fundamental gamechanger with high potential due to its better health and environmental footprint. According to an own representative consumer survey in the USA, up to 40% of the animal protein market could be covered.
Q3	**Are there different manufacturing/production methods for culturing meat? Is there a dominant scientific process?**

Answer	There is no dominant scientific production process. Due to the different end products, the processes will differ anyways. Some manufacturers are already using large-scale production methods while most companies are still looking for a suitable manufacturing process.

Q4	**On a scale from 1-5 (1 lowest; 5 highest), for which type of meat (beef, chicken pork, and fish/seafood) do you see the greatest /lowest potential for cultured meat?**					
	Type of meat	Beef meat	Chicken meat	Pork meat	Fish/Seafood	
	Potential (1 lowest; 5 highest)	5	1	2	4	
	Reason/clarification	High environmental impact; most expensive meat-type	Cheapest meat type (very efficient production)	Cheap meat type	Increasing environmental concerns	
Answer	Further details:	-				

Q5	**Do you see a particularly high/low potential for success for cultured meat in certain geographic regions?**					
	Geographical region	Northern America	Southern America	Europe	Africa	Asia	Oceania
	Potential (Very low, low, moderate, high, very high)	Moderate	Very low	Low	Very low	High	Very low
	Key factors					
	Higher potential			Lower potential		
Answer	High food dependency; High consumer acceptance			Strong agricultural lobby Protectionism		

Q6	**On a scale from 1-5 (1 lowest; 5 highest), how realistic is it to reach an industrial scale (millions of metric tons) in 2030?**		
	Likability of industrialized scale till 2030 (1 lowest; 5 highest)		4
Answer	Further details:	-	

Q7	**What do you think are the key factors determining the future pace of adoption and market size of cultured meat?**
Answer	Price parity Regulatory openness Technological progress

Q8	**On a scale from 1-5 (1 lowest; 5 highest), how likely is it that established players (FMCG companies, food chains, etc.) integrate cultured meat products into their company/product portfolio?**		
	Likability of adaption of established players		4
Answer	Further details:	The startup is working already with retailers and food processors	

Q9	**What are the benefits of producing cultured meat instead of genuine meat?**
Answer	Low consumption of resources; Reduction of GHG emissions; Reduction of disease probability in the animal population; High production efficiency; No use of antibiotics; Food security
Q10	**What are the biggest hurdles for the industry to overcome so it can become an at-scale phenomenon?**

	To achieve the ability to scale up manufacturing facilities efficiently and rapidly. To reach product matureness (texture, price, and taste) in order to serve the right customers.
Answer	Further details: -

Q11	**What needs to happen to overcome these hurdles?**
	Companies need to be more consumer-centric and less scientific-centric. Science centralism leads to a disconnection from the actual market and its demands.
Answer	Further details: -

Q12	**What is your estimate of the share (in %) that cultured meat can substitute in the animal protein market in 2030, 2040, and 2050?**			
	Year	2030	2040	2050
	Market share of animal protein market in %	20	40	70
Answer	Further details:	-		

Q13	**How will vegetarians and vegans perceive cultivated meat? Do you think plant-based proteins will compete with cultured meat?**
Answer	There will be no competition because plant-based products will focus on vegetarians and vegans while cultured meat will focus on carnivores.

Q14	**Do you see cultured meat as a viable solution to reaching net-zero or a low carbon footprint in the agricultural sector?**
Answer	Cultured meat will be a solution to reach a low carbon footprint due to its low environmental footprint compared to cattle farming.

Expert ID:	2 **Expert:**	Manager, Cultured Seafood Start-up in the U.S.		
Q1	**What are the types of products with the highest potential to be a substitution threat for traditionally produced meat in the future?**			
	Type of Alternative	Animal cell-based proteins	Plant-based proteins	Microorganism-based proteins
	Potential	High	Moderate	-
	Reason/clarification	Product without compromise	Only a stepping stone of the alternative protein movement; unable to fully imitate texture, taste, and mouthfeel	-
Answer	Further details:	-		

Q2	**How much potential do you see in cultured meat as a substitution threat? Do you see it as a temporary trend or as a fundamental game-changer?**
Answer	Fundamental gamechanger with high potential because it is a food security solution.

Q3	**Are there different manufacturing/production methods for culturing meat? Is there a dominant scientific process?**
Answer	No, so far there is no dominant manufacturing process. Every company in the cell-based industry is still trying to find the “best” process.

Q4	**On a scale from 1-5 (1 lowest; 5 highest), for which type of meat (beef, chicken pork, and fish/seafood) do you see the greatest /lowest potential for cultured meat?**				
	Type of meat	Beef meat	Chicken meat	Pork meat	Fish/Seafood

	Potential (1 lowest; 5 highest)	-	-	-	5
	Reason/clarification	-	-	-	Only species hunted wildly; Increasing environmental concerns; healthy meat-type due to its nutrients; high uncertainty in the supply
Answer	Further details:	-			

Q5	**Do you see a particularly high/low potential for success for cultured meat in certain geographic regions?**						
	Geographical region	Northern America	Southern America	Europe	Africa	Asia	Oceania
	Potential (Very low, low, moderate, high, very high)	Moderate	Low	Moderate	Very low	Very high	Low
	Key factors						
	Higher potential			Lower potential			
Answer	High meat per capita intake; Governmental openness; countries with developing diets			-			

Q6	**On a scale from 1-5 (1 lowest; 5 highest), how realistic is it to reach an industrial scale (millions of metric tons) in 2030?**		
	Likability of industrialized scale till 2030 (1 lowest; 5 highest)		4
Answer	Further details:	-	

Q7	**What do you think are the key factors determining the future pace of adoption and market size of cultured meat?**
Answer	Technological progress Price parity

Q8	**On a scale from 1-5 (1 lowest; 5 highest), how likely is it that established players (FMCG companies, food chains, etc.) integrate cultured meat products into their company/product portfolio?**	
	Likability of adaption of established players	5
Answer	Further details:	Established companies show significant interest in the seafood industry. E.g., one of the biggest sushi food chains in Japan "Food and Life" collaborates with a cultured seafood startup.

