Utrecht University

Master’s thesis – Master Sustainable Business and Innovation

The Dutch Cultured Meat Innovation System

An analysis of its systemic problems and how to accelerate development of the sector

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Abstract

Introduction
Cultured meat (CM) is a more sustainable and alternative protein created by growing animal cells in-vitro, with the potential to mitigate the negative effects of meat production. The Netherlands is considered the CM research and innovation hub of Europe. However, the sector remains in the formative stage. This research aimed to identify which barriers obstruct the transition of the TIS into the next development stage, and create suitable (policy) recommendations to overcome these barriers. The main research question is: 'How can the cultured meat TIS in the Netherlands transition into the next stage of development?''. Two sub-questions are: ''What systemic problems are causing obstruction within the Dutch cultured meat TIS?'' and ''are there insights that can be drawn from the plant-based meat alternatives sector to improve the performance of the TIS''.

Theory
Individual research into CM has mainly focused on a single aspect of CM, such as technology or regulations. The Technological Innovation Systems (TIS) framework offers a more holistic approach in which interactions between elements of the TIS are analyzed, and barriers are identified. In addition, the motors of innovation typology was used to determine which functions deserve more attention in the problem analysis. Next, the systemic policy scheme including the concepts systemic goals and instruments, was also used to identify underlying systemic problems and develop recommendations.

Methodology
This research was qualitative, and 11 interviews were conducted with key actors from the CM sector and PBMAs sector. Secondary sources such as scientific articles, news articles, industry association's websites and policy reports were researched to account for gaps of knowledge and confirm interview results.

Results
The analysis concluded the following results: Knowledge development, knowledge exchange, governmental guidance and resource mobilization are the functions that needed more attention for the TIS to develop into the next stage. A negative feedback loop was identified between these functions. The Novel Food Regulation and technological hurdles also posed a barrier to CM. The findings have set a basis for recommendations for policy makers: 1) stimulate open access research and knowledge sharing, 2) deepen governmental involvement and 3) stimulate institutionalization of CM.

Discussion & conclusion
Avenues for further research were found. The nature of systemic problems per life-cycle stage and which systemic goals and instruments are suitable at a specific stage could be investigated. Secondly, future research can focus on how CM can transition from the growth stage into the mature stage. The recommendations could possibly aid in developing the Dutch CM sector so that the technology diffuses on a wider scale.

Preface

This thesis is submitted for the degree Sustainable Business and Innovation at Utrecht University. The research herein was conducted under the supervision of Dr. Nick Verkade in the department of Geosciences, Utrecht University between February 2022 and December 2022.

I have always been interested in how we can reduce our impact through diet changes, since I personally believe that this is one of the easiest steps we can take to reduce our impact on the planet. Twelve years ago, I gave up meat because of animal welfare considerations, the impact it has on the planet, and because of health concerns. Two years later, I completely gave up all animal products and have been eating plant-based ever since. Learning about the environmental consequences of livestock farming led me to pursue my academic career in the field of environmental sciences and sustainability. My passion trickled down into other areas of my life. When I started eating plant-based, I decided to start a vegan Instagram account to share the meals and recipes with my followers, hoping to inspire others to eat plant-based. During those 12 years I have seen incredible collective changes in diet habits at a societal level. More people are aware of the negative consequences of livestock production, and this has given rise to many alternative protein sources such as plant-based proteins, fungi-based proteins, algae-based proteins, and cultured meat.

I first heard about cultured meat in 2013, when Dr. Mark Post presented the world's first cultured meat burger. I was immediately fascinated by the fact that real meat could be produced without harming animals or the planet. Due to my interest in sustainability and alternative proteins, and the fact that cultured meat is a Dutch invention, I decided that this would be the ideal research topic. A month after I started, the Dutch government allowed the tastings of cultured meat, and the National Growth Fund invested €60 million in the development of cellular agriculture. This started a domino effect of continuous developments in the cellular agriculture sector, and during my research progress I had to repeatedly change parts of my thesis. This made my research progress very engaging, and confirmed to me that I made the right decision to conduct research on this topic.

With this research, I aim to contribute to the ever-growing body of literature dedicated to cellular agriculture, as well as the development of the domain of cellular agriculture. I hope that everyone who reads this research will have a better understanding of the cultured meat landscape in the Netherlands, and what challenges it needs to overcome to start widespread commercialization

Table of Contents

List of abbreviations

CA: Cellular Agriculture
CAE: Cellular Agriculture Europe
CANS: Cellular Agriculture Netherlands
CM: Cultured Meat
EFSA: European Food Safety Authority
EC: European Commission
EU: European Union
ESA: European Space Agency
EZK: Ministerie van Economische Zaken en Klimaat (Ministry of Economic Affairs and Climate Policy)
FBS: Fetal Bovine Serum
GFI: Good Food Institute
GHG: Greenhouse Gas
GPA: Green Protein Alliance
HMEC: High Moisture Extrusion Cooking
IS: Innovation System
IP: Intellectual Property
LMEC: Low Moisture Extrusion Cooking
LNV: Ministerie van Landbouw, Natuur en Voedselkwaliteit (Ministry of Agriculture, Nature and Food Quality)
MNC: Multinational Corporation
MLP: Multi-Level Perspective
NFR: Novel Food Regulation
NGF: the National Growth Fund (het Nationaal Groeifonds)
NGO: Nongovernmental Organization
NWO: Dutch Research Council
NPS: National Protein Strategy
NVV: Nederlandse Vereniging voor Veganisme (Dutch Society for Veganism)
UM: Maastricht University
PBMAs: Plant-based Meat Alternatives
PIEK: Programma Innovatie Eiwitketens
PPPs: Public Private Partnerships
RVO: Rijksdienst voor Ondernemend Nederland (Netherlands Enterprise Agency)
R&D: Research and Development
SBI: Sustainable Business and Innovation
SBIR: Small Business Innovation and Research
SME: Small-Medium Enterprise
STP: Science and Technology Push motor
TIS: Technological Innovation Systems
TVP: Textured Vegetable Protein
UU: Utrecht University
UVA: University of Amsterdam
VWS: Ministerie van Volksgezondheid, Welzijn en Sport (Ministry of Health, Welfare and Sport)
WUR: Wageningen University and Research

List of Tables

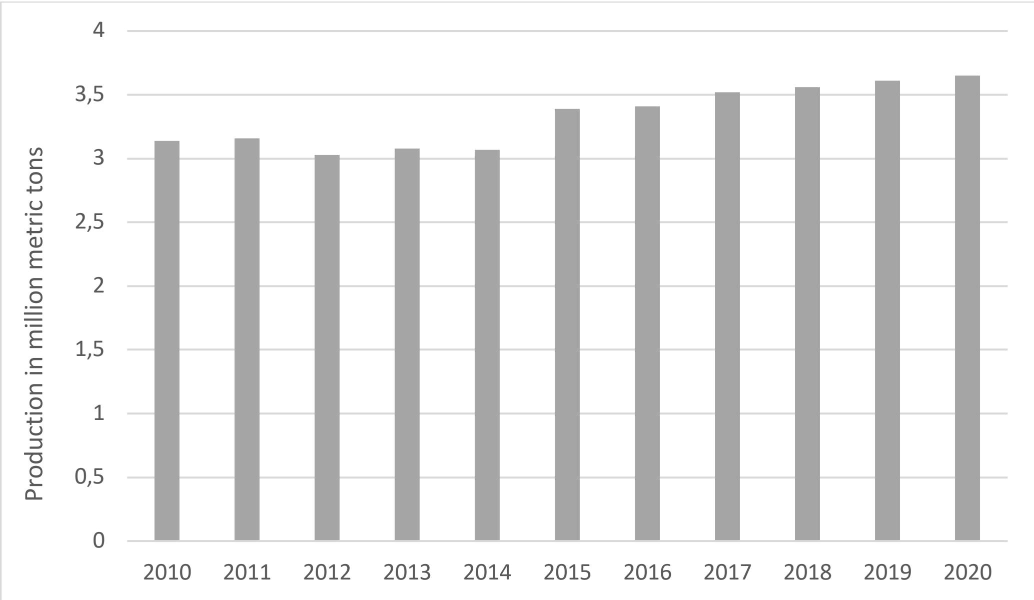
List of Figures

1. Introduction

1.1. Problem statement

Economic development and urbanization have driven animal-based protein consumption (Sans & Combris, 2015), and the global demand for meat is expected to increase by 73% by 2050 (McLeod, 2011). The increase in meat consumption is raising serious environmental, ethical, and human health concerns (Frey & Barrett, n.d.). Meat production in the Netherlands has been steadily increasing. In 2018 the production was 3.52 million tons, and by 2020 this increased to 3.65 million tons (van Gelder, 2020.). Meat consumption per capita has been stable since 2005 but has seen a slight drop of 1.9kg in 2020 due to the COVID-19 pandemic (Wageningen University and Research, 2021), whilst the average has stabilized at around 76.6 kg per person (Euro Meat News, 2022). The rise in meat consumption in the Netherlands from 2010 till 2020 can be found in Figure 1.

Figure 1. *Meat production in the Netherlands in million metric tons (van Gelder, 2022)*



The main cause of environmental damage stems from the pollution caused by livestock supply chains (Petrovic et al., 2015). Enteric fermentation, feed production, energy consumption and manure management are the biggest pollution sources (FAO, 2017). In addition, large amounts of land and water are required for raising livestock (Schlink et al., 2010; Thornton, 2010). Livestock raised for meat occupies 30% of the global ice-free terrestrial land, uses 8% of global fresh water (Tuomisto & de Mattos, 2011), and causes 18% of global greenhouse gas emissions (GHGs) (FAO, 2006). Clearcutting of carbon-dioxide absorbing vegetation for livestock grazing, and growing crops for animal feed, results in GHG emissions. Methane emission (CH_4) is the second biggest polluting substance, resulting from animals digesting their food (Petrovic et al., 2015). Overall, the GHG emissions related to livestock production constitute 34% of total GHG emissions (Tuomisto & Teixeira de Mattos, 2011).

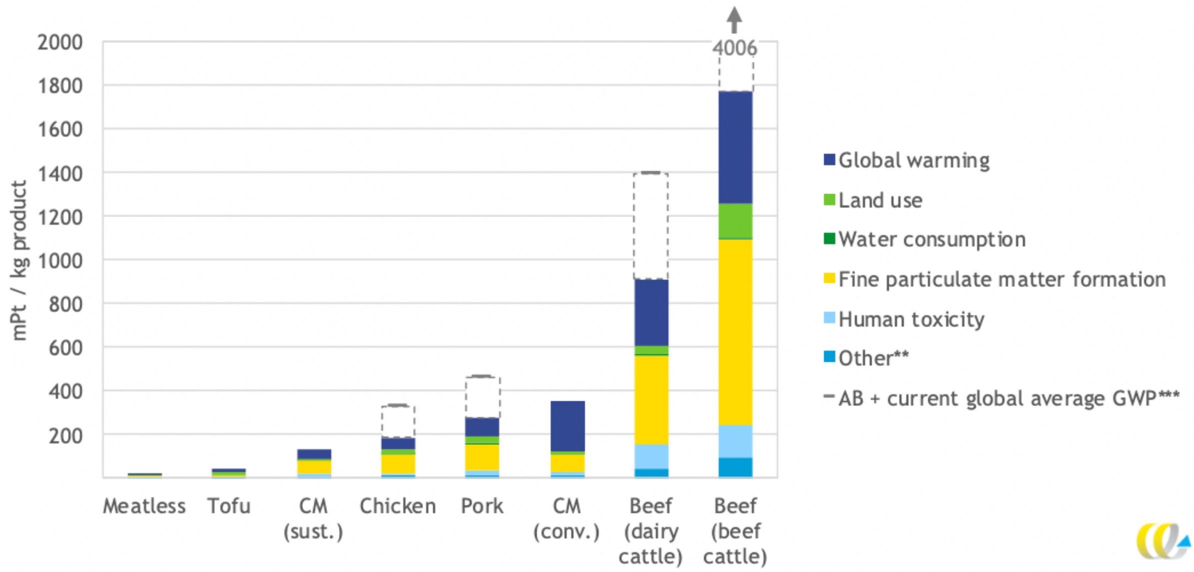
Besides meat production posing environmental risks, it also causes human health risks (Frey & Barrett, 2007). Animal feed usually contains antibiotics which consequentially increases the risk of antibiotic resistance, killing25,000 people yearly (European Medicin Agency, 2009). Another growing concern is the emergence of zoonotic diseases such as influenza, Q-fever, E-Coli (World Bank, 2010) and SARS-CoV-2 virus (ASPCA, 2020). Biodiversity has shown to have the potential to reduce diseases, but this potential is diminished since meat production lowers biodiversity (World Bank, 2010). Lastly, there is an increasing awareness of ethical issues. The way animals are raised and poorly treated is considered unacceptable by an increasing number of consumers (Ritchie & Roser, 2017).

1.2. Cultured meat

Cultured meat (CM) has the potential to mitigate the negative effects of meat production and consumption (Mancini & Antonioli, 2022). The production of CM starts with the extraction of stem cells, which are then grown in a bioreactor at high densities and volumes. An oxygen-rich cell culture medium is added to the cells, which consists of basic nutrients such as amino acids, glucose, vitamins and inorganic salts, as well as proteins and growth factors. The immature cells differentiate into skeletal muscle, fat, and connective tissues, sometimes simultaneously with signals from a scaffolding structure. The entire process takes approximately 2 to 8 weeks, depending on the meat type that is being produced (Jairath et al., 2021; GFI, n.d.). In theory, one cell sample could produce 10000 kilograms of CM, which means that only 150 cows are needed to satisfy the world's meat demand (Mosa Meat, 2019a).

CM has a lower energy impact than beef, but higher than chicken, pork, and plant-based meat alternatives (PBMAs). This environmental impact is determined by the energy use, based on electricity use during the production itself, and in addition, heat and electricity use in the upstream production of medium. However, when CM production switches to sustainable energy, CM has lower energy usage than all meat products. As seen in Figure 2, CM has a lower impact in other environmental categories such as global warming, land use, water consumption and fine particulate matter formation. PBMAs have a lower environmental impact than CM (Sinke & Odegard, 2021).

Figure 2. *LCA on environmental impact of cultured meat compared to conventional products (Sinke & Odegard, 2021)*



Several obstacles must be overcome with regards to technique, quality, reducing the costs and finding alternatives to certain components (Humbird, 2020). Price uncertainty is caused due to the complex composition and production process. However, future predictions promise a price decrease that is potentially lower than the price of conventional meat. Scaling up the production process makes for another difficulty. Installing a larger bioreactor and adding more animal tissues and cells does not work, because animal cell growth will result in failure if conditions are slightly altered (Kloosterman, 2021). Lastly, there is a growing body of research looking into consumer habits and acceptance of CM. Views on CM vary significantly per demographic. Men and younger people with higher education levels tend to be more positive about CM compared to women and older people (Bryant & Barnett, 2018). However, research has also shown that when consumers are presented with positive benefits about CM, they were more accepting (Bekker et al., 2017). Price and sensory expectations were seen as the biggest obstacles (Verbeke et al., 2015; Bekker et al., 2017).

1.3. The Netherlands: CM research and innovation hub

The Netherlands is considered the CM research hub of Europe (Grasso et al., 2019). Willem van Eelen, Dutch researcher and entrepreneur, filed the first patent for the production of meat using cell culture techniques in 1997 (Skaalure & Fernando, 2021). The Dutch government funded the first Dutch CM consortium consisting of researchers, universities, and food companies until 2009 (Wurgaft, 2021). After the governmental funding was discontinued, Professor Mark Post secured an investment by Google co-founder Sergey Brin of €250,000 (Boyle, 2013). This investment made the creation of the world's first CM burger possible in 2013 (Jairath et al., 2021). This raised expectations that the Netherlands would be the first country to introduce CM onto the market, however, regulatory constraints put a halt to this (Ysebaert, 2018). The company Eat Just planned on investing €30 million in 2017 to introduce CM onto the Dutch market. The restaurant Lab-44 intended to prepare dishes containing CM, but the Dutch Food Safety Authority (NVWA) interfered and subjugated the meat because it was not approved by the European Food Safety Authority (EFSA) yet (Ysebaert, 2018). The European Novel Food Regulation (NFR) prohibits the sale of CM in Europe (European Commission, n.d.). In 2022, positive developments started to accelerate within the CM sector. A motion to allow CM tasting under controlled conditions was adopted by the majority of The House of Representatives (de Groot & Valstar, 2022). In April, the National Growth Fund (''Het Nationaal Groeifonds'') (NGF) invested €60 million for the development of cellular agriculture (CA) (Bakker, 2022). The funds are allocated to the foundation Cellular Agriculture Netherlands (CANS) ('' Cellulaire Agricultuur Nederland''). An additional co-financing of €25 million is expected (CANS, 2022a)

While CM developments are making pace in the Netherlands, there are still several barriers that must be overcome before CM enters the Dutch market. The Technological Innovation Systems (TIS) was employed for this research because this framework is commonly used by scholars to analyze novel sustainable technologies with regards to the structures and processes that drive or obstruct development (Hekkert et al., 2011) and acts as a first step to develop policy recommendations (Bergek et al., 2008) A TIS can be defined as a social network composed of actors, institutions and infrastructure built around a specific technology (Suurs & Hekkert, 2009). The approach has been developed to analyze the factors and the affected system (Suurs et al., 2010). The TIS is composed of four structural elements and its performance is assessed by evaluating the seven system functions (Hekkert et al., 2007; Bergek et al., 2008). More about the TIS can be found under section 2.2 ''Technological Innovation Systems (TIS)'' Within the larger framework of the TIS, the systemic problems scheme constructed by Wieczorek & Hekkert (2012) based on TIS framework and additional concepts, acts as an add-on to further strengthen the TIS analysis. The structured scheme aids in identifying the underlying systemic problems and assigns the problems to eight specific systemic goals which have corresponding systemic instruments to improve the performance of a function, and therefore the overall performance of the TIS.