Q9	**What are the benefits of producing cultured meat instead of genuine meat?**
Answer	Low consumption of resources, Securing of ocean biodiversity, Food security

Q10	**What are the biggest hurdles for the industry to overcome so it can become an at-scale phenomenon?** Scalability of production processes to reduce costs and ensure affordability. Access to significant amounts of public funding. Regulatory/governmental openness to food innovation.
Answer	Further details: -

Q11	**What needs to happen to overcome these hurdles?**
Answer	Strategic partnering with established companies to ensure scalability. Governmental/public funding and inclusion of governmental authorities (like in Singapore). Further details: -

Q12	**What is your estimate of the share (in %) that cultured meat can substitute in the animal protein market in 2030, 2040, and 2050?**			
	Year	2030	2040	2050
	Market share of animal protein market in %	5	35	50
Answer	Further details:	-		

Q13	**How will vegetarians and vegans perceive cultivated meat? Do you think plant-based proteins will compete with cultured meat?**
Answer	There will be a little overlap between plant-based and cell-based proteins. However, the prime market for cultured meat/seafood is for carnivores.
Q14	**Do you see cultured meat as a viable solution to reaching net-zero or a low carbon footprint in the agricultural sector?**
Answer	Cell-based proteins can be a viable solution for the reduction of the environmental carbon footprint and can be an important contribution to making agriculture and aquaculture more sustainable. However, all manufacturing processes and resources that are used for cultured meat/seafood need to be sustainable as well.

Expert ID:	3 **Expert:**	Chief Operating Officer, Cultured Meat Start-up in the U.S.		
Q1	**What are the types of products with the highest potential to be a substitution threat for traditionally produced meat in the future?**			
	Type of Alternative	Animal cell-based proteins	Plant-based proteins	Microorganism-based proteins
	Potential	High	Moderate	Low
	Reason/clarification	Unlimited opportunity to substitute meat market; Healthier & tastier than genuine meat	Mostly limited to vegetarians and vegans;	Problems with texture and taste
Answer	Further details:	For the short term, there will be hybrid products consisting of plant-based ingredients and cultured meat to reach price parity earlier. Afterwards, products will consist of 90-100% cultured meat.		

Q2	**How much potential do you see in cultured meat as a substitution threat? Do you see it as a temporary trend or as a fundamental game-changer?**
Answer	It is not a temporary trend because consumers' preferences are changing all over the world. Health, animal, and environmental welfare are serious consumer concerns.
Q3	**Are there different manufacturing/production methods for culturing meat? Is there a dominant scientific process?**
Answer	So far, there is not really a standardized/dominant manufacturing process since all processes are in a phase of a proof of concept. Production processes will continue to develop and change.

Q4	**On a scale from 1-5 (1 lowest; 5 highest), for which type of meat (beef, chicken pork, and fish/seafood) do you see the greatest /lowest potential for cultured meat?**					
Answer	Type of meat	Beef meat	Chicken meat	Pork meat	Fish/Seafood	
	Potential (1 lowest; 5 highest)	5	2	3	3	
	Reason/clarification	High environmental impact; most expensive meat type	Cheapest meat type (very efficient production)	Moderate price; substantial environmental impact	Increasing environmental concerns	
	Further details:	The highest potential for a soon market entry is to substitute expensive, high-end beef products to reach price parity to be competitive.				
Q5	**Do you see a particularly high/low potential for success for cultured meat in certain geographic regions?**					
Answer	Geographical region	Northern America	Southern America	Europe	Africa	Asia	Oceania
	Potential (Very low, low, moderate, high, very high)	Moderate	Low	Moderate	Very low	High	Low
	Key factors					
	Higher potential			Lower potential			
	Consumer awareness about environmental & animal wellbeing; High			Strong agricultural lobby			
Q6	**On a scale from 1-5 (1 lowest; 5 highest), how realistic is it to reach an industrial scale (millions of metric tons) in 2030?**					
Answer	Likability of industrialized scale till 2030 (1 lowest; 5 highest)				2	
	Further details:	In 2021, a competitor opened a production facility with a yearly future output of 180,000 kg. In relation to global meat consumption, the industry is far away from large-scale production.				
Q7	**What do you think are the key factors determining the future pace of adoption and market size of cultured meat?**					
Answer	Price parity; Technological progress					
Q8	**On a scale from 1-5 (1 lowest; 5 highest), how likely is it that established players (FMCG companies, food chains, etc.) integrate cultured meat products into their company/product portfolio?**					
Answer	Likability of adaption of established players				3	
	Further details:	Tyson and Cargill for example are investing in cultured meat but those investments represent a small amount relative to their revenue. When the technology is market-ready, the likelihood that more established companies will enter the cultivated meat market will significantly increase.				
Q9	**What are the benefits of producing cultured meat instead of genuine meat?**					
Answer	Low consumption of resources, Reduction of GHG emissions; Preservation of biodiversity					

Q10	**What are the biggest hurdles for the industry to overcome so it can become an at-scale phenomenon?**
Answer	Access to public funding because VC funding is limited and needs a return on investment deterring investors. Regulatory approval processes in the food industry. Price parity and scalability as interrelated hurdles (without scalability no price parity). Technological feasibility to scale up the production to an industrial scale. Bio reactor development needs to be accelerated. Further details: -
Q11	**What needs to happen to overcome these hurdles?**
Answer	Expand access to funding by including governmental authorities. Specialization of companies in certain competencies (e.g. media production, bioreactor manufacturing, and meat growth) in the overall value chain. Further details: -
Q12	**What is your estimate of the share (in %) that cultured meat can substitute in the animal protein market in 2030, 2040, and 2050?**

Year	2030	2040	2050
Market share of animal protein	1	10	30
Further details:	-		

Q13	**How will vegetarians and vegans perceive cultivated meat? Do you think plant-based proteins will compete with cultured meat?**
Answer	There will be no competition or overlap between plant-based meat and cell-based products because cultured meat is a meat-related product that will be hardly distinguishable from conventional meat.
Q14	**Do you see cultured meat as a viable solution to reaching net-zero or a low carbon footprint in the agricultural sector?**
Answer	Cultured meat will clearly lead to an improvement in the carbon footprint of the agricultural sector. However, the key factor is the energy used for production that needs to be renewable.

Expert ID:	4 **Expert:**	Chief Sustainability Officer, Cultured Meat Start-up for Petfood in the United Kingdom
Q1	**What are the types of products with the highest potential to be a substitution threat for traditionally produced meat in the future?**	

Type of Alternative	Animal cell-based proteins	Plant-based proteins	Microorganism-based proteins
Potential	High	Moderate	-
Reason/clarification	Similar taste and texture properties	Unable to fully imitate texture, taste, and mouthfeel	-
Further details:	There will be a hybrid product offering including conventional meat, animal-cell, and plant-based products due to the different consumer preferences.		

Answer	
Q2	**How much potential do you see in cultured meat as a substitution threat? Do you see it as a temporary trend or as a fundamental game-changer?**

Answer	Fundamental gamechanger with high potential to be an integral part of the food offering. Especially interesting for pet food because the regulatory process is easier to overcome, and it has fewer texture requirements.

Q3	**Are there different manufacturing/production methods for culturing meat? Is there a dominant scientific process?**
Answer	There is no dominant production process. All active companies are trying out to find the "right" process.

Q4 **On a scale from 1-5 (1 lowest; 5 highest), for which type of meat (beef, chicken pork, and fish/seafood) do you see the greatest /lowest potential for cultured meat?**

Type of meat	Beef meat	Chicken meat	Pork meat	Fish/Seafood
Potential (1 lowest; 5 highest)	4	5	2	3
Reason/clarification	Most expensive meat type; Cells are hard to grow	Cheapest meat type (very efficient production); Cells are easier to grow	Cells are hard to grow	Technological advantages in cell growth; the texture of fish is harder to copy

Answer	Further details:	Due to the technology, it will start with minced meat products that do not need any texture.

Q5 **Do you see a particularly high/low potential for success for cultured meat in certain geographic regions?**

Geographical region	Northern America	Southern America	Europe	Africa	Asia	Oceania
Potential (Very low, low, moderate, high, very high)	High	Low	Very high	Very low	Moderate	Very low
Key factors						
Higher potential			Lower potential			
Consumers' willingness to pay; Consumer acceptance; High food dependency			-			

Q6 **On a scale from 1-5 (1 lowest; 5 highest), how realistic is it to reach an industrial scale (millions of metric tons) in 2030?**

	Likability of industrialized scale till 2030 (1 lowest; 5 highest)	4
Answer	Further details:	-

Q7	**What do you think are the key factors determining the future pace of adoption and market size of cultured meat?**
Answer	Price parity

Q8 **On a scale from 1-5 (1 lowest; 5 highest), how likely is it that established players (FMCG companies, food chains, etc.) integrate cultured meat products into their company/product portfolio?**

	Likability of adaption of established players	2
Answer	Further details:	-

Q9	**What are the benefits of producing cultured meat instead of genuine meat?**

Answer	Reduction of GHG emissions, High production efficiency, No use of antibiotics, Food security
Q10	**What are the biggest hurdles for the industry to overcome so it can become an at-scale phenomenon?**
Answer	Costs need to be 1000 times lower leading to a need for enormous scale-up. Cell line development needs to be accelerated to cell quality so that cells can grow indefinitely. Progress in cell culture media development because media needs to be animal-free which is very cost-intensive so far. Further details: At the moment the biggest reactors have a volume of 1200l which is way too little to reach an industrial scale.
Q11	**What needs to happen to overcome these hurdles?**
Answer	Access to public funding by including governmental authorities. Specialization of companies in certain areas to accelerate overall industry Further details: -
Q12	**What is your estimate of the share (in %) that cultured meat can substitute in the animal protein market in 2030, 2040, and 2050?**

Year	2030	2040	2050
Market share of animal protein market in %	2	10	30
Further details:	-		

Q13	**How will vegetarians and vegans perceive cultivated meat? Do you think plant-based proteins will compete with cultured meat?**
Answer	There will be little competition, but it will neglectable.
Q14	**Do you see cultured meat as a viable solution to reaching net-zero or a low carbon footprint in the agricultural sector?**
Answer	It will contribute to reaching a lower environmental footprint in the agricultural sector but it will consume a lot of energy that needs to be produced environmentally friendly.

Expert ID:	5 **Expert:** Managing Partner, Alternative Proteins Venture Capital Firm in Switzerland
Q1	**What are the types of products with the highest potential to be a substitution threat for traditionally produced meat in the future?**

Type of Alternative	Animal cell-based proteins	Plant-based proteins	Microorganism-based proteins
Potential	Moderate	High	Low
Reason/clarification	Still in the experimental/proof of concept phase	Competitive price; texture is missing; already existing on the market	Problems with texture and taste
Further details:	Cultured meat will be an additional food solution besides plant-based proteins and conventionally produced meat.		

Answer	
Q2	**How much potential do you see in cultured meat as a substitution threat? Do you see it as a temporary trend or as a fundamental game-changer?**

Answer	It is not a temporary trend because 10 billion people cannot be fed with only one plant at the Western diet level. Producing meat conventionally is too inefficient (25 calories are required to create 1 calorie of beef 25:1 ratio)
Q3	**Are there different manufacturing/production methods for culturing meat? Is there a dominant scientific process?**
Answer	There is no dominant scientific manufacturing process.

Q4 **On a scale from 1-5 (1 lowest; 5 highest), for which type of meat (beef, chicken pork, and fish/seafood) do you see the greatest /lowest potential for cultured meat?**

Type of meat	Beef meat	Chicken meat	Pork meat	Fish/Seafood
Potential (1 lowest; 5 highest)	5	4	2	3
Reason/clarification	High environmental impact; most expensive meat type	Cheapest meat type (very efficient production); Cells are easier to grow	Moderate price; Cells are harder to grow	Increasing environmental concerns

Answer	Further details:	-

Q5 **Do you see a particularly high/low potential for success for cultured meat in certain geographic regions?**

Geographical region	Northern America	Southern America	Europe	Africa	Asia	Oceania
Potential (Very low, low, moderate, high, very high)	High	Very low	Moderate	Very low	High	Low

Key factors	
Higher potential	Lower potential
High food dependency; developing countries with developing diets	-

Q6 **On a scale from 1-5 (1 lowest; 5 highest), how realistic is it to reach an industrial scale (millions of metric tons) in 2030?**

	Likability of industrialized scale till 2030 (1 lowest; 5 highest)	5
Answer	Further details:	-

Q7	**What do you think are the key factors determining the future pace of adoption and market size of cultured meat?**
Answer	Technological progress

Q8 **On a scale from 1-5 (1 lowest; 5 highest), how likely is it that established players (FMCG companies, food chains, etc.) integrate cultured meat products into their company/product portfolio?**

	Likability of adaption of established players	2
Answer	Further details:	It will still take more time that a significant number of established companies to enter the cultured meat market.