1.4 Lifecycle stages

Within evolutionary economics literature, scholars have studied the trajectories of technologies and industries. An example is the model by Abernathy & Utterback (1978), who propose that a technology can go through three stages: the Fluid Phase, the Transitional Phase and the Specific Phase. The Fluid Phase is characterized by technological and market uncertainties, high levels of experimentation and different designs. The next phase is the Transitional Phase, in which producers improve the technology, markets expand, standardization starts to take place and a dominant design emerges. The Specific Stage includes standardization of the technology, mass market application, few competitors, and the focus lies on improving the quality of the innovation. However, the focus of this model lies on one technology rather than the entire innovation system (Abernathy & Utterback, 1978). The lifecycle concept has been adapted by TIS scholars to study the trajectories the TIS can go through. Typically, a TIS goes through four stages: formative, growth, mature and decline. Each of these stages have different characteristic, drivers and barriers (Jacobsson & Bergek, 2003; Bergek et al., 2008; Markard, 2020). It is not assured that a TIS will go through all stages, and a TIS may not develop further than the formative stage (Suurs, 2009).

For the purpose of this research, the lifecycle stages concept is used as a ''background'' reference to clarify in what stage the Dutch CM TIS is currently situated in. Additionally, the formative stage of the CM TIS will be analyzed in further depth through the lens of the ''Motors of Innovation'' concept developed by Suurs (2009). A more elaborate explanation of the motors of innovation can be found under section 2.2.3 ''Motors of Innovation''. After conducting the structural-functional analysis, it was determined what motor is the most similar to the CM TIS. This provides additional insight on which functions require extra consideration. The functions that need more attention will be assessed in the systemic problem analysis.

The formative stage is relevant for this research as it is the stage that the Dutch CM TIS is currently situated in. During the formative stage, the structural elements, and essential processes of the TIS are emerging and establishing (Bergek et al., 2008). Low structurization of structural elements (actors, institutions, networks, infrastructure) and a variety of product designs (Markard & Hekkert, 2013, as cited in Bento & Wilson, 2016) are examples of characteristics of the formative stage. In addition, there are uncertainties concerning the technology and the market application during the formative stage. Secondly, the price-performance ratio is poor (Bergek et al., 2008). Uncertainty remains on whether technological obstacles will be overcome, and if CM can ever become economically viable and compete with conventional meat production in terms of pricing (Humbird, 2021; Sinke et al., 2021). Thirdly, economic activity is usually rather low during the formative stage (Bergek et al., 2008). In the Netherlands, CM is not yet sold on the market (NU, 2020). In the formative phase there are usually different product designs. Both companies produce CM slightly differently and are producing distinct end-products. For example, Meatable is producing foods such as dumplings and sausages while Mosa Meat is developing beef burgers (Jacobsson & Bergek, 2004; Cell Based Tech, n.d.; Meatable, 2022a; Mosa Meat, 2018). If CM were to develop into the growth stage, the technology diffuses on a larger scale and markets expand (Jacobsson & Bergek, 2004). The technology would establish, and the innovation system would be more elaborate and structured (Jacobsson & Bergek, 2004; Bergek et al., 2008). Positive feedback loops stimulate the self-sustenance and development of the TIS (Suurs, 2009). Suitable policies must be created and implemented to strengthen the TIS in the formative stage and help it reach the growth stage.

1.5. PBMAs sector analysis

Just like CM, PBMAs fall under the same category of alternative proteins. Alternative proteins can be divided into two categories: 1) plant-based meat, seafood, eggs and dairy and 2) cultivated meat and seafood (GFI, n.d.) PBMAs differ from CM because they are made from plant-based ingredients and CM is made from animal cells. However, both technologies are part of a wider transition called the ''protein transition''. The aim of the protein transition is to increase the consumption of alternative protein sources, and increase the efficiency of greenhouse gas emissions of existing protein production systems (GFI, n.d.)

The PBMAs sector is booming in the Netherlands and the Dutch are the biggest consumers of PBMAs in Europe (Proveg, 2021). The Netherlands is considered a leader in the sector due to favorable infrastructure and knowledge development conditions (A10; Gbordzoe, 2020). Two internationally successful brands *The Vegetarian Butcher* and *Vivera* are Dutch (Proveg, 2021). The Dutch government is encouraging the protein transition and has implemented the National Protein Strategy (NPS) with the main goal of promoting the development of alternative proteins and increasing food independency (Staghouwer, 2022). Another reason why people are eating more PBMAs is that prices of meat have risen due to inflation and increasing resource costs, in contrary to PBMAs (Proveg, 2022a). Trends continue to show growth for the meat substitutes sector (Potestio, 2022). The market for PBMAs in the Netherlands has grown over the past 14 years. In 2007, the revenue was 58 million, 97 million in 2018 and 118 million in 2020 (van Gelder, 2020). The total sales of PBMAs in 2021 was €174 million (Potestio, 2022). Thus, it can be argued that the PBMAs sector in the Netherlands is leaning more towards the late formative stage, almost entering the growth stage (Tziva et al., 2020). Insights from analyzing the history, development, and barriers of PBMAs in the Netherlands could aid in proposing suitable policy goals and systemic instruments that can improve the performance of weak systemic functions.

1.6. Research questions

CM is still in the formative phase, and therefore it is essential to research what barriers obstruct the transition into the growth phase. The main research question of this research is:

1.''How can the cultured meat TIS in the Netherlands transition into the next stage of development?''

The main research question was answered by combining the results and insights of the two sub-questions stated below:

2. *''What systemic problems are causing obstruction within the Dutch cultured meat TIS?''*

The first sub-question was answered by using the TIS framework to map the structural elements and to analyze the dynamics through assessing the seven system functions (Hekkert et al., 2007; Bergek et al., 2008). Next, it was determined which motor of innovation shared the most similarities to the CM TIS. Based on the functions that are the most relevant in this motor and the structural-functional analysis, it was determined which functions needed to be assessed in the systemic problem analysis. The underlying systemic problems were determined using the scheme constructed by Wieczorek & Hekkert (2012). Afterwards, the systemic goals and instruments as described in Wieczorek & Hekkert (2012) were prescribed to the observed systemic problems.

3. *''Are there insights that can be drawn from the plant-based meat alternatives sector to improve the performance of the TIS?''*

The third sub-question was added to examine whether there were relevant insights to be taken from the PBMAs sector which could aid in developing suitable policy recommendations.
This part of the research outlines a brief overview of the history and key development of the PBMAs innovation system. The main factors that drove the diffusion of the technology were summarized, as well as the barriers that caused obstructions. This historical analysis served three purposes: First, to obtain an overview of the development of the PBMAs sector. Secondly, to discover if the sector had similar drivers and barriers, and how these barriers were overcome. Lastly, to find out if any of the systemic goals and instruments were implemented to determine whether these could also be applicable for CM, based on the similarities and differences between the two technological innovations. The comparison of the innovation systems is outlined in the second part in order to give the reader a better understanding on the similarities and differences between CM and PBMAs. This comparison can highlight which policies implemented for PBMAs could also potentially be effective for CM's diffusion. Lastly, the insights that were derived from the interviews with experts were outlined in the third part of this chapter. Concepts that were used for analyzing this chapter were the structural elements and the systemic functions of the TIS (Hekkert et al., 2007; Bergek et al., 2008), and the concepts systemic problems (Klein-Woolthuis et al., 2005; Jacobsson & Johnson, 2010; Chaminade & Edquist, 2010; Smith, 2000; OECD, 1997), systemic goals and systemic instruments (Smits & Kuhlmann, 2004; Wieczorek & Hekkert, 2012)

1.7. Scientific relevance

The focus within the Sustainable Business and Innovation (SBI) field lies on creating (technological) solutions to the increasing sustainability challenges business face. Cooperation between a wide range of stakeholders such as businesses, governments, knowledge institutes, local communities and NGO's is crucial (Utrecht University, n.d.). The TIS is used by scholars within the innovation sciences field to assess the development and diffusion of sustainable innovations by looking at the dynamic network and interaction between key actors (ETH Zürich, n.d.). CM is a sustainable innovation that can mitigate the negative consequences of meat production (Mancini & Antoniolo, 2022). Most scientific publications about CM have focused on either the technology (Dohmen et al., 2022; Messmer et al., 2022; Post et al., 2020), sustainability (Hubalek et al., 2022, Post et al., 2020; Bodiou et al., 2020), consumer acceptance (Rombach et al., 2022; Onwezen et al., 2022; Onwezen et al., 2021; Bekker et al., 2021), safety (Ketelings et al., 2021; Banach et al., 2022; Ong et al., 2021), regulations (Post et al., 2020; Verzijden & Buijs, 2020) or ethics (van der Weele, 2021; Driessen & Korthals, 2012). By using the TIS, one can map the separate structural elements of the CM TIS and identify their connection and dynamics through the functional analysis. After the barriers are identified, the systemic policy framework helps determine the systemic problem and provides a framework for assigning policy goals and instruments.

The chosen theoretical framework for this research was the TIS framework (Hekkert et al., 2007; Bergek et al., 2008). Wieczorek & Hekkert in their 2012 paper ‘’*Systemic instruments for systemic problems: A framework for policy makers and innovation scholars’’* provide a scheme combining the structural-functional analysis together with the systemic problems and instruments concepts to identify underlying systemic problems and assign specific goals and instruments to address these problems, ultimately improving the functioning of the TIS. The use of this scheme creates a deeper understanding of the underlying systemic problems rather than solely recognizing the symptoms of the weak functions.

One study was identified specifically using the TIS for CM in the Netherlands (Guurink, 2020). This research was conducted in 2020, and since then several important developments within the CM innovation system have occurred. These developments have inevitably changed the structural make-up and functionality of the TIS. Examples of events that have changed and sped up the evolution of the CM TIS are the permittance of tasting experiments (De Groot & Valstar, 2022), the funding provided by the Dutch government (Schuengel, 2022), and lastly the expansion of Mosa Meat and Meatable to Singapore (Meatable, 2022a; Hull, 2022), all occurring in 2022. Especially in the formative stage of the TIS development, the structural elements such as actors and institutions are continuously changing throughout the unfolding of the innovation process (Suurs, 2009). Thus, it is valuable to consistently analyze a TIS. This can lead to a better understanding of the TIS as well as the general dynamic patterns that happen during the formative stage.

In addition, a comparison was made to a similar TIS that is also part of the protein transition: PBMAs. PBMAs are in the late formative stage, and thus by making this additional comparison, possible new insights could be obtained for the development of suitable policy instruments and recommendations. Making a comparison with a similar transition allows for potentially obtaining insights which might have not been considered if the focus had been solely on the chosen TIS. By applying the TIS framework to analyze a new sustainable innovation, a greater insight of how new innovations emerge is created. In addition, by identifying which policy goals were implemented during the formative phase of the CM sector and PBMAs sector, possible insights could be obtained on which policy goals and instruments could be beneficial for an innovation to transition through the stages. Comparing a TIS with similar TIS(s) can be beneficial, as it creates a deeper understanding for decision makers of the innovation system. The comparison can help determine what the important functions are, and after making the comparison, provisional conclusions can be drawn concerning the functionality of the TIS. Additionally, it can also increase the understanding of what is rational to expect considering the comparison with the similar TIS (Bergek et al., 2008).

2. Theoretical framework

This section provides a background on the theoretical underpinnings of the innovation systems (IS) framework, the TIS framework (Hekkert et al., 2007; Bergek et al., 2008), motors of innovation typology (Suurs, 2009), and the following concepts: systemic problems (Jacobsson & Johnson, 2010; Klein-Woolthuis et al., 2005; Chaminade & Edquist, 2010; Smith, 2000; OECD, 1997), and systemic goals and instruments (Smits & Kuhlmann, 2004; Wieczorek & Hekkert, 2012)

2.1. Innovation Systems (IS)

The concept of 'Systems of Innovations'' was put forward by Lundvall (1985) and takes into consideration the systemic aspect of the innovation process (Sternberg, 2009). The innovation system (IS) is composed of all institutions and economic structures that influence the speed and path of technological change in society, and it comes forth from individual and collective acts (Edquist, 2001). The IS framework aids in understanding the societal subsystems, actors and institutions that influence the emergence, speed, and direction of a technological innovation (Edquist & Lundvall, 1993; Carlsson et al., 2002). All innovation systems have common characteristics (Lundvall, 1992; Carlsson et al., 2002): 1) Whilst the central focus is a technology, institutional and organizational values are also deemed to be important, 2) knowledge development is seen as one of the core processes of an IS, and all innovation systems include the creation, diffusion and use of knowledge, 3) innovation systems are made out of components that have different characteristics or attributes and that dynamically interact with each other in several ways, 4) innovation is a continuous process, 5) every country has a distinct innovation system, 6) IS employs a holistic approach, which includes combining the actor and structural view, 7) setting the boundaries of an IS is difficult, as well as predicting the direction of an innovation process.

The IS approach has been conceptualized in several ways depending on the geographical boundaries or techno-economical delineation. For example, innovation systems can be studied on the national level (Nelson, 1993; Lundvall, 1992), regional level (Cooke et al., 1997), sectoral level (Breschi & Malerba, 1997) and technological level (Hekkert et al., 2007; Bergek et al., 2008). The National Innovation System (NIS) approach is applied to study the innovative performance of a country, thus on a national level. Regional Innovation Systems (RIS) encompasses how regions create competitive advantage based on innovation activities and processes on the regional level (Cooke et al., 1997). Due to the different nature of innovation per region, different policies might be suitable per region (Todtling & Trippl, 2005). The Sectoral Innovation System (SIS) approach is based on a specific sector and constitution of agents, including individuals and organizations who perform market and non-market interactions with the aim to develop, produce and sell sectoral products (Malerba, 2002). Lastly, the TIS is used as a framework to study the emergence of a technological innovation. A further explanation about the TIS can be found in the next section.

2.2. Technological Innovation System (TIS)

The TIS framework assists research on how technological innovations develop and diffuse through the dynamic interactions between actors and their networks under specific infrastructures and institutions (Huang et al., 2016). It is often used to analyze radical and sustainable technologies at the beginning stages of the development (Markard et al., 2012). Whereas the IS approach focuses mainly on the macro-level (institutions), the TIS also focuses on the micro-level (entrepreneurs). Entrepreneurs play a fundamental role in the innovation system because they have the power to change parts of the system's structure and steer the IS into a certain direction (Hekkert et al., 2007; Bergek et al., 2008). The framework's application consists of the structural analysis and functional analysis. By identifying barriers that obstruct the expansion of a new technology, the TIS acts as a steppingstone to create policy recommendations (Hekkert et al., 2007; Bergek et al., 2008).