Q9 **What are the benefits of producing cultured meat instead of genuine meat?**

Answer	Reduction of GHG emissions, No use of antibiotics; Food security
Q10	**What are the biggest hurdles for the industry to overcome so it can become an at-scale phenomenon?**
Answer	Progress in technological development to be competitive with conventional meat or alternatives (tech-cost curve). Scalability of the production process. Further details: -
Q11	**What needs to happen to overcome these hurdles?**
Answer	Advancement of process engineering. Industrial-scale availability of raw materials. Industrial-scale availability of manufacturing/ production machines (bioreactor). Established companies such as Merck or Anheuser-Busch InBev will help to take the cost out of the process. Further details: -

Q12 **What is your estimate of the share (in %) that cultured meat can substitute in the animal protein market in 2030, 2040, and 2050?**

Year	2030	2040	2050
Market share of animal protein market in %	5	10	20
Further details:	-		

Answer

Q13	**How will vegetarians and vegans perceive cultivated meat? Do you think plant-based proteins will compete with cultured meat?**
Answer	There will be no competition with plant-based proteins. Cultured meat targets carnivores and will be an additional source of food and will coexist with other protein alternatives.
Q14	**Do you see cultured meat as a viable solution to reaching net-zero or a low carbon footprint in the agricultural sector?**
Answer	Cultured meat is clearly a way to reduce greenhouse gas emissions in the agricultural sector. However, the whole value chain needs to be considered. Meaning, that the electricity for the manufacturing process needs to come from renewables.

Expert ID:	6 **Expert:** Chief Investment Officer, Alternative Proteins Venture Capital Firm

Q1 **What are the types of products with the highest potential to be a substitution threat for traditionally produced meat in the future?**

Type of Alternative	Animal cell-based proteins	Plant-based proteins	Microorganism-based proteins
Potential	Moderate	Moderate	Low
Reason/clarification	Not fully technologically approved yet; as of now only minced meat	Limited to a certain amount of consumers as not all carnivores can be converted into plant-based protein consumers	Problems with texture and taste

Answer	Further details:	The future mix of the protein market will be a hybrid consisting of all animal-cell-based, plant-based, and animal-based meat products.

Q2	**How much potential do you see in cultured meat as a substitution threat? Do you see it as a temporary trend or as a fundamental game-changer?**
Answer	It is a long-lasting trend with a fundamental impact on the meat sector. Cultured meat will disrupt the meat market but only locally where the product is indispensable.

Q3	**Are there different manufacturing/production methods for culturing meat? Is there a dominant scientific process?**
Answer	There is not a dominant manufacturing process yet. However, there are constantly new production and manufacturing processes developed.

Q4 **On a scale from 1-5 (1 lowest; 5 highest), for which type of meat (beef, chicken pork, and fish/seafood) do you see the greatest /lowest potential for cultured meat?**

Type of meat	Beef meat	Chicken meat	Pork meat	Fish/Seafood
Potential (1 lowest; 5 highest)	4	1	3	-
Reason/clarification	High environmental impact; most expensive meat type	Cheapest meat type (very efficient production); Cells are easier to grow	Popular meat type in Asia with a growing middle class	-

Answer	Further details:	Retail value-added products have a high potential to integrate cultured meat because the margins are higher and for those products is no texture needed. Furthermore, real meat (e.g., tie bone steak) needs a scaffold. From a technological perspective, this scaffold is the bottleneck.

Q5 **Do you see a particularly high/low potential for success for cultured meat in certain geographic regions?**

Geographical region	Northern America	Southern America	Europe	Africa	Asia	Oceania
Potential (Very low, low, moderate, high, very high)	Low	Very low	Low	Moderate	High	Low

Key factors	
Higher potential	Lower potential
High food dependency; developing countries with developing diets	-

Answer

Q6	**On a scale from 1-5 (1 lowest; 5 highest), how realistic is it to reach an industrial scale (millions of metric tons) in 2030?**
Likability of industrialized scale till 2030 (1 lowest; 5 highest)	2

Answer	Further details:	There is a long way to go in terms of technology. Furthermore, there is a capacity challenge. The market needs companies to produce the manufacturing machines on a large scale which is very demanding very high investments. Now, there is a Chicken or egg problem because the solution of producing cultured meat on a large scale is also the cause of the problem.

Q7	**What do you think are the key factors determining the future pace of adoption and market size of cultured meat?**			
Answer	Price parity Regulatory openness			
Q8	**On a scale from 1-5 (1 lowest; 5 highest), how likely is it that established players (FMCG companies, food chains, etc.) integrate cultured meat products into their company/product portfolio?**			
	Likability of adaption of established players			2
Answer	Further details:	Food chains took a very long time to introduce plant-based products into their product portfolio because the first thing that must be secured for a food chain is the supply chain and production. From a technological perspective, cultured meat is still too far away from being adopted soon by a food chain.		
Q9	**What are the benefits of producing cultured meat instead of genuine meat?**			
Answer	Low consumption of resources, Reduction of GHG emissions, Food security			
Q10	**What are the biggest hurdles for the industry to overcome so it can become an at-scale phenomenon?**			
Answer	Enormous cost reduction to reach price parity. Technological advancement to reach scalability in scaffold materials. Regulatory openness. Further details: -			
Q11	**What needs to happen to overcome these hurdles?**			
Answer	Changing the manufacturing process to cheaper one (production of texture less meat). Access to public funding by including governmental authorities. Further details: Technology and production are very capital intensive and access to debt is not possible for startups.			
Q12	**What is your estimate of the share (in %) that cultured meat can substitute in the animal protein market in 2030, 2040, and 2050?**			
	Year	2030	2040	2050
	Market share of animal protein market in %	1	1.5	2.25
Answer	Further details:	-		
Q13	**How will vegetarians and vegans perceive cultivated meat? Do you think plant-based proteins will compete with cultured meat?**			
Answer	There will be no competition because cultured meat will be perceived as normal meat due to its similarities with conventional meat.			
Q14	**Do you see cultured meat as a viable solution to reaching net-zero or a low carbon footprint in the agricultural sector?**			
Answer	It will be only partly a solution and now it is not realistic because to achieve a low-carbon footprint the energy for production needs to be 100% renewable. This will not be possible soon. Food security will be a more challenging problem for humanity than making food production completely environmentally sustainable.			

Expert ID:	7 **Expert:**	Global Agribusiness Lead, Top Tier Consultancy in the U.S.			
Q1	**What are the types of products with the highest potential to be a substitution threat for traditionally produced meat in the future?**				
	Type of Alternative	Animal cell-based proteins	Plant-based proteins	Microorganism-based proteins	
	Potential	Moderate	High	Low	
	Reason/clarification	Still in the experimental/proof of concept phase; price parity	Competitive price; already existing on the market	Problems with texture and taste	
Answer	Further details:	-			
Q2	**How much potential do you see in cultured meat as a substitution threat? Do you see it as a temporary trend or as a fundamental game-changer?**				
Answer	It has moderate potential and can be a gamechanger if technology evolves and the theoretical concept becomes a practical case. However, there is a likelihood that the technology will not succeed and fall after a couple of years when investments are too high to continue the development.				
Q3	**Are there different manufacturing/production methods for culturing meat? Is there a dominant scientific process?**				
Answer	There is no dominant manufacturing process yet because the technology is still in its infancy. There might be different production processes evolving. The industry and startups are constantly looking for new manufacturing processes.				
Q4	**On a scale from 1-5 (1 lowest; 5 highest), for which type of meat (beef, chicken pork, and fish/seafood) do you see the greatest /lowest potential for cultured meat?**				
	Type of meat	Beef meat	Chicken meat	Pork meat	Fish/Seafood
	Potential (1 lowest; 5 highest)	4	2	3	-
	Reason/clarification	High environmental impact; most expensive meat type	Cheapest meat type; Cells are easier to grow; Most popular meat type	Popular meat type in Asia with a growing middle class	-
Answer	Further details:	-			
Q5	**Do you see a particularly high/low potential for success for cultured meat in certain geographic regions?**				
	Geographical region	Northern America	Southern America	Europe	Africa	Asia	Oceania
	Potential (Very low, low, moderate, high, very high)	Low	Very low	Moderate	Low	High	Moderate
	Key factors						
	Higher potential			Lower potential			
Answer	High food dependency; Huge governmental financial resources; Governmental			Strong agricultural lobby			
Q6	**On a scale from 1-5 (1 lowest; 5 highest), how realistic is it to reach an industrial scale (millions of metric tons) in 2030?**				
	Likability of industrialized scale till 2030 (1 lowest; 5 highest)				4

Answer	Further details:	-		
Q7	**What do you think are the key factors determining the future pace of adoption and market size of cultured meat?**			
Answer	Price parity Regulatory openness Technological progress			
Q8	**On a scale from 1-5 (1 lowest; 5 highest), how likely is it that established players (FMCG companies, food chains, etc.) integrate cultured meat products into their company/product portfolio?**			
	Likability of adaption of established players			4
Answer	Further details:	It will happen that established companies start to integrate cultivated meat products into their portfolio. However, it is also essential that upstream established companies such as Cargill will adopt this product to push and increase scalability.		
Q9	**What are the benefits of producing cultured meat instead of genuine meat?**			
Answer	Reduction of GHG emissions, reduction of disease probability in the animal population, No use of antibiotics, Food security			
Q10	**What are the biggest hurdles for the industry to overcome so it can become an at-scale phenomenon?**			
Answer	Regulatory openness in the food industry. Political acceptance in countries with a strong meat industry. Price parity with conventionally produced meat. Further details: However, the regulatory hurdles in GMOs, for example, are also very high.There are conflicting goals such as food safety and sustainability.			
Q11	**What needs to happen to overcome these hurdles?**			
Answer	Established companies entering the market and making significant investments. Further details: -			
Q12	**What is your estimate of the share (in %) that cultured meat can substitute in the animal protein market in 2030, 2040, and 2050?**			
	Year	2030	2040	2050
	Market share of	2.5	15	20
Answer	Further details:	-		
Q13	**How will vegetarians and vegans perceive cultivated meat? Do you think plant-based proteins will compete with cultured meat?**			
Answer	There will be no competition within the protein market because cultured meat does not target vegetarians/vegans but carnivores who want to achieve a healthier dietwith a less damaging environmental footprint.			
Q14	**Do you see cultured meat as a viable solution to reaching net-zero or a low carbon footprint in the agricultural sector?**			
Answer	It will help contribute to reaching a lower environmental footprint. However, cultivated meat will not substitute conventionally produced meat fully. There will be a hybrid mix of animal-cell-based, plant-based, and conventionally produced meat. Furthermore, to reach economies of scale, a centralized production will be required leading to emissions due to logistics.			

Expert ID:	8 **Expert:**	Director of Responsible Research and Innovation, Nonprofit Research Institute for Cultured Meat in the U.S.			
Q1	**What are the types of products with the highest potential to be a substitution threat for traditionally produced meat in the future?**				
	Type of Alternative	Animal cell-based proteins	Plant-based proteins	Microorganism-based proteins	
	Potential	High	High	-	
	Reason/clarification	Superior taste and texture experience; Still in the experimental/proof of concept phase	Unable to fully imitate texture, taste, and mouthfeel; already existing on the market	-	
Answer	Further details:	There will be a high probability of a mixed product portfolio for proteins including plant-based proteins, cultured meat, and, conventionally produced meat.			
Q2	**How much potential do you see in cultured meat as a substitution threat? Do you see it as a temporary trend or as a fundamental game-changer?**				
Answer	Fundamental gamechanger that will transform the way of food production.				
Q3	**Are there different manufacturing/production methods for culturing meat? Is there a dominant scientific process?**				
Answer	There is no dominant scientific process since the technology is still in a proof-of-concept phase. The manufacturing process is also depending on the end product.				
Q4	**On a scale from 1-5 (1 lowest; 5 highest), for which type of meat (beef, chicken pork, and fish/seafood) do you see the greatest /lowest potential for cultured meat?**				
	Type of meat	Beef meat	Chicken meat	Pork meat	Fish/Seafood
	Potential (1 lowest; 5 highest)	3	5	2	4
	Reason/clarification	Cells are hard to grow	Cells are easier to grow	Cells are hard to grow; Moderate price	Technological advantages in cell growth (low-temperature growth)
Answer	Further details:	-			
Q5	**Do you see a particularly high/low potential for success for cultured meat in certain geographic regions?**				
	Geographical region	Northern America	Southern America	Europe	Africa	Asia	Oceania
	Potential (Very low, low, moderate, high, very high)	Moderate	Low	Moderate	Very low	High	Low
	Key factors						
	Higher potential			Lower potential			
Answer	High food dependency; Governmental openness			-			
Q6	**On a scale from 1-5 (1 lowest; 5 highest), how realistic is it to reach an industrial scale (millions of metric tons) in 2030?**				
	Likability of industrialized scale till 2030 (1 lowest; 5 highest)				2