2.2.1. Structural elements

The TIS is composed of *actors*, *institutions*, *interactions*, and *infrastructure* that influence the speed and direction of the innovation (Bergek et al., 2008; Wieczorek & Hekkert, 2012). The subcategories of the structural elements can be found in Table 1. *Actors* are the direct and indirect developers and users of the technology. The wide range of different actors include civil society, companies, knowledge institutes, government, NGOs and third parties (Hekkert et al., 2007;v Wieczorek & Hekkert, 2012). *Institutions* are the rules and laws shaped by society and determine human interaction. Formal institutions are created, codified, and enforced by an authority. Informal institutions are shaped by the collective and can for example be norms, values and accepted behavioral habits (Douglas, 1991; Helmke & Levitsky, 2012)

Interactions is a dynamic element of the system and is characterized by the relationships between networks and individual contacts. Some literature defines this element as *network,* however, Wieczorek and Hekkert (2012) argue that interactions go beyond networks, and reciprocal interactions can also be seen in the early stages of development. There are different conceptions and definitions of *infrastructure* in key literature. The main elements of *infrastructure* are considered physical (Smith, 1997; Klein-Woolthuis et al., 2005), knowledge (Smith, 1997) and financial infrastructure (O'Sullivan, 2005). Physical infrastructure has the power to shape and establish the dominance of a technology. Examples include railroads, airports, harbors, and telecommunication networks. The absence of infrastructure can be considered a systemic problem (Klein-Woolthuis et al., 2005). Knowledge infrastructure consist of organizations that create, distribute, manage, and protect knowledge. Examples include universities, research labs and libraries (Smith, 1997). Examples of financial infrastructure are financial programs, subsidies, and grants (O'Sullivan, 2006)

Table 1*. Structural elements of the TIS (Hekkert et al., 2007; Bergek et al., 2008; Wieczorek & Hekkert, 2012)*

Structural elements	**Subcategories**
Actors	• Civil society • Companies: start-ups, SME's, large firms, MNC's • Knowledge institutes: universities, technology institutes, research centers, schools • Government • NGOs • Third parties: legal organizations, financial organizations/banks, intermediaries, knowledge brokers, consultants
Institutions	• Hard: rules, laws, regulations, instructions • Soft: customs, common habits, routines, established practices, traditions, patterns of behavior, norms, expectations
Interactions	• At the level of networks • At the level of individual contacts
Infrastructure	• Physical: artifacts, instruments, machines, roads, buildings, networks, bridges, harbors. • Knowledge: knowledge, expertise, know-how, strategic information • Financial: subsidies, fin. programs, grants etc.

2.2.2. Systemic functions

The performance of a TIS cannot be explained solely by analyzing the structural elements because they are relatively static by character (Suurs, 2009). By adopting the systemic functions, the dynamics within the TIS can be analyzed. Thus, the seven system functions assess *how* the TIS is functioning, and go further than the previous step, which assesses *what* constitutes the TIS (Kivimaa & Virkamäki, 2014). The functions are regarded as crucial determinants of the performance of innovation (Bergek, 2002).

F1. Entrepreneurial activity
Entrepreneurs drive the initial development of a technological innovation. They accumulate knowledge by experimenting under different conditions. Entrepreneurial activity is tightly linked to the other six functions since an absence of activity could be assigned to a lack of performance from the other functions (Hekkert et al., 2007).

F2. Knowledge development
Producing knowledge can be considered as the core of any innovation process. This includes 'learning by doing' and 'learning by searching' (Hekkert et al.,2007). Types of knowledge include scientific, technological, production, logistics, markets, and design (Bergek et al., 2008).

F3. Knowledge exchange
This is the exchange of information, which happens within an R&D setting and where it meets the market, competitors, and the government (Hekkert et al., 2007). It takes place through networks, partnerships, and shared project collaborations and experiences (Van der Loos, 2020). Changing norms and values should influence the R&D agenda, and simultaneously, policy decisions (long term targets and standards) should overlap with the newest technological insights (Hekkert et al., 2007).

F4. Guidance of the search
This refers to the direction where the technological innovation is going (Hekkert et al., 2007). This function looks at the activities within the IS that can stimulate the visibility and clarity of wants amongst users. Industry, governments and/or the market, and the amount of available funding shapes this function (Bergek et al., 2008). The direction in which the technological change is going is partially determined by the R&D priority setting. Long-term policy goals set by the government, companies and the private sector can also influence the direction of the search (Hekkert et al., 2007; van der Loos et al*.* 2020).

F5. Market formation
New technologies often endure difficulties integrating into established markets because embedded technologies are benefitting from existing infrastructures and institutions (Hekkert et al., 2007). It could be that in a formative TIS, markets do not exist. Therefore, the establishment of technology specific institutions such as standards is necessary (Bergek et al., 2008.

F6. Resources Mobilization
Resources are needed to fuel and sustain all activities (Hekkert et al., 2007) and come in three types: financial (venture capital, public seed money and private investments), human (education and specialized training programs) and physical (natural resources and infrastructure) (van der Loos et al., 2020).

F7. Counteract Resistance of Change/ Legitimacy Creation
Actors and parties with certain interests might resist the new technology. Therefore, it is necessary for advocacy coalitions to put the new technology on the agenda to increase legitimacy and lobby for advantageous tax regimes and resources (Hekkert et al., 2007). The success of these coalitions is reliant on consumer acceptance and support from the government (Bergek et al., 2008), funding (F6) and future expectations (F4) (Hekkert et al., 2007).

2.3 Motors of Innovation
Functions interact with each other, and as the TIS develops, these interactions usually change. The TIS incorporates the concept of cumulative causation, which entails that the TIS progresses cyclically and cumulatively through the process of reciprocal reinforcement of the systemic functions (Suurs, 2009). If positive feedback loops keep occurring, the TIS eventually develops into the growth stage (Jacobsson & Bergek, 2004). Suurs (2009) researched what type of different feedback loops, in this case called ‘’motors of innovation’’, could be identified during the formative stage of an TIS. Suurs presented four different motors: the Science and Technology Push Motor (STP), the Entrepreneurial Motor, the System Building Motor and the Market Motor. Every motor has different dominant functions and distinct interaction dynamics between the functions. Thus, depending on the motor that is present, different systemic functions have greater influence. In addition, each motor has several drivers and barriers which obstruct or drive the emergence of the motor. The drivers, barriers and impacts of each motor can be found in Table 2.

In the STP Motor, functions F2, F3, F4 and F6 play the most significant role. Positive expectations and/or research outcomes (F4) lead to the establishment of government supported R&D programs (F4) which is financed by the government (F6). This stimulates Knowledge Development (F2), and the number of occurring conferences, meetings, and networks (F3). The Entrepreneurial Motor is similar to the STP Motor; however, Entrepreneurial Activity (F1) and Counteract Resistance of Change/ Legitimacy Creation (F7) play a bigger role. This motor starts with the initiation of experiments and projects by firms, utilities, or local governments (F1), because they have positive expectations for the innovation (F4). These actors lobby for financial resources to fund these projects because of the pre-commercial state of the technology (F7). If the outcome is positive, the financial resources are given (F6). This starts the projects (F1), and the outcome of the projects determines whether such projects will be initiated again (F4). Just like the STP motor, F2 and F3 are also established and connected to F1 because the knowledge accumulation through entrepreneurial experimentation complement the feasibility studies and trials (F2).

The System Building Motor is characterized by the involvement of all functions. Actors and companies begin projects which possibly lead to positive outcomes (F1, F4). Because of these projects, actors mobilize themselves to share knowledge and discuss how the technology should develop further (F2, F3, F4). Again, lobbying takes place to secure resources (F6, F7). The feedback loop is similar to the Entrepreneurial Motor, however, there is a weighed importance of Market Formation (F5). Networks are aiming to stimulate the establishment of mass markets. The difference from the Entrepreneurial Motor is that in the System Building Motor, the lobbies have the goal to achieve policy measures that expand the TIS rather than receiving project-specific subsidies. Lastly, the Market Motor is strongly fulfilled by all functions except for F7, which does not play an important role because Market Formation (F5) is no longer dependent on politics but driven by regular business activities connected to Entrepreneurial Activity (F1). The technology is widely diffused and reliable at this point, and the basis for wide commercial expansion has been established. This motor starts with the establishment of institutional structures that promote the commercial demand for the technology (F5). This creates positive expectations (F4) and a larger number of available resources (F6). New entrants are stimulated to embrace the new technology (F1) in which they will likely invest resources (F6) and develop marketing strategies that will increase the demand for the technology (F5) (Suurs, 2009).

Table 2. Overview of the drivers, barriers and impacts of the motors of innovation (Suurs, 2009)

	STP Motor	**Entrepreneurial Motor**	**System Building Motor**	**Market Motor**
Enactors*	There is a small enactor group, typically consisting of research institutes, technology developers and sometimes governments.	An enactor group has grown in number and variety. Enactors are primarily aiming to develop An enactor group has grown in practical and commercially oriented projects	The enactor group is large and covers a broad variety of actors. The enactors are increasingly organized in networks.	The enactor group is large and develops nationwide activities. It typically includes incumbent firms as well as national government actors (e.g., ministries, provinces)
Selectors*	Selectors are practically absent. Drawing in one or more selectors is the prime objective of enactors at this stage. The first selectors to enter the TIS are often governments.	Selectors have become more active under the influence of enactors, serving as institution builders and launching customers especially when the first demonstrations have delivered positive results.	A large group of selectors, including incumbent firms, support the efforts of enactors. They are increasingly organized in networks. At the same time the resistance of other selectors increases.	The supportive selector group is large and closely involved with the cause of the enactors.
Institutions	Institutions are poorly aligned to the emerging technology. The main driver is the presence of a technological promise as communicated by enactors. As the motor is sustained, more formal institutions complement this promise in the form of R&D policy programs aiming for pilots and demonstration projects	Alignment to the emerging technology is still poor. Prospective structures are most important, especially if related to the urgency of (local) environmental issues as conceived by selectors. Additional institutional support comes mainly in the form of project-specific government subsidies.	Institutions are more aligned to the emerging technology. The most important institutions are policies that facilitate the exchange of knowledge and the shaping of political coalitions.	Institutions are aligned to the emerging technology. The main driver is formed by market creation policies.
Technology	The technology is unknown, unreliable and costly, but is holding a promise for the future	The technology is still unreliable and costly but sufficiently improved to allow for practical applications.	The technology is reliable and beyond the stage of demonstration but is still costly.	The technology is reliable but is usually still costly. Costs may decrease rapidly as the result of mass production

Impacts	Build-up of a shared vision. Build- up of knowledge structure Build-up of supply-side structures	Build-up of demand-side structures. Build-up of intermediary structures and networks. Formal institutions are adjusted (safety standards, licensing procedures, etc.). The technology is improved.	Enactors and particularly selectors are drawn into the TIS in large numbers. Build-up of political networks in the form of coalitions and platforms. Build-up of government structures in the form of market creation policies. Incumbents increasingly become part of the TIS.	Technologies and institutions are increasingly linked to the incumbent energy sector. The costs of technology decrease rapidly as the result of mass production.

* Enactors are actors that are closely tied to the evolution of a technology, and strongly determine the success of it. Examples are small technology developers and industries committed to a specific technology
* Selectors are actors that are less involved with the technology. Examples are regulators, financers, users, or large firms.

2.4 Systemic problems, goals and instruments

Wieczorek and Hekkert (2012) propose a scheme combining the structural and functional analysis from the TIS, the systemic problems concept (Klein-Woolthuis et al., 2005; Wieczorek & Hekkert, 2012; Smith, 2000; Chaminade & Edquist, 2010; OECD 1997; Kemp & Nill, 2009) and systemic instruments concept (Smiths & Kuhlmann, 2004) to identify underlying systemic problems of weak functions, and secondly, assign systemic goals and policy instruments to resolve problems. An absent or weak functioning IS indicates that there is an underlying systemic problem. The systemic problems are related to the structural components and can be a presence issue or capacity and/or capability associated. A presence related problem indicates that certain elements are missing. A capabilities related problem means that the interactions are either too strong, or there is a lack of capacity or capabilities. Either way, the choices that are being made do not lead to successful outcomes (Wieczorek & Hekkert, 2012). Every structural element has specific systemic problems. For example, when the actors' problems are presence related, then relevant actors are absent (OECD, 1997). Or, when it is an interactions problem and it is quality related, it could mean the network connectivity is weak (Chaminade & Edquist, 2010). A full overview of specific structural systemic problems can be found in Table 2.

Table 3. *Specific structural problems (Klein-Woolthuis et al., 2005; Wieczorek & Hekkert, 2012; Smith, 2000; Chaminade & Edquist, 2010; OECD 1997; Kemp & Nill, 2009)*

Actor problems	**Institutional problems**	**Interaction problems**	**Infrastructural problems**
Presence - relevant actors are possibly absent **Capacity** – Actors lack the capacity to learn or make use of available resources. The actors might not be able to identify and articulate their needs, and to cultivate visions and strategies. These problems are also referred to as transition problems.	**Presence** – Specific institutions are absent **Capacity** – The problems lie with their lack of capacity/quality. Weak institutions often result in the insufficient support for a new technology or development. Stringent institutional problems result in incumbent actors being favored.	**Presence** – when necessary, interactions are missing due to differences in needs, visions, capacities, or lack of trust. **Quality** – Strong network problems mean that actors are wrongfully guided by stronger actors. This could be caused by the over involvement of incumbent actors, dependence on the stronger partners because of specific resources and favoring the incumbent actor's set-up Weak network problems arise from insubstantial networks between actors, which inhibit learning and innovations. The latter is called complimentary problems.	**Presence** – specific infrastructure is absent **Quality** – insufficient infrastructure

A specific goal can be assigned per specific problem. Build upon previous literature by Smiths and Kuhlman (2004), Wieczorek & Hekkert present eight policy goals that systemic instruments should achieve. The corresponding policy instruments can be found in Table 7. The eight goals are:
1. Stimulate and organize the participation of various actors (NGOs, companies, government etc.)
2. Create space for actors' capability development (e.g. through learning and experimenting).
3. Stimulate the occurrence of interaction among heterogenous actors (e.g. by managing interfaces and building a consensus).
4. Prevent ties that either too strong or too weak.
5. Secure the presence of (hard and soft) institutions.
6. Prevent institutions being too weak or too stringent.
7. Stimulate the physical, financial and knowledge infrastructure.
8. Ensure that the quality of the infrastructure is adequate.

The eight policy goals each have their own specific set of suggested systemic instruments that help realizing the goals. These systemic instruments can be found in Table 7 in the methodology chapter.

3. Methodology

The following chapter outlines the chosen research design, data collection methods, the operationalization of the theoretical frameworks and concepts, the sampling strategy, the selected data analysis method, and lastly ethical considerations.

3.1. Research design

A qualitative research approach was applied to identify systemic problems within the Dutch CM TIS. Qualitative methods offer an effective way of obtaining in-depth knowledge on a specific subject that is under-researched, with the goal of generating new ideas and solutions (Bryman, 2014). Qualitative research produces a possible outcome, but this does not necessarily positively prove it. The theoretical account is dependent on the worldviews of the participants one is using for one's research (Bryman, 2014). Thus, the conclusions that are made have a degree of uncertainty (Sober, 2013). This research is deductive because a specific theory (the TIS) is tested by collecting and analyzing data, and eventually more specific conclusions are drawn (Bryman & Bell, 2014).

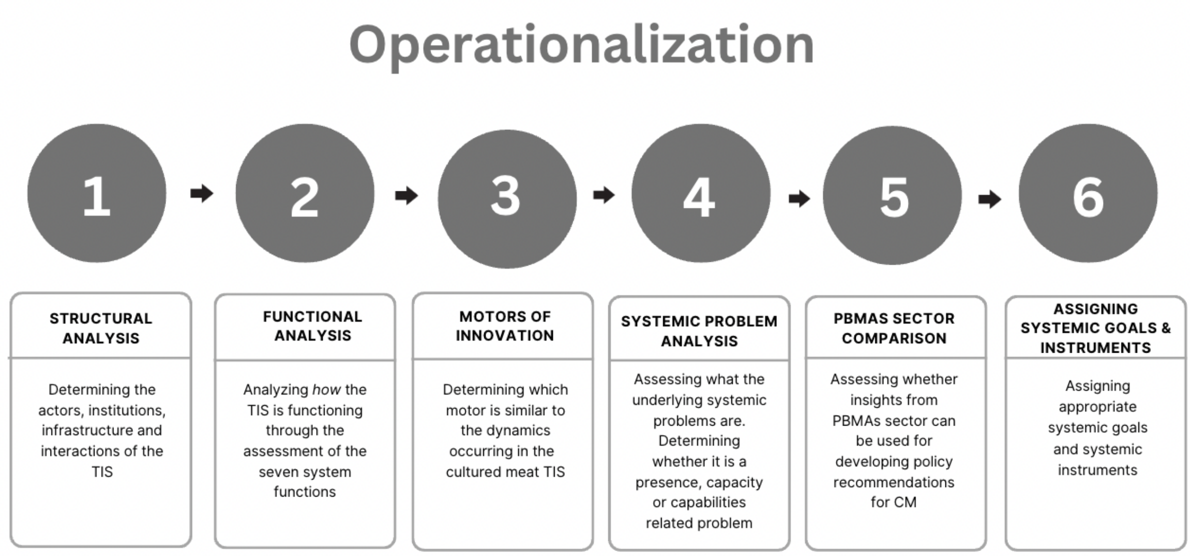
3.2. Data collection

The data that was collected throughout this research consisted of primary and secondary sources. Primary sources are data collected by the researchers (Bryman, 2014), in this case the interviews conducted with key actors from the CM sector and PBMAs sector. Conducting interviews with relevant key actors is an effective way to get useful insights and knowledge from key actors in the CM industry. Furthermore, the interviews were used to review and confirm the desktop research and obtain knowledge that could not be attained through solely desktop research. Nine interviews were held with actors from within the CM sector to obtain knowledge and insights for step 1, 2 and 3 (see figure 4). During the interviews with the CM actors, questions regarding PBMAs were asked (see Appendix B) Two interviews were held with people who from within the alternative protein sector to gather insights for step 4 (see figure 4). The interviews were held between June 29th and September 2nd via Zoom or via telephone. An overview of the interviewees can be found in table 8 under section 3.5 ''Sampling strategy''. The interviews were semi structured and between 30-60 minutes, with one interview being 20 minutes due to the busy schedule of the participant. The questions can be found in Appendix A. Secondary sources included peer reviewed scientific articles, firms and industry association's websites, policy reports, journal articles, publications, news articles, and reports. *Cultured meat*, *cultivated meat*, *in-vitro meat* and *plant-based meat alternatives* were used as keywords for searching for secondary resources on Google, Google Scholar, and Scopus. These keywords were also translated to Dutch, and more keywords were added to specify the search.

3.3. Operationalization

The operationalization of the TIS and systemic policy scheme consists of five steps, as seen in Figure 4. Step 1) the structural analysis, 2) the functional analysis, 3) the systemic problem analysis and 5) systemic problem analysis are based on Hekkert et al. (2007), Wieczorek and Hekkert (2012) and Bergek et al. (2008). Step 4 is the PBMA sector analysis. The operationalization of each step will be elaborated on in the following sections. The last section outlines the structuration of the interview guide.

Figure 3. *Overview of the operationalization*



3.3.1. Structural analysis

The mapping of the structural elements was completed through desktop research and by conducting interviews with key actors. To map the structural elements of the CM IS, queriesseveral queries were resolved by answering questions related to the assigned indicators. Table 4 provides an overview of the structural elements and the corresponding diagnostic questions and indicators.

3.3.2. Functional analysis

The indicators and diagnostic questions in Table 5 were used to assess the performance of the functions, and are based on Hekkert et al. (2007), Bergek et al. (2008) and Wieczorek and Hekkert (2012). Afterwards, the indicators were rated on a 5-point Likert-scale, where 0 is absent, 1 is very weak, 2 is weak, 3 is moderate, 4 is strong and 5 is very strong. The scores were based on desktop research and conducted interviews. The overall score of the function was determined by combining the points and dividing them by the number of indicators. Depending on the function and context, an indicator could be weighed more and therefore alter the overall score. It should be noted that this is based on the assumptions and view of the researcher.

3.3.3. Motors of Innovation

After the structural and functional analysis, it was determined which motor resembled the CM TIS the most. This comparison was conducted by comparing the CM TIS to the function dynamics and interactions, drivers, barriers and impacts of the different motors as described in Suurs (2009). An overview of the drivers, barriers and impacts can be found in Table 2 under the theory section. The feedback loops of the different motors have been discussed in section 2.2.3 ‘’Motors of Innovation’’.

Table 4. *Questions and indicators for the structural components (Hekkert et al., 2007; Bergek et al., 2008; Wieczorek & Hekkert, 2012).*

Structural element	**Diagnostic questions**	**Indicators**
Actors	Who are the actors? Are all actors and their values included? What are the types of organizations involved in knowledge production? Which parties try to engage collaboration between different parties?	Civil society Companies: start-ups, Small and medium-sized enterprises (SMEs), Multinational Corporations (MNCs) Government Knowledge institutes: universities, technology institutes, research centers, schools NGOs Other parties: legal organizations, financial organizations/banks, intermediaries, knowledge brokers, consultants.
Institutions	What are the rules of the TIS?	Hard: Rules, laws, regulations, instructions Soft: Customs, common habits, routines, established practices, traditions, norms, expectations, ways of conduct
Interactions	What does the network look like? Do the interactions have a localized or globalized character?	At the level of networks At the level of individual contacts
Infrastructure	What are the technological trajectories? Which parties develop knowledge Where are knowledge producers located? How much knowledge is produced?	Physical: artefacts, instruments, machines, roads, buildings, networks, bridges, harbors Knowledge: knowledge, expertise, patents, publications, know-how, strategic information Financial: subsidies, fin programs, grants.

3.3.4. Systemic problem analysis

The functional analysis showed which functions perform well and which do not. The systemic problem analysis is aimed at determining what the root problem of the weak performing function is. The four structural dimensions are considered as the operating parts of the system, and their problems can be attributed to their absence (presence) or to it being a capacity, capability, intensity, or quality related problem.

Table 5. *Overview of the system functions, indicators, and diagnostic questions for analyzing the performance of the TIS (Hekkert et al., 2007, Bergek et al., 2008; Bergek et al., 2008; Wieczorek & Hekkert, 2012).*

Functions and indicators	Diagnostic questions	Sources
F1 – Entrepreneurial Activity Number of new entrants, number of diversification activities of incumbent actors, and number of experiments with the new technology	• Are these the most relevant actors? • Are there sufficient industrial actors in the innovation system? • Do the industrial actors innovate sufficiently and on large scale production? • Does the experimentation and production by entrepreneurs form a barrier for the IS to move to the next phase?	• Interviews • Scientific literature • Newspaper articles • Websites of CM companies
F2 – Knowledge Development Number of patents, publications & R&D projects	• Is the amount and quality of knowledge development sufficient for the development of the TIS, or does it form a barrier?	• Interviews • Scientific literature • Newspaper articles • Patent databases • Interviews with actors • Reports on CM
F3 – Knowledge Exchange Number of workshops & conferences, network size and intensity over time and knowledge exchange between industry, science, and users.	• Is there enough knowledge exchange between science, industry, and users? • Is there sufficient knowledge exchange across geographical borders? • Is knowledge exchange forming a barrier for the IS to move to the next phase? • Are there strong partnerships?	• Interviews • Number of consortiums, conferences, and EU/ NL projects • Scientific literature • Scopus search • Newspaper articles
F4 – Guidance of the Search Regulations, visions, expectations of the government and key actors	• Is there a clear vision on how the industry and market should develop in terms of growth and in terms of technological design? • Are there clear policy goals regarding this technological field and are they viable? • Are the visions and expectation of actors involved sufficiently aligned to reduce uncertainties? • Does this (lack of) shared vision block the developments of the TIS?	• Interviews • Reports • Scientific literature • Policy goals • Governmental documents/ reports • Newspaper articles
F5 – Market Formation Specific tax regimes for new technologies, expected market size	• Is the expected future market size sufficient? • Does market size form a barrier for the development of the Innovation System? • Should a new market be created?	• Interviews • Scientific literature • Reports on projects
F6 – Resource Mobilization Rising volume of capital, rising volume of seed and venture capital, changing volume and quality of human resources, change in physical resources	• Are there sufficient human/financial/physical resources? If not, does that form a barrier? • Is the physical infrastructure sufficient to support the diffusion of technology?	• Interviews • Scientific literature • Governmental documents: governmental budgets for innovation projects/ subsidies • Amount of investment in CM companies
F7 – Counteract Resistance to Change/ Legitimacy Creation Rise and growth of interest groups and their lobby actions.	• Is there a lot of resistance towards the new technology? • If yes, does it form a barrier?	• Interviews • Newspaper articles

3.3.5. PBMAs sector comparison

To answer research sub-question three ''Are there insights that can be drawn from the PBMAs sector to improve the performance of the TIS?'', an analysis was conducted on the Dutch PBMAs sector. Primary and secondary sources were used for researching this question. Secondary sources included scientific literature, journal articles, reports, policy reports, governmental documents, company reports and websites, and news articles. The primary sources are the interviews conducted with actors from the PBMAs sector and actors from the CM sector. The aim of this research question was to determine whether there are relevant insights from the PBMAs transition from the early formative stage into the late formative stage that could be incorporated into the recommendations for the CM sector. Due to time limitations, an entire TIS analysis including the motors of innovation, systemic problems, systemic goals and systemic goals instruments was not conducted. Alternatively, different concepts from the TIS framework and its supplementary concepts (goals and instruments), and the drivers and barriers concept were integrated in this additional part of the research.

In the first part, the key developments, drivers, and barriers of the PBMAs sector in the Netherlands between the early formative stage and late formative stage are outlined. This period ranges from the early 1990's until present day. This analysis includes the main (external) factors that drove the diffusion of the technological innovation, as well as the barriers that the sector faced. The purpose of this historical analysis is to get a clear overview of how the PBMAs sector developed; what obstructs did the sector face and what were the factors that drove the transformation of the sector. Drivers and barriers were identified through analyzing secondary sources and by asking experts during the interviews what the main drivers and barriers were according to their perspective. Then, the systemic functions of the TIS and what their dynamics and role were during the transition were identified. The same was done for the concepts systemic goals and systemic instruments (Wieczorek & Hekkert, 2012). If so, the identified systemic functions, goals or instruments are indicated with a number between brackets, for example: (1), (2), (F1).

Comparisons between the focal TIS and a similar TIS can advance the comprehension of decision makers of what is reasonable to expect for the stage of development the focal TIS is currently situated in. Therefore, it is important to understand not only what the similarities are, but also the differences so that policy goals and instruments can be chosen accordingly. Strategies and policies that were beneficial for PBMAs can also be effective for CM, depending on the conditions. The similarities and differences were identified through literature research and interviewees. Interviewees were asked how they perceived the (trajectory) similarities and differences between PBMAs and CM. The interview guide for the PBMAs experts was composed of four sections: 1) personal introduction and their view on CM and PBMAs, 2) drivers and barriers of PBMAs, 3) systemic goals and instruments and 4) similarities and differences between the two technologies. Examples of questions are: ''What are the barriers the sector has encountered? And if applicable, how were these overcome?'' and ''Are there policy instruments and/or strategies that have been beneficial for the development of plant-based meat alternatives?''. The entire interview guide can be found in Appendix B. The questions were created based on the function analysis questions in Wieczorek & Hekkert (2012), and on the systemic goals concept and instrument concept. The focus of the question was on policies and recommendations, as the aim of this part was to obtain useful insights for the construction of recommendations for the CM sector. Interviewees from the CM sector were also asked questions about the PBMAs sector because the two technologies are both part of the protein transition and there could be a possible overlap of knowledge. For CM experts this only constituted of a small part of the interview as most time was dedicated to the structural and functional analysis. The interview questions for CM experts can be found in Appendix A. The coding for the PBMAs interview questions was based on drivers, barriers, differences, similarities, systemic goals, and systemic instruments. The coding can be found in Appendix C. The third part summarizes the insights that were obtained through the interviews with the experts from the PBMAs sector. The advice from the PBMAs experts was complimented with advice from experts from the CM interviewees whenever applicable. If goals or systemic instruments were recognized, they were indicated with the corresponding goal between brackets such as (1), (2).

3.3.6. Systemic goals and instruments

Specific goals need to be created before implementing a systemic instrument (Wieczorek & Hekkert, 2012). The type of goal depends on whether it is a presence-relatedor capabilities-related problem. The complete framework including the type of systemic problem and correspondent instrument goal can be found in Table 6. The goals are effective in targeting specific malfunctioning elements to improve the system's functions altogether. Eight goals were created that could address all systemic problems, with every goal having a corresponding policy tool that alleviates these systemic problems. The goals are prescriptive and made to support policy design and can be found in section 2.4. ''systemic problems, instruments, and goals''

Table 6. *Systemic innovation policy framework (Wieczorek & Hekkert, 2012)*

System function	**Structural element**	**Systemic problem**	**Type of systemic problem**	**Systemic goals**
e.g. F1: entrepreneurial activity	Actors	Actor problem	Presence? Capabilities?	Stimulate and organize the participation of relevant actors (1) Create space for actors capability problems (2)
	Institutions	Institutional problem	Presence? Capacity/quality?	Secure presence of hard and soft institutions (3) Prevent too weak and too stringent institutions (4)
	Interactions	Interaction problem	Presence? Intensity/quality?	Stimulate occurrence of interactions (5) Prevent too strong and too weak ties (6)
	Infrastructure	Infrastructural problem	Presence? Capabilities?	Stimulate physical, financial and knowledge infrastructure (7) Ensure adequate quality of infrastructure (8)

To fulfill the systemic instrument goals, Wieczorek and Hekkert (2012) composed a list of policy instrument recommendations that can be found in Table 7. Which instruments are chosen depends on the problem, the mutual interaction in between instruments and the influence of the social-political and economic environment, and other competing TISs.

Table 7. *Systemic goals and corresponding individual instruments (Wieczorek & Hekkert, 2012)*

Goals of systemic instruments	Examples of individual instruments
1. Stimulate and organize participation of actors	Clusters; new forms of Public Private Partnerships, interactive stakeholder, involvement techniques; public debates; scientific workshops; thematic meetings; transition arenas; venture capital; risk capital.
2. Create space for actor's capability development	Articulation discourse; backcasting; foresights; road-mapping; brainstorming; education and training programs; technology platforms; scenario development workshops; policy labs; pilot projects
3. Stimulate occurrence of interactions	Cooperative research programs; bridging instruments (centers of excellence, competence centers); collaboration and mobility schemes; police evaluation procedures' debates facilitating decision-making; science shops; technology transfer
4. Prevent too strong and too weak ties	Timely procurement (strategic, public, R&D-friendly); demonstration centers; strategic niche management; political tools (awards and honors for innovation novelties); loans/guarantees/tax incentives for innovation projects or new technological applications; prizes, Constructive Technology Assessment' technology promotion programs, debates, discourses, venture capital; risk capital.
5. Secure presence of (hard and soft) institutions;	Awareness building measures; information and education campaigns; public debates' lobbying, voluntary labels; voluntary agreements
6. Prevent too weak/stringent institutions	Regulations (public, private); limits, obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms
7. Stimulate physical, financial and knowledge infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs
8. Ensure adequate quality of infrastructure	Foresights: trend studies; roadmaps; intelligent benchmarking; SWOT (strength, weaknesses, opportunities and threats) analysis; sector and cluster studies;problem/needs/stakeholders/solution analyses; information systems (for program management or project monitoring); evaluation practices and toolkits; user surveys; databases; consultancy services; tailor-made applications of group decision support systems; knowledge management techniques; Technology Assessments; knowledge transfer mechanisms; policy intelligence tools (policy monitoring and evaluation tools, system analysis); scoreboards; trend boards

3.4. Sampling strategy

Selective sampling is a widely used technique in qualitative research which includes identifying and selecting individuals and groups that have the most knowledge on the subject of choice (Cresswell & Plano Clark, 2011). This method is subjective and therefore criteria have to be set up to select suitable interview participants (Palinkas et al. 2016). The criteria for the chosen interviewees is based on the structural actor elements from the TIS.

Interviewee works for:

- a CM start-up
- MNC or SME involved with CM
- an NGO involved with CM
- an innovation platform involved with CM

Interviewee is:

- a scientist/researcher working at a research institute/university/technology institute
- part of an CM consortium
- an investor in CM
- a journalist that reports on CM

In addition to the selective sampling method, the snowball sampling method was also implemented to acquire more participants for the research. Finding potential interviewees contributes to determining the structure of the CM in The Netherlands. Furthermore, interviews are useful for mapping actors since interviewees can point to further important actors within the TIS (Bergek et al., 2008). With the snowball sampling method, a researcher initially interviews a small group of relevant actors, which are then used to establish further connections (Bryman, 2014).

3.4.1 Selective sampling bias

Selective sampling is subject to bias because the researcher chooses participants based on certain qualities and knowledge. This might result in a biased view on the studied case. Furthermore, there is only a limited number of participants and that limits the generalization of the research (Bryman, 2014). To reduce the degree of selective sampling bias, various of actors with different expertise were interviewed to align with the structural element *actors* from the TIS. The range of actors include politicians, NGOs, public figures, non-profit organizations, and academics. The CM landscape in the Netherlands is still relatively small and 9 interviews is therefore a representative number. In addition, two interviews were held with actors from the PBMAs sector as the PBMA comparison is a part of the analysis. The interviewees were Jeroen Willemsen and Robin Haakmat, who both have played an important role in the development of PBMAs in The Netherlands. An overview of the interview participants can be found in Table 8.

Table 8. *Overview of interview participants*

#	Name	Position	Interview channel	Actor group
A1	Anonymous	Employee at large corporation	Microsoft Teams	MNC/SME
A2	Tjeerd de Groot	Member of the house of representatives. Party member D66	Phone	Government
A3	Peter Valstar	Member of the house of representatives. Party member VVD	Phone	Government
A4	Linsay Ketelings	PhD student – Maastricht University	Zoom	University
A5	Koert van Mensvoort	Public figure. Next Nature Network, In Vitro Bistro.	Zoom	Public figure
A6	Esther van Voorden	NVV (Dutch Society for Veganism)	Zoom	Non-profit organization
A7	Dwayne Holmes	Director, Responsible Research & Innovation, New Harvest	Google Meet	Non-profit organization
A8	Jeroen Willemsen	Innovation Lead Green Protein Alliance	Zoom	Organization
A9	Joey Cramer	Proveg International	Zoom	NGO
A10	Robin Haakmat	Senior Product Developer Vivera	Zoom	SME
A11	Cindy Gerhardt	Planet B.io and board member CANS	Zoom	Non-profit organization/ consortium

3.5. Data analysis

The interviews were recorded, transcribed, and coded in English or Dutch. The program used for transcribing is called '’Trint’', which automatically transcribed the interviews in Dutch or English. Each transcript was checked and reviewed to ensure that the transcription preserved nuances and details. If the flow of the respondent was not coherent enough, the distinction between the ending and beginning of sentences was adjusted and accounted for. The software used for coding is called '’NVIVO’'. The open coding approach with aspects of axial coding was used during the first iteration of coding. The tags were allocated on sentence level to reflect as much nuance as possible. The coding was done by the author and categories were based on the structural elements, seven system functions and systemic policy framework. For the questions related to PBMAs, separate codes were created. A full overview of the codes can be found in Appendix C.