Answer	Further details:	The problem is not only to have the machinery and the equipment ready. It is also crucial to have a secure supply chain.
Q7	**What do you think are the key factors determining the future pace of adoption and market size of cultured meat?**	
Answer	Price parity	
Q8	**On a scale from 1-5 (1 lowest; 5 highest), how likely is it that established players (FMCG companies, food chains, etc.) integrate cultured meat products into their company/product portfolio?**	
Answer	Likability of adaption of established players	2
	Further details:	-
Q9	**What are the benefits of producing cultured meat instead of genuine meat?**	
Answer	Low consumption of resources, Reduction of GHG emissions, No use of antibiotics, Food security	
Q10	**What are the biggest hurdles for the industry to overcome so it can become an at-scale phenomenon?**	
Answer	Technological progress in production processes and production machines (bioreactors). Access to public/governmental funding. Closed and capitalistic innovation attitude Further details: Every company is developing processes on its own which makes development very costly and inefficient.	
Q11	**What needs to happen to overcome these hurdles?**	
Answer	Governmental intervention with public and governmental funding. A mature supply chain for all raw materials is needed because without any secure supply chain, the production cannot be executed properly on a large scale. Further details: On 14.04.2022, the Dutch government started to fund cultured meat with €60m.	
Q12	**What is your estimate of the share (in %) that cultured meat can substitute in the animal protein market in 2030, 2040, and 2050?**	
Answer	Year	2030 / 2040 / 2050
	Market share of	- / - / -
	Further details:	This question cannot be answered from a scientific point of view. The technology and market are way too novel and in their infancy. The assumptions of potential market share to predict potential savings in GHG are vague.
Q13	**How will vegetarians and vegans perceive cultivated meat? Do you think plant-based proteins will compete with cultured meat?**	
Answer	There will be no competition between those two alternatives. Vegetarians and vegans would not choose to eat cultured meat products.	
Q14	**Do you see cultured meat as a viable solution to reaching net-zero or a low carbon footprint in the agricultural sector?**	
Answer	Cultured meat has the potential to be a viable solution to reaching a low-carbon footprint. However, the technology alone is not sufficient enough because the whole value chain of cultured meat production is a critical pillar. If the sourcing and the production of raw materials need high logistics effort, the technology is not environmentally sustainable. Hence, the question that also needs to be answered is if the production is decentralized or centralized. Centralized production would lead to to adverse effects as well.	

Expert ID:	9	Expert:	Scientist, Academic Research Institution at a well-known University in Germany

Q1 **What are the types of products with the highest potential to be a substitution threat for traditionally produced meat in the future?**

Type of Alternative	Animal cell-based proteins	Plant-based proteins	Microorganism-based proteins
Potential	High	Moderate	-
Reason/clarification	Origin of the animal and is, therefore, possible to reproduce; Structures can be reproduced without limitation	Already existing but technologically limited to fully replace meat in terms of taste and texture	-

Answer Further details: -

Q2 **How much potential do you see in cultured meat as a substitution threat? Do you see it as a temporary trend or as a fundamental game-changer?**

Answer It is no temporary trend, and it is just starting. Looking at the rising demand for proteins, it is very attractive to find and establish new and sustainable meat sources.

Q3 **Are there different manufacturing/production methods for culturing meat? Is there a dominant scientific process?**

Answer There is no dominant scientific process. It is dependent on the end product. For minced meat, the manufacturing process is quite similar. However, for products with a texture like a steak, the processes vary (e.g., 3D printing or scaffold method): 3D printing has some potential because it can use both fat and meat cells while in a bioreactor there can be only one cell type used.

Q4 **On a scale from 1-5 (1 lowest; 5 highest), for which type of meat (beef, chicken pork, and fish/seafood) do you see the greatest /lowest potential for cultured meat?**

Type of meat	Beef meat	Chicken meat	Pork meat	Fish/Seafood
Potential (1 lowest; 5 highest)	5	3	3	3
Reason/clarification	High environmental impact; most expensive meat type	Cheapest meat type	Limited by cultural beliefs; moderate price	Technologically different from meat production (DNA sequences cannot be applied so well)

Answer Further details: -

Q5 **Do you see a particularly high/low potential for success for cultured meat in certain geographic regions?**

Geographical region	Northern America	Southern America	Europe	Africa	Asia	Oceania
Potential (Very low, low, moderate, high, very high)	High	Low	Very high	Very low	Moderate	Low
Key factors						

	Higher potential		Lower potential	
Answer	Governmental openness; High willingness to pay; High food dependency; High meat per capita consumption		Strong agricultural lobby Protectionism	
Q6	**On a scale from 1-5 (1 lowest; 5 highest), how realistic is it to reach an industrial scale (millions of metric tons) in 2030?**			
	Likability of industrialized scale till 2030 (1 lowest; 5 highest)			3
Answer	Further details:	-		
Q7	**What do you think are the key factors determining the future pace of adoption and market size of cultured meat?**			
Answer	Technological progress			
Q8	**On a scale from 1-5 (1 lowest; 5 highest), how likely is it that established players (FMCG companies, food chains, etc.) integrate cultured meat products into their company/product portfolio?**			
	Likability of adaption of established players			4
Answer	Further details:	Once the industry is developed to the point where companies can confidently consider it a potential business, the number of investments and collaborations will increase rapidly. For now, these are just occasional first movers.		
Q9	**What are the benefits of producing cultured meat instead of genuine meat?**			
Answer	Reduction of GHG emissions; Food security			
Q10	**What are the biggest hurdles for the industry to overcome so it can become an at-scale phenomenon?**			
Answer	Technological progress in cell-line development with genetic modification and in culture media serum development (animal-free). Low level of collaboration within the industry. Access to public funding. Further details: -			
Q11	**What needs to happen to overcome these hurdles?**			
Answer	Collaboration with all stakeholders (government, research institutes, and companies). Further details: -			
Q12	**What is your estimate of the share (in %) that cultured meat can substitute in the animal protein market in 2030, 2040, and 2050?**			
	Year	2030	2040	2050
	Market share of animal protein market in %	0.5	1.5	7.5
Answer	Further details:	-		
Q13	**How will vegetarians and vegans perceive cultivated meat? Do you think plant-based proteins will compete with cultured meat?**			
Answer	There is only a little competition. However, vegetarians and vegans aren't a target group. Hence competition with plant-based proteins is neglectable.			
Q14	**Do you see cultured meat as a viable solution to reaching net-zero or a low carbon footprint in the agricultural sector?**			

Answer	It is a viable solution, and it will lead to a reduction in emissions. However, the wholesupply chain needs to be sustainable including the energy used for the production.