3.6. Reliability and validity

Qualitative research is often critiqued for being too subjective or difficult to replicate, posing issues with generalization, and lacking in transparency. The reliability and validity of qualitative research depends on four criteria (LeCompte & Goetz, 1982, as cited in Bryman, 2014):

- *External reliability:* This is the degree to which the study can be replicated, and this is usually difficult as the social setting is dynamic.
- *Internal reliability:* If the research is conducted by several people, then what is being observed should be agreed on.
- *Internal validity:* Whether the researchers’ observations and the developed theoretical ideas correspond.
- *External validity:* The extent to which results can be generalized to other (social) settings.

During this research several methods were implemented to increase the validity of the findings. To attain internal validity, the triangulation methods was employed which means that several methods and sources are used (Bryman, 2014). For this research, both primary sources (interviews) and secondary sources (peer reviewed scientific articles, firms and industry association’s websites, policy reports, journal articles, publications, news articles, and reports) were used. Secondly, the respondent validation technique was employed during the last few interviews. The respondent validation process seeks to find verification from respondents to ensure that there is coherence between the researcher’s findings and the respondent’s perspectives and experiences (Guba & Lincoln, 1995, as cited in Bryman, 2014). The external validation was strengthened through the description of the research process, observations, and theoretical framework. The transcribing and quoting of interviews give the reader concrete observations (Guba & Lincoln, 1995, as cited in Bryman, 2014). Thirdly, all records of all phases of the research process are saved, which increases the trustworthiness of the research as external peers can audit whether the research has been conducted according to correct procedures (Guba & Lincoln, 1995, as cited in Bryman, 2014).

3.6.1. Notes on TIS framework

The context of the TIS and spatial aspects are still difficult to effectively integrate in the analysis (Markard et al., 2015). Setting up of boundaries is useful for the determination of which technology and what level of analysis should be used (Bergek et al., 2015). However, it is also considered as an analytical difficulty. It depends on the interests of the author and the type of analysis used, because boundaries can be set up in many ways and be adjusted during the research progress (Bergek et al., 2008; Carlsson et al., 2002). This TIS context critique suggests that the TIS framework lacks consideration for contextual factors such as complementary and competing technologies, landscape influences and socio-technical regimes. The emergence of complementary or competing technologies, and the influence of established technologies, could go unnoticed (Markard & Truffer, 2008; Wirth & Markard, 2011). The spatial critique explains that by focusing on a TIS in a selecting country or region there is the possibility to miss out on the foreign or global parts of the TIS that also contribute to the TIS performance. Variation of the context has consequences for the transferability of results but also for the applicability of the framework in research settings different from the ones in which the framework was originally developed (Blum et al., 2015; Schmidt & Dabur, 2014). For this research, European policy and technological developments in other countries such as the USA and Singapore are influential to the developments in the Netherlands. During this research, boundaries were limited to the Netherlands, but it is also acknowledged that international developments are influencing the TIS.

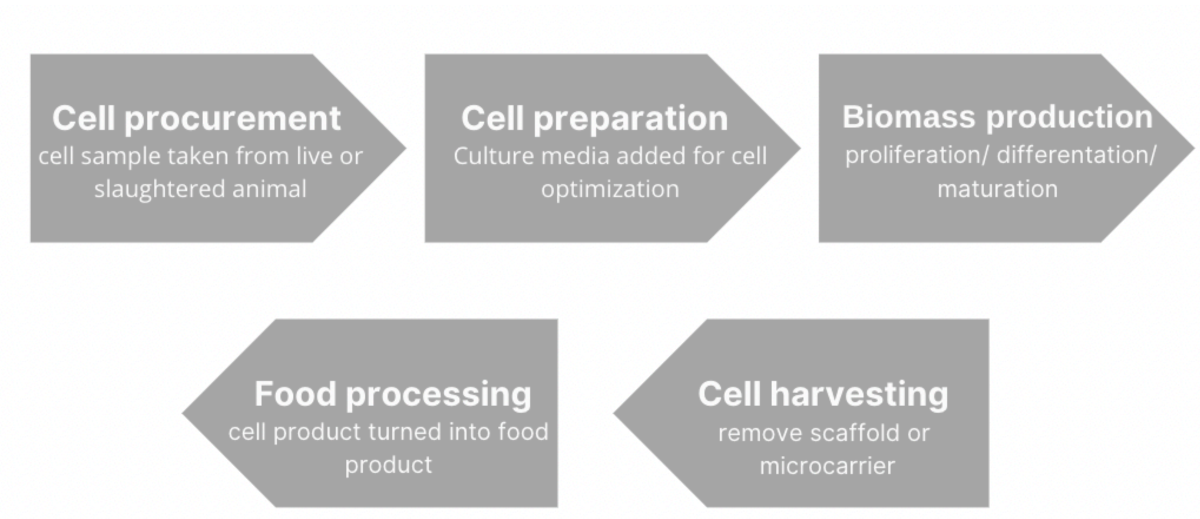
3.7. Ethical considerations

To protect scientific integrity, dignity, human rights and the collaboration between science and society, it is important that the participants in this research are safe, consented, and informed. A code of conduct is in place that covers issues of privacy, plagiarism, harm to participants and fraud that must be followed. The interviewees will be asked to fill in the informed consent participation form. Respect and dignity of the research participants was a priority, and it was in the researchers interest to ensure that full consent was obtained before conducting the interviews. By signing the consent form the interviewee agrees that the recorded audio will be used for scientific purposes, that they hold the right to withdraw the consent to use data, and that they can see the report afterwards. The interviewees were asked whether they wanted to remain anonymous or whether their name could be mentioned. At the end of the interview, the participants were asked whether they wanted to read how they were sourced in the research before submitting the thesis. This was done to avoid any misinterpretations and misrepresentations of the statements made by the participants. Transparency about the aims and objections of the research was ensured. The goal of this research is to analyze the CM TIS of the Netherlands and set up (policy) recommendations to transition the TIS into the growth phase. Therefore, it is important that any exaggeration, deception, misleading representation of data and bias is avoided.

4. Background description of the technology
This section outlines the production process of CM and PBMAs.

4.1. Cultured meat production process
The manufacturing process of CM is complex and varies per manufacturer (Ong et al., 2021). However, the article by Ong et al. (2021) presents a clear and brief overview of a general CM production process. The process starts with obtaining cells from live or slaughtered animals. Several cell types can be used, as described in section 4.2 ''cells''. Then, the cells are prepared and optimized by adding culture media (see section 4.3 ''culture media'') and transformed into the selected starting cell types. The next step is cell proliferation, differentiation and/or maturation. Depending on whether the cell is anchorage dependent, which means that the cell needs to be attached to an inert surface to proliferate (Williams, n.d.), the cells are attached to a scaffold or carrier (Ong et al., 2021). These could be, for example, a collagen meshwork or microcarrier breads that are immersed in a plant-origin growth medium inside a rotating or stationary bioreactor. Subsequently, the stem cells are transformed into myofibers, which are then turned into the product (Kosnik et al., 2003). The scaffold acts as structural support and provides oxygen and nutrients. Conjointly with the cell culture media, scaffolds control how the cell populations grow and differentiate (GFI, n.d.). Without the scaffold the meat will likely end up like a mush (Southey, 2021; GFI, n.d.). After the cells are at the desired biomass, they are harvested and processed. During harvesting, the scaffolds and microcarriers are removed. Food processing entails the transformation into food products. The cell-cultured product might be mixed with flavors, binders, additives for example, to end up as a commercial food product (U.S. Government Accountability Office, 2020; as cited in Ong et al., 2021). Figure 5 illustrates an overview of the manufacturing process.

Figure 4. *Overview of the CM manufacturing process (Ong et al., 2021)*



4.2. Cells

There are two types of stem cells: multipotent stem cells and pluripotent stem cells. The difference between multipotent and pluripotent stem cells is that the latter can form into any type of cell, while multipotent stem cells can only form specific type of cells in the body (Osborn, 2019). Multipotent stem cells are derived from post-birth umbilical cords, placentas, and body tissues and are only capable of creating the same type of tissue cells from which they originated. Pluripotent cells are derived from pre-embryos and created by the in vitro fertilization process and can be grown into any tissue type (Knoepfler, 2021). Several types of cells are suggested for CM production, such as myosatellite cells, adult stem cells, embryonic stem cells (Sharma et al., 2015; Suresh, 2018). Myosatellite cells, a type of multipotent cells, are found in mature muscle, are considered and are the most suitable type of cell because they efficiently differentiate into myotubes and mature myofibrils (Post, 2012).

Meatable licensed the OPTi-OX technology (Zaringhalam, 2021). With this technology, an induced pluripotent stem cell can be engineered for any specific cell, in this case a muscle or fat cell (Luining, 2020). The technology allows for consistent and homogeneous production of cell batches in a handful of days (Davenport et al., 2020). Genetic intervention is included because the pluripotent cells can be converted into any cell type (Sharma et al., 2015; Zaringhalam, 2021). Furthermore, pluripotent cells do not need Fetal Bovine Serum (FBS) or growth (Zaringhalam, 2021). Previously it was difficult to obtain pluripotent cells as they originate from pre-embryos. Yamanaka and Takahashi (2006) discovered four specific genes encoding transcription factors that made it possible to convert any adult somatic cell into pluripotent cells, called the 'induced pluripotent stem cell' (iPSC). Induced pluripotent cells also remove the need for a microcarrier or surface for the cells to attach at the time of the initial proliferation phase, which enables Meatable to reduce the costs. Furthermore, Meatable is integrating an edible scaffolding into the end-product. Thus, the main changes that Meatable are implementing are to advance the cell proliferation speed by refining the cell culture medium, which will reduce costs as well (Cell Based Tech, n.d.)

4.3. Culture media

The nutrition for the tissue is composed of the culture media and growth factors. Cell culture media consists of essential nutrients such as glucose, inorganic salts, water-soluble vitamins, and amino acids. It also contains recombinant proteins, growth factors or hormones, lipids, and antioxidants, which ensure the proliferation, differentiation and maintenance of the cells (Good Food Institute, n.d.). The serum that is commonly used as culture media stems from adult, newborn, or fetal sources (Coecke et al., 2005), which contradicts the ethical reasonings of CM with regards to animal welfare. Animal serum-free growth media also obsoletes the risk of disease and reduces costs (Froud, 1999). Therefore, companies are actively looking for ways to replace FBS. Meatable and Mosa Meat have successfully removed FBS from their product (Meatable, 2019b; Messmer et al., 2022). Culture media and growth factors are expensive and Meatable and Mosa Meat are researching how to produce cost-effective growth factors (Ho, 2022; Nutreco, 2021).

4.4. Hybrid products

Several CM companies, including Meatable, have started to produce hybrid products, hereby speeding up market introduction (Meatable, 2022a; Garwood, 2022). Hybrid products consist of both CM and plant-based ingredients. Introducing hybrid products can possibly prompt consumers to be comfortable with the idea of CM. Additionally, hybrid products are less complex and expensive to produce, and less regulatory barriers prevail to market introduction (Garwood, 2022; Sawers, 2022).

4.5. Technological barriers

There are several technological barriers that must be overcome for CM to be produced on a larger scale, while simultaneously being economically viable and profitable (A1; A11). Within the sector there are opposing conclusions on the technological and economic viability of CM. Two of the most recent technological economic analyses (TEA) by Humbird (2021) and by Sinke et al. (2021) have different conclusions regarding the technological and economic viability of CM. While Sinke et al. (2021) argue that CM can be economically viable by 2030, Humbird (2021) strongly claims that given the difficult biological aspects of growing animal cells, the CM price will not be lower than $25 per kg, and not be economically viable by 2030. According to Sinke et al. (2021), the current production costs of CM are between 100 to 10,000 times higher than conventional meat production. The price can be reduced from $10,000 per kilogram to $2.50, given that reductions are made in all aspects of production. The following conditions are important for the price to drop:

1. The use and production costs of medium ingredients, especially growth factors and recombinant proteins, should be reduced. If the demand for growth factors increases, then the costs are likely to lower. Cell growth media components such as amino acids, glucose, protein micronutrients, and plant protein hydrolysate are costly (Humbird, 2021; Fassler, 2021; Sinke et al., 2021). A viable alternative for the amino acids is soybean hydrolysate, but cheaply sourced soy is not sustainable (Fassler, 2021). Potato protein could serve as an alternative, and food-grade amino acids achieve the same as pharma-grade sources (Specht, 2021). More research is needed to find suitable growth media components (Humbird, 2021; Sinke et al., 2021).
2. The equipment costs for perfusion reactors need to be lowered. With increasing demand for bioreactors, prices are expected to go down (Sprecht, 2021).
3. Choosing favorable cell types and improving the production process can also help lower production costs. For example, larger cell volumes produce more meat cell mass, and a shorter production time can lower energy demand. The latter does lower the quality. Thirdly, maximum energy efficiency will result in lower production costs.
4. Investing in sustainable energy will be more cost effective in the future.
5. Collaborations within the supply chain can lower impact and production costs of all substances and input parts for CM.

However, the technological and economic challenges might be more stringent than Sinke et al. (2021) presents. Several barriers prevail with regards to bioreactor design, thermodynamics, cell metabolism, ingredient costs and facility construction (Humbird, 2021; Fassler, 2021). The costs will likely be higher than presented by Sinke et al. (2021) due to technological and biological limitations (Humbird, 2021; Fassler, 2021). The GFI commissioned report assumes that food-grade hygiene standards and inputs are used (Sinke et al., 2021). Humbird (2021) argues that animal cell culture cannot be manufactured at a large-scale with food-grade standards as there is a high risk of cell contamination. Cleanliness of the environment, media and equipment are critical at every stage of the cell-culture process. The large amount of safety measures required for animal cell culture increases the cost of the facility and equipment. Any bacteria in a cell turns into a contamination event due to the multiplying rate of bacteria versus animal cells (20 minutes – 24 hours) (Humbird, 2021; Fassler, 2021). Since the animal cells do not have an immune system, viruses also pose a threat (Moody et al., 2011). Pharmaceutical-grade inputs and equipment are more expensive and will therefore increase the costs of the facility. Humbird (2020) argues that a Class 8 clean room is needed, which costs between $40 and $50 million. In addition, this type of room only holds 12- 20000-liter bioreactors, or 96 smaller perfusion reactors. This is a stark reduction compared to the envisioned hypothetical plant by GFI with 130 fed-batch bioreactors and 430 perfusion reactors (Sinke et al., 2021; Fassler, 2021).

Growing animal cells requires specific conditions and has proven to be extremely difficult. Microbial bioprocess technologies such as yeast and fuel ethanol can be produced in large production volumes. However, this cannot be compared to industrial bioprocess designs of animal cell culture. Firstly, the growth rate of animal cells is slower than microbial cells. Secondly, bioreactor volumes for animal cells are smaller: they cannot be cultured in bioreactors that are larger than 25 m^3, compared to the 200-1000 m^3 bioreactors that are used for industrial aerobic fermentation. Thirdly, the final cell density of animal cell culture is lower. This means that more bioreactors are needed for production, meaning production costs will rise (Humbird, 2021). These engineering constraints of bioreactor size, proliferation rate and the lower cell density result in higher production costs compared to microbial fermentation processes (Humbird, 2021).
In addition, a bigger bioreactor cannot deliver to the cells the appropriate amount of nutrients and oxygen. A proposed solution is to increase stirring or add more oxygen, but this can result in batch failure as animal cells can easily be ruptured due to rising air bubbles, cell-to-cell collisions, and rotating impellers (Tramper, 1995).

Thus, simply creating a bigger bioreactor will result in batch failure as there are several limitations to the nature of the cells. Because the cells are wild-type cells and cultured outside of the animal's body, inefficiencies likely are to occur (Lindskog, 2018). Animal cells secrete catabolites, including ammonia and lactate. These compounds are toxic and slow down cell growth. The accumulation of toxic catabolites inhibits bulk cell mass (Hassell et al., 1991). The catabolite inhibition can be alleviated, but the correct bioreactor volumes are lower (Humbird, 2021). Companies are actively researching ways to mitigate this problem and are implementing some form of recycling or metabolic shunting (Sprecht, 2021). To conclude, CM needs to be produced on a large scale and ingredient costs must lower for it to become more economically viable. This remains challenging due to the specific conditions animal cells grow in. The environment must be clean, and bioreactors cannot simply be made larger as this may result in batch failure. More R&D needs to be conducted to find solutions for the previously described technological barriers.