Appendix B

Database

Global meat production including growth rate

Year	Tons (millions)	Growth rate
2020	328	14%
2030	373	14%
2040	424	14%
2050	482	

Source: OECD-FAO Agricultural Outlook 2021-2030

Global market share of cultured meat

Year	Market share cultured meat
2030	4.63%
2040	15.38%
2050	28.72%

Source: Expert interviews (Appendix A)

Global meat type distribution in 2030

Meat type	Tons (millions)	Share
Beef meat*	93	25%
Chicken meat	153	41%
Pork meat	127	34%
Sum	**373**	**100%**

*Including sheep meat due to a similar environmental footprint

Source: OECD-FAO Agricultural Outlook 2021-2030

GHG emissions on the 2030 benchmark

Meat type	kg CO2eq/kg
Beef meat	30.5
Chicken meat	3.5
Pork meat	6
Cultured meat (sustainable)	2.5
Cultured meat (conventional)	13.6

Source: CE Delft lifecycle assessment study

Land use on the 2030 benchmark

Meat type	m² a crop-eq./kg
Beef meat	31.6
Chicken meat	4.6
Pork meat	6
Cultured meat (sustainable)	1.7
Cultured meat (conventional)	1.8

Source: CE Delft lifecycle assessment study

Blue water use on the 2030 benchmark

Meat type	liter/kg
Beef meat	258
Chicken meat	46
Pork meat	40
Cultured meat (sustainable)	56
Cultured meat (conventional)	42

Source: CE Delft lifecycle assessment study

Scenario analysis

2030

Scenario 1 Cultured meat fails to enter the market

Meat type	Meat distribution	Volume in million tons	Market share cultured meat	Volume cultured meat in million tons	Market volume (conv.) meat in million tons	kg GHG emissions CO2eq/t	Total GHG (CO2eq in kg)	Total GHG CO2eq in t	Land use m² a crop-eq./t	Total land use in ha	Water footprint liter/t	Total Water footprint in m³
Beef meat	25%	93.25	0.00%	0	93.25	30,500	2,844,125,000,000	2,844,125,000	31,600	294,670,000	258,000	24,058,500,000
Chicken meat	41%	152.93	0.00%	0	152.93	3,500	535,255,000,000	535,255,000	4,600	70,347,800	46,000	7,034,780,000
Pork meat	34%	126.82	0.00%	0	126.82	6,000	760,920,000,000	760,920,000	6,000	76,092,000	40,000	5,072,800,000
Cultured meat												
TOTAL		**373**		**-**	**373**		**4,140,300,000,000**	**4,140,300,000**		**441,109,800**		**36,166,080,000**

Scenario 2 Cultured meat succeeds in entering the market but is operated with conventional energy

Meat type	Meat distribution	Volume in million tons	Market share cultured meat	Volume cultured meat in million tons	Market volume (conv.) meat in million tons	kg GHG emissions CO2eq/t	Total GHG (CO2eq in kg)	Total GHG CO2eq in t	Land use m² a crop-eq./t	Total land use in ha	Water footprint liter/t	Total Water footprint in m³
Beef meat	25%	93.25	4.63%	4	89	30,500	2,712,442,012,500	2,712,442,013	31,600	281,026,779	258,000	22,944,591,450
Chicken meat	41%	152.93	4.63%	7	146	3,500	510,472,693,500	510,472,694	4,600	67,090,697	46,000	6,709,069,686
Pork meat	34%	126.82	4.63%	6	121	6,000	725,689,404,000	725,689,404	6,000	72,568,940	40,000	4,837,929,360
Cultured meat						13,600	234,870,640,000	234,870,640	1,800	3,108,582	42,000	725,335,800
TOTAL		**373**		**17**	**356**		**4,183,474,750,000**	**4,183,474,750**		**423,794,998**		**35,216,926,296**

Scenario 3 Cultured meat succeeds in entering the market and is operated with sustainable energy

Meat type	Meat distribution	Volume in million tons	Market share cultured meat	Volume cultured meat in million tons	Market volume (conv.) meat in million tons	kg GHG emissions CO2eq/t	Total GHG (CO2eq in kg)	Total GHG CO2eq in t	Land use m² a crop-eq./t	Total land use in ha	Water footprint liter/t	Total Water footprint in m³
Beef meat	25%	93.25	4.63%	4	89	30,500	2,712,442,012,500	2,712,442,013	31,600	281,026,779	258,000	22,944,591,450
Chicken meat	41%	152.93	4.63%	7	146	3,500	510,472,693,500	510,472,694	4,600	67,090,697	46,000	6,709,069,686
Pork meat	34%	126.82	4.63%	6	121	6,000	725,689,404,000	725,689,404	6,000	72,568,940	40,000	4,837,929,360
Cultured meat						2,500	43,174,750,000	43,174,750	1,700	2,935,883	56,000	967,114,400
TOTAL		**373**		**17**	**356**		**3,991,778,860,000**	**3,991,778,860**		**423,622,299**		**35,458,704,896**