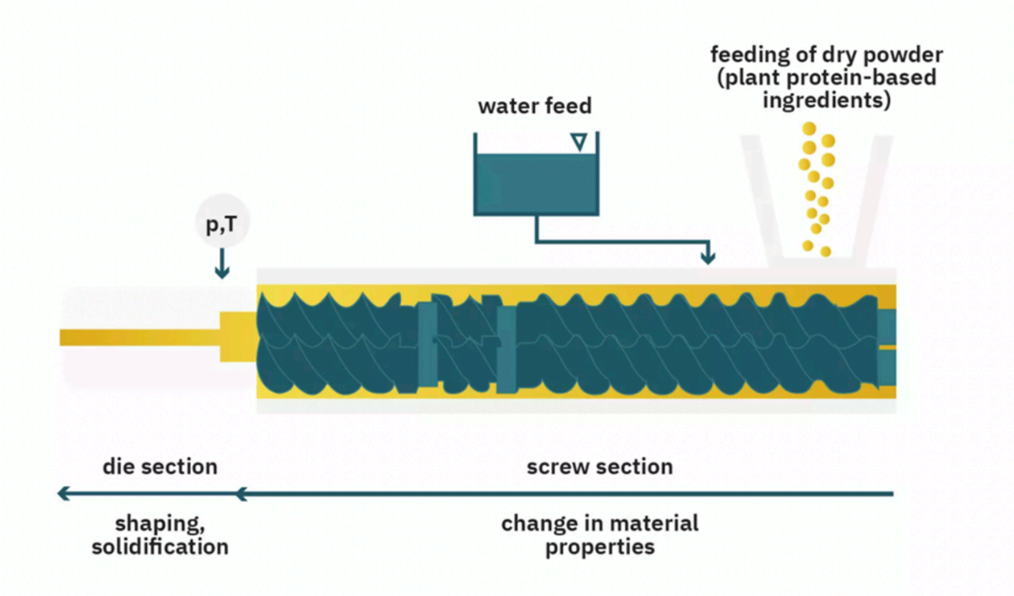
4.6. PBMAs production process

PBMAs are meat alternatives based on plants and other non-animal-based products. They are meant to mimic the flavor, texture, and appearance of conventional meat (Kumar et al. 2017). Soy, wheat gluten, mushrooms and pea proteins are common main ingredients (Krosofsky, 2021). A typical meat replacement is made from water (50%-80%), textured vegetable proteins (TVP) (10%-25%), nontextured proteins (4%-20%), flavorings (3%-10%), fat (0%-15%), binding agents (1%-5%) and colorings (0%-0.5%) (Egbert & Borders, 2006).

Extrusion is the dominant production technology used to produce PBMAs. There are two types of extrusion processes used: Low Moisture Extrusion Cooking (LMEC) and High Moisture Extrusion Cooking (HMEC)(Lin et al., 2000). The production process is as follows: The food materials are prepared and added to the extruder. Then, ingredients are mixed and cooked to create a homogeneous texture. Lastly, the product is cooled in a dye to preserve its final form (Kyriakopoulou et al., 2019). LMEC is suitable to produce Textured Vegetable Proteins (TVPs) (Berk, 1992; Riaz, 2011). Textured vegetable proteins (TVP) are derived from vegetable proteins and mixed with minor ingredients or chemicals. These are usually in the form of defatted flours. Pulse seeds such as lentils, peas, faba beans and peanuts are also used for TVP production (Kim, 2018).

PBMAs producers have improved the meat-like qualities of PBMAs with regards to taste, appearance, aromas, and nutritional profile (A8; A10). The nutritional content of these alternatives shares more similarities with meat compared to the previous TVP based products. Certain innovations were implemented to mimic meat characteristics. Beet juice is being used to make the burger ‘'bleed'' (Kenji López-Alt, 2019). Soy leghemoglobin is an iron rich heme and adds the unique flavor of meat that is released during the cooking process. It also gives the burger a red color (Dhuey, 2022). As for the production process, HMEC is used for these more advanced PBMAs since it creates a more meat-like texture and flavor (Green, 2020). The setup for HMEC is illustrated in Figure 6. The meat has a fibrous structure, and the moisture content is around 60-70%. The process is like LMEC, but more water is added during the production process (Kinney et al., 2019)

Figure 5 Setup for High Moisture Extrusion Cooking (Good Food Institute, 2022)



5. Structural analysis

The first step of the analysis was to map the structural elements of the CM TIS. The structural elements are actors, institutions, interactions, and infrastructure (Hekkert et al., 2007; Bergek et al., 2008; Hekkert et al., 2011; Wieczorek & Hekkert, 2012).

5.1. Actors

Actors can be divided into civil society, start-ups, SMEs, MNCs, knowledge institutes, the government, NGOs, legal organizations, financial organization/banks, intermediaries, knowledge brokers and consultants (Wieczorek & Hekkert, 2012). An overview of the actors can be found in Table 9.

Table 9. *Overview of actors*

Actors	Name
Civil society	Public figures (Ira van Eelen, Mark Post, Koen van Mensvoort) Religious communities (Jewish, Islamic, Hinduism, Christian) Vegan/Vegetarian organizations (Nederlandse Vereniging voor Veganisme; Vegetariersbond, Proveg) Environmental organizations (Natuur en Milieu; Greenpeace)
Start-ups	Meatable Mosa Meat RESPECTfarms Cultured Blood
SMEs / MNCs	DSM (MNC) Nutreco (SME) CELL-tainer
Knowledge institutes (universities, technology institutes, research centers, schools)	Maastricht University (UM) Wageningen University & Research (WUR) TU Delft Utrecht University (UU) University of Amsterdam (UVA) Eindhoven University of Technology (TU/e) Brightlands Maastricht Health Campus Cellular Agriculture Netherlands Foundation (CANS) New Harvest
Government	Ministry of Economic Affairs and Climate Policy (EZK) Ministry of Health, Welfare and Sport (VWS) Dutch Food Safety Authority (NVWA) Ministry of Agriculture, Nature and Food Quality (LNV) Netherlands Enterprise Agency (RVO) European Food Safety Authority (EFSA) European Space Agency (ESA) Tjeerd de Groot Peter Valstar
NGOs	Proveg Good Food Institute Europe (GFI Europe)
Legal Organizations	Planet B.io (nonprofit/innovation hub) Kindearth.TECH (nonprofit) CANS (consortium)
Financial organizations/banks	N/A
Intermediaries	N/A
Knowledge brokers	Planet B.io Kindearth.TECH New Harvest
Consultants	CE Delft

5.1.1. Civil society

Civil society is often defined as individuals or organizations that are independent from the government and are serving the will and interests of society. Often, civil society is considered the third sector of society as it has the power to influence the decisions that politicians and businesses make (Jezard, 2018). The following subsection outlines important public figures, religious communities, vegan/vegetarian organizations, and environmental organizations.

Public figures

Three prominent CM advocates were identified: Ira van Eelen, Dr. Mark Post and Koert van Mensvoort and Mark Post. Ira van Eelen is the daughter of CM inventor, Willem van Eelen, and is advocating for her father's legacy (Rafferty, 2020). She is a board member of the CANS, co-founder of Kindearth.tech, advisor for the American CM company Eat Just, and co-founder of RESPECTfarms (KindEarth.Tech n.d.). Her father's vision was to bring awareness to the farmer's importance and explore the possible roles for them in the transition (RESPECTfarms, n.d.). Dr. Mark Post is a pharmacologist Professor of Vascular Physiology at Maastricht University (''M.J. Post'', n.d.) and CSO of Mosa Meat (Rodriguéz Fernández, 2017). He gained public prominence after presenting the first CM burger in 2013 (Rodriguéz Fernández, 2017). Post co-authored many scientific articles on CM (see section 6.2.2. ''Number of publications''). Koert van Mensvoort is a philosopher, artist, scientist, and founder of *Next Nature Network.* Mensvoort has been vocal about CM for over 10 years (A5). He has written *The Invitro Meat Cookbook* (A5), gave a TED-talk on CM (van Wilgenburg, 2017) and founded *Invitro Bistro*, the first virtual CM restaurant (Winston, 2015).

Religious communities

There are 1.8 billion Muslims, 1.1 billion Hindus, 2.4 billion Christians and approximately 10 million Jewish people worldwide. (Awang, 2019; World Population Review, 2022). This signifies a large percentage of the human population, and therefore it is important to consider religious views when CM becomes widely commercialized (Hamdam et al., 2021). Most religions have special dietary rules (Chouraqui et al., 2021). For example, Muslims are only allowed to eat halal food, and Jewish people can only eat food that is certified kosher (Patience, 2016). Views on the consumption of CM differ per religion. Some Christians and Muslims consider CM to be against the law of nature (A2; Gross, 2014). Muslims follow the *halalan tayyiban* diet. For CM to be accepted four requirements must be fulfilled: 1) the cells must be taken from animals that are slaughtered according to halal rules, and pig remains forbidden, 2) consumption is forbidden if the cells are taken from a live animal (Hamdam et al., 2018), 3) blood or animal-based serums and/or growth enhancers are also not accepted (Awang, 2019), 4) CM must go through halal certification (Hamdam, 2021).

Jewish people abide by the dietary law called kosher. There is a divide amongst rabbis whether CM can be consumed and whether it should even be considered meat. If it would be defined as ''cloned meat'', then CM can be consumed without restrictions. Even cultured pig meat can be consumed, which is normally prohibited. For it to be allowed for consumption, CM must adhere to kosher laws (Kenigsberg & Zivotofsky, 2020). Hindus do not have a central authority or rule of law, but most adhere to either of the following three diets: vegetarian, lacto-vegetarian and non-vegetarian. Cows are holy and are therefore prohibited for consumption. Views on CM differ, as some Hindu scholars would not accept CM since the use of animal cells is seen as ''an example of human arrogance'' and because animal cells are still used for the production (Gross, 2014; Sugden & Malhotra, 2013). Other Hindu scholars have accepted CM if the *ahimsa* principle is taken into consideration, which means ''not to injure'' or ''compassion'' (Jagadeesan & Salem, 2020). In conclusion, there are many different religious views on CM, but it is important that CM adheres to religious standards so that consumers who practice religious diets can also consume CM.

Vegan and vegetarian organizations

Two of the biggest vegan and vegetarian organizations, The Dutch Vegan Society (NVV) and the Dutch Vegetarian Society (''Vegetariersbond'') are not advocating for CM. NVV firmly stands against CM because it goes against the ethical values of veganism (A6). Vegans abstain from the use of any product that stems from animals (NVV, n.d.). NVV is against CM because animals are used for the production (A6). The Dutch Vegetarian Society also does not see the need for CM, as they believe a vegetarian diet offers enough choices and CM is not yet advanced enough (Vegetariersbond, n.d.).

Environmental organizations
Environmental organizations do not have a firm stance for or against CM. Greenpeace published one article on CM (Greenpeace Belgium, 2018). Nature and Environment (''Natuur & Millieu) does not have an outspoken stance on CM (Bas Kraaijeveld, personal communications, August 17, 2022).

5.1.2. Start-ups
Four start-ups are present in The Netherlands: Mosa Meat, Meatable, RESPECTfarms and Cultured Blood. Meat was founded in 2016 by Dr. Mark Post and Peter Verstrate. Meatable was founded in 2018 by Krijn de Nood, Daan Luinig and Mark Kotter. Their main products are pork and beef (Meatable, 2022a; Behne, 2021). Before the company was officially established, Mosa Meat's main scientist Mark Post introduced the world's first CM burger in 2013 (Dent, 2020; Saigol & Keown, 2020; Edwards, 2021), and therefore the company is regarded as a pioneer (Snoeck, 2021). Cultured Blood was founded in 2018 by Robert ten Hoor with the aim to produce blood for the CM sector. The company is creating an artificial blood circulation system. Cultured Blood is looking for seed capital, and it is unclear from the website how far the company is progressing with developing an artificial blood circulation system (Cultured Blood, n.d.). RESPECTfarms was founded by Ira van Eelen and Ruud Zanders. The start-up is developing a proof-of-concept farm that strives to close the gap between scientists and farmers. In addition, R&D and knowledge sharing is stimulated (RESPECTfarms, n.d.).

5.1.3. SMEs and MNCs
There are currently no SMEs or MNCs privately producing CM, but two Dutch companies are investing and collaborating with Mosa Meat and Meatable.

DSM and Meatable
Meatable started a joint development agreement with DSM, a Dutch multinational corporation in the field of health, nutrition, and materials (DSM, n.d.; Meatable, 2021). The MNC has also invested in Meatable. Through their collaboration they aim to obtain patentable findings that will make CM production on a large scale affordable (Meatable, 2021).

Nutreco, CELL-tainer and Mosa Meat
Nutreco is a Dutch animal nutrition, aqua feed and processed meats producer and has invested in Mosa Meat for their Series B funding (Byrne, 2013). In addition, the company has partnered with Nutreco to lower the costs of cell growth media. Nutreco supplies feed- and food-grade byproducts from Nutreco's supply chain, which decreases the costs and increases the sustainability of CM. The companies have received a 2 million dollar grant in 2020 from the European REACT-EU for their ''Feed for Meat'' project (Nutreco, 2021). In 2020, CELL-tainer announced a collaboration with Mosa Meat to develop a bioprocess platform to produce CM on a larger scale (CELL-tainer, 2020)

5.1.4. Knowledge institutes
Several knowledge institutes are involved within the CM sector.

Wageningen University and Research
The Wageningen University and Research (WUR) is a university specialized in different areas of environmental, food, health, and sustainability sciences (Wageningen University and Research, n.d.). WUR has been involved in the protein transition in various ways. For example, The Wageningen Alternative Protein Project was initiated by students in 2020 and advocates for the R&D of various protein alternatives such as plant-based proteins, CM and precision fermentation. The project has been supported by the Good Food Institute (GFI), which is an international non-profit that promotes plant-based and cell-based protein alternatives (The Green Office Wageningen, 2020). WUR has published the largest amount of academic research papers on CM, mainly focused on the social and environmental aspects of CM[1].

[1] A Scopus search on the terms "cultured meat" OR "cultivated meat" OR "In vitro meat" between 1994 and 2022 yields in 20 publications by WUR researchers

Maastricht University & Brightlands Maastricht Health Campus
Maastricht University (MU) is a public research university that is involved in the research on CM. Maastricht University was able to receive funding from Sergey Brin to continue research on CM, with the POC burger being presented in 2013 (Hemphill, 2020). The university publishes academic research papers on CM[2]. The Brightlands Maastricht Health Campus is an open innovation community in Limburg affiliated with Maastricht University and hosts pilot facility and workspace for Mosa Meat (Mosa Meat, 2022a; Brightlands Maastricht Health Campus, n.d.).

Biotech Campus Delft, Planet B.io & Kadans
Biotech Campus in Delft is an open innovation platform and hosts Meatable (Biotech Campus Delft, 2019; A11). Planet B.io is a non-profit organization that provides information and infrastructure via Biotech Campus Delft (A11). They offer low-cost space to start ups, such as Meatable in this case. They are actively involved with companies to accelerate their growth. Politicians regularly visit Planet B.io to talk about regulation hurdles (A3; A11). In October 2022, Meatable announced a partnership with Kadans. Kadans offers tailorized workspaces for innovative companies. Meatable will be hosted at one of their locations, Ultra Plus Leiden, where they will double their laboratory and office space (Kadans, 2022)

New Harvest
New Harvest is a non-profit research institute founded in 2004, focused on the advancement of cellular agriculture (CA) by supporting and funding research projects and educational opportunities, and by creating bridges between stakeholders (New Harvest, n.d.). The institute is planning to open an office in The Netherlands (A7). Recently, the non-profit has become a member of the CANS (Dwayne Holmes, personal communications, September 20, 2022)

Cellular Agriculture Netherlands Foundation (CANS)
All of the abovementioned institutes are part of the CANS, a foundation consisting of scientists, universities, entrepreneurs, and organizations that see CA as a means to make the food system more sustainable. The consortium has presented their growth plan to the Dutch government and secured a €60 million investment, with the possibility of an extra 25 million (Schuengel, 2022; CANS, 2022). More information about CANS can be found under 5.3.1. ''CANS network''.

5.1.5. Government
There are several ministries and governmental bodies involved with CM: Ministry of Economic Affairs and Climate Policy (EZK), The Ministry of Health, Welfare and Sport (VWS) and The Ministry of Agriculture, Nature and Food Quality (LNV), the Dutch Food Safety Authority (NVWA), Netherlands Enterprise Agency (RVO), the Dutch Research Council (NWO), and European Food Safety Authority (EFSA). In addition, Tjeerd de Groot and Peter Valstar are politicians who have made a significant impact on the regulatory landscape in the Netherlands.

Governmental bodies
The EZK oversees economic growth, climate and energy, and technological innovation (EKZ, n.d.). In 2022, minister Micky Adriaansens announced that the NGF, an initiative of EKZ, is providing funding of €60 million for research, innovation, and education in the field of CA (Schuengel, 2022). The VWS oversees health care, social work, sport, quality of life and public health. Their role is to ensure food safety with regards to CM (VWS, n.d.). The LNV is involved in agriculture policy, food policy and safety, animal welfare, nature conservation, fisheries, and forestry (LNV, n.d.). The LNV aims to increase the production and consumption of alternative proteins, including CM. The NVWA is an agency of LNV and concerned with food safety, and checks whether companies comply with laws and regulations (Rijksinspecties, n.d.). The EFSA is an agency of the European Union that is concerned with the protection of consumers, the environment, and animals from food related risks (EFSA, n.d.). The EFSA needs to approve CM before it can enter the market. The Dutch Food Safety Authority (NVWA) is concerned with food safety and checks whether companies comply with laws and regulations (Rijksinspecties, n.d.). The RVO is an agency of the Dutch government and aids businesses in running a sustainable, innovative, and international business. The Dutch government aims to create a favorable business climate by creating specific policies, which RVO implements. The aim of the RVO is to create a strong position for the Netherlands in the CM and

2 A Scopus search on the terms "cultured meat" OR "cultivated meat" OR "In vitro meat" between 1994 and 2022 yields in 16 publications by MU researchers

alternative protein sector. Between October 24th and 28th 2022, the RVO organized the Singapore International Agri-food Week for actors from within the CA and alternative proteins industry to explore the equal collaboration between researchers and businesses with research and development of alternative proteins (RVO, 2022). The NWO (The Dutch research institute) recently awarded Meatable and their partners 1 million euros to conduct R&D into scalability and cost-effectiveness of elastin-like polypeptides and non-animal derived collagen (Meatable, 2022b)

European Space Agency
The ESA is researching whether the CA techniques could be applied in space missions to produce food for astronauts, in particular CM. Two teams were selected to work on the project: one consisting of German company Yuri and Reutlingen University, and the other of three UK companies Cellular Agriculture, Kayser Space and Campden BRI. Whilst these are not Dutch companies, the research has been initiated by ESA engineer Paolo Corradi, who is based at ESA Noordwijk (ESA, 2022)

Tjeerd de Groot and Peter Valstar
In March, a motion was submitted by politicians Tjeerd de Groot and Peter Valstar to allow CM tastings, which was approved by the House of Representatives (A2; A3). Currently, conversations between Mosa Meat, Meatable and De Groot are taking place about the possibilities of the tastings. The VWS is investigating the additional information about the conditions that was submitted by De Groot (Staghouwer, 2022).

5.1.6. NGOs
NGOs are (usually) non-profit organizations that are independent from the government. They are important actors because they often achieve a high degree of public trust (IISD, n.d.). Proveg is a worldwide food awareness organization with the goal to reduce animal consumption by 50% by 2040 (Proveg, n.d.; A8). Proveg is currently the only NGO in the Netherlands that is advocating for CM (A8). The NGO is actively promoting CM by publishing articles and hosting webinars on CM. Furthermore, Proveg initiated the CellAg Project with the objective to increase the awareness of cellular agriculture (Cullen, 2021). CellAg also works on building cross-sectoral networks and promoting collaboration within the sector (Proveg, n.d.). Lastly, Proveg Incubator is the business incubator which supports vegan startups, including cellular agriculture businesses (Ettinger, n.d.). The Good Food Institute Europe (GFI Europe) is an NGO which aims to ''*build a more sustainable, secure and just food system by transforming meat production*.'' (GFI Europe, n.d.). The GFI commissioned the ''LCA of cultivated meat'' report written by Odegard and Sinke (2021) at CE Delft.

5.1.7. Legal organizations
KindEarth.Tech (KET) is a privately funded non-profit organization that focuses on the protein transition through in-person and digital events. The non-profit is based in the Netherlands and the United States of America. KET has organized events in Amsterdam with speakers from alternative proteins related actors, including Mosa Meat and Meatable. Planet B.io is a non-profit organization located on the Biotech Campus Delft that promotes industrial biotechnology by sharing biotech knowledge and infrastructure. The non-profit creates a unique hub for biotechnology start-ups by giving access to the biotech ecosystem of Delft and stimulating R&D (Lucas, 2020). Meatable was the first start up to settle with Planet B.io (Biotech Campus Delft, 2021)

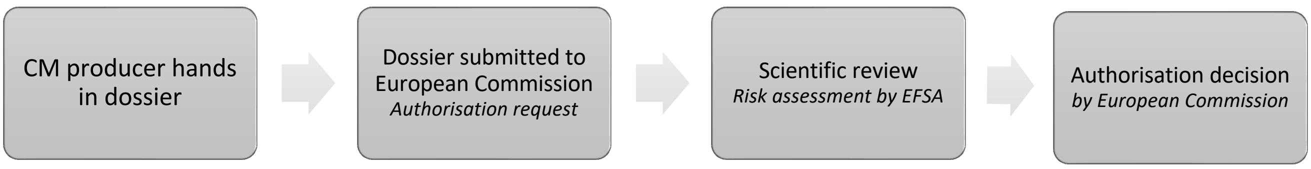
5.1.8. Consultants
CE Delft is an independent research and consultancy firm, specialized in developing innovative solutions for environmental and sustainability challenges. Along with GFI, GAIA has commissioned the ''LCA of cultivated meat'' (Vergeer et al., 2021) and ''TEA of cultivated meat'' (Sinke & Odegard, 2021) reports at CE Delft.

5.2 Institutions
The second structural element of the TIS are institutions, because they have influence over the speed and direction of diffusion of technologies (Hekkert et al., 2011). Institutions can be divided into two types: formal and informal. Formal institutions can be defined as codified rules, laws, and regulations by an authority, which mold the interactions between people (North, 1990). The motivation to follow the rules comes from norms, which are socially constructed behavioral standards and beliefs. Social norms and values that influence the way people think and behave are informal institutions (Greif, 2006).

5.2.1. Formal institutions

Dutch companies must adhere to European laws and regulations, and CM specifically to No 2015/2283: the *Novel Foods Regulation* (NFR). The NFR went into effect on January 1st, 2018. The European Food and Safety Association (EFSA) classifies Novel Foods as: ''Food that had not been consumed to a significant degree by humans in the EU before 15 May 1997, when the first Regulation on novel food came into force.'' (European Commission, n.d.). The regulation requires novel foods to be tested for safety and quality by the EFSA. The application process takes two years, and all European member states must agree to the admission of CM onto the European market (van Dinther, 2018; Kessel, 2018). Figure 7 outlines the Novel Foods procedure. First, the novel food application must be sent to the European Commission (EC). Based on the submitted application and the scientific dossier, The EC requests the EFSA to conduct a risk assessment (European Parliament and Council of the European Union, 2015). The dossier that has been handed in should include scientific evidence on the nutritional, kinetic, allergenic, and toxicological properties proving that the novel food is safe for consumption (de Boer & Bast, 2018). Then, EFSA conducts the risk assessment (de Boer & Bast, 2018) and the last decision is made by the EC (European Parliament and Council of the European Union, 2015).

Figure 6. *The centralized authorization procedure under Regulation 2015/2283 (NFR) and 2015/412 (GMO) (Ketelings et al., 2021)*



The assessment of CM is complicated since there is a lack of scientific research on its safety (A4; Ketelings et al., 2021). CM companies must establish their own safety procedures because there is no standard safety procedure guideline yet (A4; A7). Assessment procedures will be based on hypothetical situations, as currently there are no large-scale production facilities built (A4; Ketelings et al., 2021). Therefore, it is complicated to predict which risks, hazards and effects might occur. For example, the environment in which the cells grow is never completely controlled, which can result in unexpected biological hazards (Chriki & Hocquette, 2020). In 2021, New Harvest published a paper which detailed the potential hazards that could occur during the production process. Existing safety assessment approaches were evaluated, and research priorities were highlighted (Ong et al., 2021).

If the production process includes genetic modification of stem cells, then the product has to be authorized by the EU (European Parliament and Council of the European Union, 2003). Companies must be aware of hygiene and labelling regulations after the EFSA approval (Ketelings et al., 2021). The NVWA considers the safety and labelling after CM has been approved by the EFSA. ''As soon as the company has demonstrated the safety of the product to the European Union, the CM can be introduced to the market and therefore be served in the restaurant.'' (NVWA, 2018). The NFR is seen as one of the barriers to commercialization according to experts (A1; A2; A3; A4; A5; A9) The outcome of the NFR procedure can have influence on the informal institutions. It is important that the market introduction goes well. ''*There is only one chance to bring this product to the consumer. If something goes wrong during the introduction, and it goes viral for example, then nobody will want it anymore. You will have missed your chance, including the millions, or even billions, of euros that have been invested.*'' (A4)

5.2.2. Informal institutions

There has been a growing awareness of environmental, ethical, and human health issues caused by meat production (Bryant & van der Weele, 2021). Consequently, there has been an increasing interest in meat alternatives (Gerber et al., 2013). With CM coming closer to commercialization, there is a growing body of research looking into consumer habits and consumer acceptance of CM (Bryant and Barnett, 2020). Consumer trust is regarded as one of the most important prerequisites for establishing a market for credence goods (Nuttavuthisit & Thøgersen, 2017) and success depends for a large part on consumer acceptance (Pakseresht et al., 2022). Few studies and surveys have been conducted on the public opinion on CM in The Netherlands. A summary of the findings of these studies is given in the following paragraph.

Positive information, previous awareness and knowledge had a positive effect on acceptance of CM (Verbeke et al. 2015; Rolland et al. 2020). Van der Weele and Driessen (2019) found that there is a high level of ambivalence and ambiguity surrounding both conventional meat and CM. Participants named several disadvantages concerning CM, such as the costs, uncertainties, and artificiality (Rolland et al., 2020). Survey respondents agreed that CM would have a negative effect on farmers. The ending of traditional farming, and cultural traditions such as Sunday roasts and barbeques, was not favored (Bekker et al., 2017). The greatest perceived benefit was the reduction of animal suffering, environmental benefits less so. Unlike other studies, sex and social economic status did not play a significant factor in determining different acceptance rates (Rolland et al., 2020). Surprisingly, Rolland et al. (2020) found that 58% were willing to pay a higher price for CM, up to 37% above the price of conventional meat. Price of CM should be the same, if not lower than conventional meat (A1; A10). The study by Grasso et al. (2019) found that amongst the older population (65+) only 6% accepted CM. The most popular alternative to animal protein was plant-based protein (58%). However, compared to participants from other countries, Dutch participants were much more likely to eat CM. Consumer acceptance is one of the barriers that must be overcome for commercial success (A4). However, after consumers are informed on the perceived benefits of CM, they were more likely to try CM (Rolland et al., 2020; van der Weele and Driessen, 2019). It is expected that CM will be accepted by consumers, provided that the price and taste are acceptable (A11).

5.3. Interactions

The second structural element is interactions, a dynamic element which refers to the cooperation and relationships between actors. Generally, the occurrence of networks in the beginning stages of a TIS are scarce. However, interactions within the CM innovation system were identified and are outlined in the following section.

5.3.1. CANS network

The CANS was established to form a CA community and to create awareness amongst the general public (A11), and stimulate the development of CA in the Netherlands and worldwide. Thirteen parties had founded the consortium and 38 parties are part of their community. The founding members are:

- Meatable
- Mosa Meat
- RESPECTfarms
- Those Vegan Cowboys
- Wageningen University
- TU Delft
- KindEarth.Tech
- CE Delft
- Bio Process Facility (BPF)[3]
- Planet B.io
- Nutreco
- DSM

Amongst the community members are New Harvest, Proveg, Givaudan, Friesland Campina, Unilever, Holland Bio, Maastricht University, Blue Horizon, Getinge, INH, Has Hogeschool, COE Groen, University of Groningen, The Protein Brewery, NOUBio, Vista College, FoodValley, Upstream foods, IQ, LIOF, Catalyze, Genius Biotect Solutions, LenioBio, Educated Choices Program, CellAg.org, CellRev, Orange Light Ventures and Enough (CANS, 2022). Because these new partners have just recently been announced, it is unclear how exactly they are involved in the CM sector.

The consortium submitted a ‵′growth plan′′ proposal for financing to the NGF and received a €60 million investment. This money will be allocated for creating educational programs, conducting R&D, creating shared facilities and infrastructure for companies to do scaling-up research, and managing the foundation (A11; Schuengel, 2022). An extra 25 million is expected, and this is estimated to bring another 1.25-2 billion to the Dutch earning capacity by 2050 (CANS, 2022).

[3] BPF was declared bankrupt in November 2022 (Smit, 2022).

5.3.2. Cellular Agriculture Europe coalition

At the end of 2021, thirteen CA companies have partnered together to advance CA in Europe and established Cellular Agriculture Europe (CAE) (Mosa Meat, 2021d). Both Mosa Meat and Meatable are part of this coalition. The head of public affairs of Mosa Meat is the coalition's president (Morrison, 2022). On July 13th, the European Parliament held the first debate on CM, urging to invest more in R&D and public research. Representatives included Pelle Sinke from CE Delft, who presented the first ever life-cycle assessment on the environmental impact of CM (Morrison, 2022). In October 2022, CAE became part of the Global Cultivated Foods Alliance. Together with US' Alliance for Meat, Poultry and Seafood Innovation and APAC Society for Cellular Agriculture, the alliance works together to connect the industry (Vegconomist, 2022).

5.3.3. CM startups and their interactions

Mosa Meat and Meatable are the only two startups that produce CM in The Netherlands, and can thus be considered as key actors in the Dutch CM sector. Both companies have their own networks (see Figure 8 and Figure 9) in different regions in the Netherlands. Mosa Meat's headquarters are located at Brightland Maastricht Health Campus (Brightlands, n.d.). Mark Post is professor at MU (Maastricht University, n.d.) and 21% of Mosa Meat's employees have studied at MU (Linkedin, n.d.). On an EU level, Mosa Meat became part of the RisingFoodStars (RSF) network, which is part of the European Institute of Innovation and Technology. The goal is to drive the creation of a sustainable and future-proof food sector (Mosa Meat, 2021a). In 2022, the company signed a partnership deal with Singaporean company ESCO Aster, the first commercially licensed CM manufacturer, to produce CM in Singapore (Hull, 2022).

Figure 7. *Mosa Meat network*

Meatable has built their network in the Delft region. Together with Planet B.io, DSM, CE Delft and Biotech Campus Delft, they form the hub for cellular agriculture in Delft (TU Delft, 2022). Meatable is also part of the ScaLABle-MEAT project, including three other partners Bit Bio Ltd (United Kingdom), HCS Pharma (France) and Ebers Medicals (Spain). The goal of the project is to develop CM based on the Nobel prize winning iPSC stem cell technology. The ScaLABle-MEAT project has been rewarded a €1.2 million award from Eurostars to support R&D between 1st of November 2019 until 3rd of November 2022 (Catalyze group, n.d.). In 2022, Meatable has signed a partnership with Love Handle and ESCO Aster to introduce hybrid CM products such as dumplings and sausages into restaurants (Meatable, 2022a). In December 2022, Meatable also announced a partnership with TU Delft, VIVOLTA and DSM to conduct a new R&D project (see 6.2.3 ''number of R&D projects'') (Meatable, 2022b)

Figure 8. *Meatable network*

5.3.4. Senternovem Research Project

A former consortium consisting of University of Amsterdam (UVA), Utrecht University (UU), Eindhoven University of Technology (TU/e), VitroMeat BV, Meester Stegeman researched culturing skeletal muscle cells from farm animal stem cells (Haagsman et al., 2009). The findings of this research established the foundation for the first CM burger in 2013 (Stephens et al., 2019). The Dutch government agency SenterNovem, part of the former Ministry of Economic Affairs, facilitated the consortium from 2004-2009 with a €2 million fund (Proveg, 2022b). The Swammerdam Institute of Life Sciences (UVA) researched the ingredients needed to grow cells. At the Faculty of Veterinary Medicine (UU), it was analyzed how muscle cells proliferate and at the Faculty of Biomedical Technology (TU/e), research was conducted on creating a suitable bioreactor (Macintre, 2007; Haagsman et al., 2009). However, the government decided not to invest any further into the consortium because the researchers 'failed to generate sufficient interest from the private sector and the public' (Post, 2014).

5.4. Infrastructure

The fourth structural element is infrastructure, which consists of physical, knowledge and financial infrastructure (Wieczorek & Hekkert, 2012).