2040

Scenario 1 Cultured meat fails to enter the market

Meat type	Meat distribution	Volume in million tons	Market share cultured meat	Volume cultured meat in million tons	Market volume (conv.) meat in million tons	kg GHG emissions CO2eq/t	Total GHG (CO2eq in kg)	Total GHG CO2eq in t	Land use m² a crop-eq./t	Total land use in ha	Water footprint liter/t	Total Water footprint in m³
Beef meat	25%	106	0.00%	0	106	30,500	3,234,325,076,220	3,234,325,076	31,600	335,097,287	258,000	27,359,208,841
Chicken meat	41%	174	0.00%	0	174	3,500	608,689,375,000	608,689,375	4,600	79,999,175	46,000	7,999,917,500
Pork meat	34%	144	0.00%	0	144	6,000	865,314,512,195	865,314,512	6,000	86,531,451	40,000	5,768,763,415
Cultured meat												
TOTAL		**424**		**-**	**424**		**4,708,328,963,415**	**4,708,328,963**		**501,627,913**		**41,127,889,756**

Scenario 2 Cultured meat succeeds in entering the market but is operated with conventional energy

Meat type	Meat distribution	Volume in million tons	Market share cultured meat	Volume cultured meat in million tons	Market volume (conv.) meat in million tons	kg GHG emissions CO2eq/t	Total GHG (CO2eq in kg)	Total GHG CO2eq in t	Land use m² a crop-eq./t	Total land use in ha	Water footprint liter/t	Total Water footprint in m³
Beef meat	25%	106	15.38%	16	90	30,500	2,736,885,879,497	2,736,885,879	31,600	283,559,324	258,000	23,151,362,522
Chicken meat	41%	174	15.38%	27	147	3,500	515,072,949,125	515,072,949	4,600	67,695,302	46,000	6,769,530,189
Pork meat	34%	144	15.38%	22	122	6,000	732,229,140,220	732,229,140	6,000	73,222,914	40,000	4,881,527,601
Cultured meat						13,600	887,235,813,171	887,235,813	1,800	11,742,827	42,000	2,739,992,952
TOTAL		**424**		**65**	**359**		**4,871,423,782,012**	**4,871,423,782**		**436,220,367**		**37,542,413,264**

Scenario 3 Cultured meat succeeds in entering the market and is operated with sustainable energy

Meat type	Meat distribution	Volume in million tons	Market share cultured meat	Volume cultured meat in million tons	Market volume (conv.) meat in million tons	kg GHG emissions CO2eq/t	Total GHG (CO2eq in kg)	Total GHG CO2eq in t	Land use m² a crop-eq./t	Total land use in ha	Water footprint liter/t	Total Water footprint in m³
Beef meat	25%	106	15.38%	16	90	30,500	2,736,885,879,497	2,736,885,879	31,600	283,559,324	258,000	23,151,362,522
Chicken meat	41%	174	15.38%	27	147	3,500	515,072,949,125	515,072,949	4,600	67,695,302	46,000	6,769,530,189
Pork meat	34%	144	15.38%	22	122	6,000	732,229,140,220	732,229,140	6,000	73,222,914	40,000	4,881,527,601
Cultured meat						2,500	163,094,818,598	163,094,819	1,700	11,090,448	56,000	3,653,323,937
TOTAL		**424**		**65**	**359**		**4,147,282,787,439**	**4,147,282,787**		**435,567,987**		**38,455,744,248**

2050

Scenario 1 Cultured meat fails to enter the market

Meat type	Meat distribution	Volume in million tons	Market share cultured meat	Volume cultured meat in million tons	Market volume (conv.) meat in million tons	kg GHG emissions CO2eq/t	Total GHG (CO2eq in kg)	Total GHG CO2eq in t	Land use m² a crop-eq./t	Total land use in ha	Water footprint liter/t	Total Water footprint in m³
Beef meat	25%	121	0.00%	0	121	30,500	3,678,058,699,481	3,678,058,699	31,600	381,071,000	258,000	31,112,758,835
Chicken meat	41%	198	0.00%	0	198	3,500	692,198,588,034	692,198,588	4,600	90,974,672	46,000	9,097,467,157
Pork meat	34%	164	0.00%	0	164	6,000	984,031,442,222	984,031,442	6,000	98,403,144	40,000	6,560,209,615
Cultured meat												
TOTAL		**482**		**-**	**482**		**5,354,288,729,737**	**5,354,288,730**		**570,448,815**		**46,770,435,607**

Scenario 2 Cultured meat succeeds in entering the market but is operated with conventional energy

Meat type	Meat distribution	Volume in million tons	Market share cultured meat	Volume cultured meat in million tons	Market volume (conv.) meat in million tons	kg GHG emissions CO2eq/t	Total GHG (CO2eq in kg)	Total GHG CO2eq in t	Land use m² a crop-eq./t	Total land use in ha	Water footprint liter/t	Total Water footprint in m³
Beef meat	25%	121	28.72%	35	86	30,500	2,621,720,240,990	2,621,720,241	31,600	271,627,409	258,000	22,177,174,498
Chicken meat	41%	198	28.72%	57	141	3,500	493,399,153,550	493,399,154	4,600	64,846,746	46,000	6,484,674,590
Pork meat	34%	164	28.72%	47	117	6,000	701,417,612,016	701,417,612	6,000	70,141,761	40,000	4,676,117,413
Cultured meat						13,600	1,884,092,201,374	1,884,092,201	1,800	24936514.43	42,000	5,818,520,034
TOTAL		**482**		**139**	**344**		**5,700,629,207,931**	**5,700,629,208**		**431,552,430**		**39,156,486,534**

Scenario 3 Cultured meat succeeds in entering the market and is operated with sustainable energy

Meat type	Meat distribution	Volume in million tons	Market share cultured meat	Volume cultured meat in million tons	Market volume (conv.) meat in million tons	kg GHG emissions CO2eq/t	Total GHG (CO2eq in kg)	Total GHG CO2eq in t	Land use m² a crop-eq./t	Total land use in ha	Water footprint liter/t	Total Water footprint in m³
Beef meat	25%	121	28.72%	35	86	30,500	2,621,720,240,990	2,621,720,241	31,600	271,627,409	258,000	22,177,174,498
Chicken meat	41%	198	28.72%	57	141	3,500	493,399,153,550	493,399,154	4,600	64,846,746	46,000	6,484,674,590
Pork meat	34%	164	28.72%	47	117	6,000	701,417,612,016	701,417,612	6,000	70,141,761	40,000	4,676,117,413
Cultured meat						2,500	346,340,478,194	346,340,478	1,700	23,551,153	56,000	7,758,026,712
TOTAL		**482**		**139**	**344**		**4,162,877,484,750**	**4,162,877,485**		**430,167,068**		**41,095,993,212**