5.4.1. Physical infrastructure

The physical infrastructure that exists are the laboratories, small-scale production facilities and offices of Mosa Meat and Meatable, as well as the existing infrastructure of the universities and the innovation hubs like Planet B.io. Mosa Meat has announced a scale-up of their production facility and will then become the largest CM campus in the world. This will provide Mosa Meat a solid foundation for their European and global commercialization plans. In addition, their operations at Brightlands Health Campus and their existing pilot facility in Maastricht have also grown (Mosa Meat, 2022a). Infrastructure building is also taking place outside the Netherlands. Meatable and Mosa Meat have established ties in Singapore by partnering with ESCO Aster. ESCO Aster is the world's only licensed CM manufacturer (Meatable, 2022a; Hull, 2022), and their knowledge could be very valuable for setting up production facilities in the Netherlands. Meatable is also building a Future of Meat Innovation Center in Singapore, where their first hybrid products will be created (Meatable, 2022a). This global expansion is likely to be beneficial, because the (infrastructure) knowledge from Singapore could be transferred and applied in the Netherlands.

5.4.2. Knowledge infrastructure

The knowledge infrastructure for CM in The Netherlands are the companies, universities, research centres and innovation hubs that allow the development and diffusion of knowledge. Unlike many other innovations, CM did not have a strong academic foundation, and R&D is still mainly conducted within the start-ups (A7). Most of the research happens within Mosa Meat and Meatable, whom therefore have a strong and growing knowledge base. For example, Mosa Meat announced that their employee count has grown to over 160, including 80 scientists and a five-fold increase of production team members in the last three months (Mosa Meat, 2022a). Several Dutch universities have ties with Mosa Meat and Meatable. Universities that are currently most active in the publishing of scientific research are WUR and MU[4]. Research centres and innovation platforms are offering Mosa Meat and Meatable infrastructure to further accelerate innovation. As mentioned previously, this includes Brightlands Maastricht Health Maastricht for Mosa Meat, and Biotech Campus Delft and Planet B.io for Meatable (Brightlands Maastricht Health Campus, n.d.; Biotech Campus Delft, 2021). Other actors that are involved in the knowledge infrastructure are GFI Europe and New Harvest. GFI Europe work together with scientists and businesses, and New Harvest is a research institute which funds research projects (New Harvest, n.d.; GFI Europe, n.d.).

5.4.3. Financial infrastructure

Several funds have been allocated by governmental bodies (see Table 10). The first consortium was founded in 2004, with Mark Post leading the research. The consortium received a €2 million subsidy from SenterNovem, an agency of the Ministry of Economic Affairs (now EKZ) (Haagsman et al., 2009; Jönsson, 2016). Meatable, along with three other companies, received a € 1.2 million funding in 2019 from the Eurostars programme to conduct R&D. The project runs from 1-11-2019 to 3-11-2022 (Catalyze group, n.d.). The collaborative project ''Feed for Meat'' by Mosa Meat and Nutreco received €2 million in 2021 from the European Union to bring CM closer to commercialization. The money will be used for research into reducing the costs of cell culture media, which is the most expensive step of the culturing of beef (Nutreco, 2021). As previously elaborated on, the NGF has invested €60 million in the advancement of CM (Schuengel, 2022). The funding will be used to implement the ''Growth Plan'' (CANS, 2022).

[4] A Scopus search on the terms "cultured meat" OR "cultivated meat" OR "In vitro meat" between 1994 and 2022 yields in 36 publications by UM and WUR researchers

***Table 10**. Public funding from 2004-2022 (Jha, 2013; Haagsman et al., 2009; 'Catalyze group',n.d.; Nutreco, 2021; Schuengel, 2022; Meatable, 2022)*

Year	Name	Funding	Company/university/consortium	Source
2004-2009	SenterNovem research project	€2 million	VitroMeat BV, TUE, UVA, UU, Meester Stegeman	SenterNovem
2019-2022	ScaLABe-MEAT project	€1.2 million	Meatable, Bit Bio, Ebers, HCS Pharma	Eurostars Program
2021	Feed For Meat	€2 million	Mosa Meat & Nutreco	European REACT-EU programme
2022	Growth Plan	€60 million	CANS	The NGF
2022	N/A	€ 1 million	Meatable, DSM, VIVOLTA, TU Delft	NWO

6. Functional analysis

The following section outlines the results of the functional analysis of the TIS. Combined with the structural analysis, it provides the basis for the answer to the question: *''What systemic problems are causing obstruction within the Dutch cultured meat TIS?''.* Section 6.8 discusses which motor is driving the CM TIS, based on the structural and functional analysis.

6.1. Function 1 – Entrepreneurial Activity

The following section outlines the analysis of function 1 - Entrepreneurial activity. The indicators for F1 are the *number of new entrants*, *diversification of incumbent actors* and *the number of experiments with the new technology* (Hekkert et al., 2007)

6.1.1. Number of new entrants

New CM companies are emerging globally and there are now over 100 companies working in the CM sector (Cohen et al., 2022). The Netherlands hosts four companies that are related to CM specifically: Mosa Meat, Meatable, RESPECTfarms and Cultured Blood. The latter two have only recently entered the TIS (RESPECTfarms, n.d.; Cultured Blood, n.d.). Thus, the number of new entrants is low. This is most likely contributed to by the fact that CM needs to be approved by the EFSA as a novel food. It is expected that more actors will be incentivized to enter the Dutch IS once the EFSA has approved CM as a food group (A4).

Because there are only four CM companies in the Netherlands and no new companies are entering, this indicator scores a 1 (very weak)

6.1.2. Diversification of incumbent actors

Diversification of incumbent actors indicates that experimentation is taking place, which could reduce uncertainty (Bergek et al. 2008). All four companies produce different products. In collaboration with Love Handle, a Singaporean-based plant-based butcher, Meatable is focusing on creating hybrid products such as dumplings, pulled pork, pork belly and meat balls (Meatable, 2022a). The company can diversify their product portfolio because they licensed the OPTi-OX technology, which enables them to produce meat for any other cell type including beef, sheep, and fish (McCarthy & van de Vliet, 2021). Mosa Meat is developing CM beef (Mosa Meat, n.d.). Cultured Blood is creating an artificial blood circulation system (Cultured Blood, n.d.). Lastly, RESPECTfarms is working on building the first CM farm where R&D, experiments and knowledge sharing will be stimulated (RESPECTfarms, n.d.)

All companies are creating different products or providing different services. Therefore, this indicator scores a 4 (strong)

6.1.3. Number of experiments with the new technology

Experiments consist of practical applications of the researched technology such production rounds with pilot plants, tastings and trying out new products. Due to the unfavorable regulatory landscape, it has been difficult for companies to conduct experiments. Until March 2022, tasting experiments were forbidden. Tjeerd de Groot and Peter Valstar proposed a motion to allow the tasting experiments for CM. This motion was adopted, and companies are preparing for tasting experiments (A2; taketonews, 2022). Mosa Meat conducted a tasting event in 2021 for their ''cultured fat''. The fat was cooked and tried on its own, as well as mixed with lean meat (Mosa Meat, 2021c). It is likely that the number of experiments will increase as Meatable and Mosa Meat are planning to manufacture CM in Singapore. Meatable announced that new products will be tested in Singapore, including pork meat dumplings and sausages (Meatable, 2022a).

Experimenting with products was not possible up until 2022 due to regulations. Now that tastings are allowed and both Mosa Meat and Meatable are planning to produce and test their products in Singapore, the number of experiments will likely increase. Therefore, this indicator scores a 3 (moderate). The overview of the scoring of F1 can be found in Table 11.

Table 11. *Assessment of F1*

Indicator	Score
Number of new entrants	1 – Very weak
Diversification of incumbent actors	4 – Strong
Number of experiments with the new technology	3 – Moderate
Overall score	**3 – Moderate**

6.2. Function 2 - Knowledge Development

The following section outlines the analysis of function 2 - Knowledge Development. The indicators for F2 are the *number of patents*, *number of publications* and *number of R&D projects*, (Hekkert et al., 2007).

6.2.1. Number of patents

Three patents have been filed, as seen in Table 12. In 1997, Willem van Eelen filed the world's first CM related patent on ‵′industrial production of meat using cell culture methods′′ (van Eelen, 2005). This patent was prolonged in 2005 and assigned to Good Meat Inc., but expired in 2019 (van Eelen, 2005). Mosa Meat has filed for two patents. In May 2018, the company filed a patent for ‵′Apparatus and process for production of tissue from cells′′ (Breemhaar & Post, 2018). The second patent for a ‵′serum-free medium for differentiation of a progenitor cell′′ was filed in November 2020 and has been issued in July 2022 (Cruz et al., 2020). The low number of patents is likely due to the fact that there are only two companies producing CM, and secondly because the technology is still in a relatively early stage. Because of the low number of patents, this indicator scores a 1 (very weak)

Table 12. Patents by Dutch inventors (van Eelen, 2005; Breemhaar & Post, 2018; Cruz et al., 2017).

Patent	Inventor	Assignee	Date	States
US7270829B2 Industrial production of meat using cell culture methods	Willem Frederik van Eelen	Good Meat Inc.	Application was filed 1997 Re-applied in 2005	Expired – Lifetime
US20190338232A1 Apparatus and process for production of tissue from cells	Jonathan Jan Breemhaar & Mark Post	Mosa Meat BV	May 2018	Pending
WO2022114955A8 Serum-free medium for differentiation of a progenitor cell	Helder Cruz, Joshua Edwin Flack, Carolina Furquim, Iva Klevernic, Lea Melzener, Tobias Messmer, Mark Post, Anon van Essen	Mosa Meat BV	November 2020	Active

6.2.2. Number of publications

The number of publications related to CM from The Netherlands was measured by utilizing Scopus, which is an abstract and citation database (Scopus, n.d.). The following query string was used: ‵′cultured meat′′ OR ‵′cultivated meat′′ OR ‵′In vitro meat′′, This showed 566 document results. Then, ‵′The Netherlands′′ was opted as country, resulting in 48 publications. The Netherlands comes after United States (122), United Kingdom (67), and China (54). Notably, WUR had the most publications (20) worldwide and UM comes close with 16 publications. Mark Post has (co-)authored the most articles (16) worldwide. Thus, the Netherlands plays a meaningful role in contributing to academic literature on CM. Therefore, this indicator scores a 4 (strong).

6.2.3. Number of R&D projects

Although there are a wide range of actors involved in the CM sector, R&D projects are for the most part conducted at Mosa Meat, Meatable (A4; A7), WUR and UM[5]. Many of the actors that are listed in the structural analysis are collaborating with Meatable and Mosa Meat in R&D projects. For example, UM is connected with Mosa Meat because the company employs PhD students from UM to conduct research for Mosa Meat. Thus, a substantial amount of research conducted at UM is related to Mosa Meat. An example of this is the research conducted on serum-free media formulation for CM production by employees of Mosa Meat and the department of Physiology at UM (Messmer et al., 2022). Another example of the close connection between universities and companies is the collaboration between Meatable and TU Delft. In December 2022, the company announced a partnership with TU Delft, DSM and VIVOLTA to research the scalability and cost-effectiveness of producing elastin-like polypeptides (ELPs) and non-animal derived collagen. The 5-year long research project received a grant of 1 million euros from the NWO (Dutch Research Council) (Meatable, 2022b).

The SME and MNC companies discussed in the structural analysis are also collaborating with Mosa Meat and Meatable in R&D projects. Identified R&D projects were as followed: In 2021, Mosa Meat announced the collaboration with Nutreco for their Feed for Meat project. The aim of the project is to formulate a cell culture media out of feed- and food-grade byproducts from Nutreco's supply chain. Using byproducts will lower the costs compared to using pharma-grade ingredients (Nutreco, 2021). Mosa Meat is also continuously working on increasing the production capacity without reducing the quality of the meat and finding alternatives to expensive growth media (Keep Talking, 2022). Together with DSM, Meatable is conducting R&D to find cost-effective alternatives for growth media. DSM also provides knowledge on producing bioreactors for larger-scale production (Watson, 2022). In 2019, Meatable received funding for R&D into CM through the ScaLABle-MEAT project (Catalyze group, n.d.). Mosa Meat and Meatable hardly share information about the specifics of their production processes and technology due to IP concerns. Thus, besides these publicly announced collaboration projects, it is unclear how many R&D projects happen within the companies.

There is a fair amount of R&D conducted at the companies and universities, therefore, this indicator scores a 3 (moderate)

The overview of the scoring of F2 can be found in Table 13.

Table 13. *Assessment of F2*

Indicator	**Score**
Number of patents	1 – Very weak
Number of publications	4 – Strong
Number of R&D projects	3 – Moderate
Overall score	**3 – Moderate**

6.3. Function 3 - Knowledge Exchange

The following section outlines the analysis of function 3: Knowledge Exchange. The indicators for F3 are *the number of conferences and workshops*, *the network size and intensity over time*, and *knowledge exchange between industry, science, and users*.

6.3.1. The number conferences and workshops

Several CM and CA related symposia have been held over the past 12 years. Mark Post co-organized the first CM symposium in 2010 at NEMO Amsterdam (NCWT, 2011). The yearly International Scientific Conference on Cultured Meat is also co-organized by Mark Post (Mosa Meat, 2021b; Cultured meat conference, n.d.). KindEarth.Tech has organized two alternative protein symposia in Amsterdam in 2019, 2021 and 2022 (KindEarth.Tech, 2022).

[5] A Scopus search on the terms "cultured meat" OR "cultivated meat" OR "In vitro meat" between 1994 and 2022 yields in 36 publications by UM and WUR researchers

Few workshops have been held to increase the awareness of CM amongst the public. The first identifiable workshop was held in 2012, called ''Make your own cultured meat'' and was about the cultural context and research of CM (MU, 2012). The EKZ (formerly Ministry of Economic Affairs) commissioned to explore the public reactions and possible acceptation of CM by hosting workshops with focus groups in 2013 (van der Weele & Driessen, 2014). On the SDG action day, Mosa Meat hosted an informational workshop on CM to the public (Duivenvoorden, 2020). In 2020, WUR organized a project called ''Cultured meat as new option for farmers?'' (van der Weele, 2020), with the goal of exploring potential future scenarios for traditional farmers. ''Meat ice cream'', was a workshop intended for school kids between 8-12 years old to be introduced to a possible future including CM. The workshop was hosted by Submarine Channel and Next Nature Network (Jacob, 2021). ''Cultured beef inspiration session and tasting with Star Chef'' (''Inspiratiesessie gecultiveerd rundvlees en proeverij met Sterrenchef'') was organized by De Crole Hoeve, Staatsbosbeheer, RESPECTfarms, Mosa Meat and restaurant De Rozario. De Crole Hoeve is actively engaged in the process of becoming a CM farm. The goal of the workshop was educating the public on CM (Crole, 2022).

There is only one conference specifically for CM, and the number of workshops has been limited. Therefore, this indicator scores a 2 (weak)

6.3.2. Network size and intensity over time

Both companies have created their own networks (see section 5.3.3. ''CM startups and their networks''). There is a high degree of vertical integration, meaning that companies take ownership of various parts of the production process. A few elements of the production process are left to external companies, such as the bioreactors from CELL-tainer for Mosa Meat and the partnership between Meatable and DSM to produce cost-effective growth media (CELL-tainer, 2020; Meatable, 2021). The establishment of the CANS indicates that network size and intensity are increasing. In 2021, both Mosa Meat and Meatable joined forces with 11 other important actors from within the TIS to stimulate the development of CA. The consortium is growing, and 38 new community members have joined CANS in the last quarter of 2022 (CANS, 2022). The CANS is the most prominent network, as it has succeeded in bringing together 51 actors and obtaining funding from the government.
Because the network has increased and is getting stronger, this indicator scores a 3 (moderate)

6.3.3. Knowledge exchange between industry, science, and users

The purpose of networks is the exchange of knowledge. Therefore, it is important that recent technological developments are in line with policy decisions and changing norms and values (Hekkert et al., 2007). Knowledge sharing between producers, science and users in the Dutch CM sector is compartmentalized (A1; A2; A4; A5; A7). Mosa Meat and Meatable are heavily funded by private investors and concerned with IP, and therefore careful with what knowledge is made public. IP concerns have resulted in data silos, in which developers have collected data solely for themselves. Normal scientific processes, such as practicing open science, are avoided. Failed lines of research are not shared and other researchers risk repeating them, which ultimately slows down progress (Holmes et al., 2022). Inadequate knowledge sharing from companies also results in uninformed policy makers, resulting in lack of public funding (New Harvest, 2022). These issues are present in the CM sector worldwide (A7).

'' *Right now, it's segmented. But I would say this is true everywhere (…). This is a very unusual field in that it didn't really start with a lot of academic research that set the foundation. And then it took off. It became predominantly private sector-driven, which I think is a hindrance for the field*.'' (A7)

Mosa Meat rarely share findings or details on production processes. Mosa Meat acknowledges the importance of openness, transparency and collaborating to overcome barriers and advance the CM technology. The company published a peer-reviewed article in Nature Food, in which achieving muscle differentiation without using FBS or genetically modifying the cells is explained (Messmer et al., 2022), and an article on muscle-derived fibro-adipogenic progenitor cells for the production of cultured fat (Dohmen et al., 2022). However, the information presented in the article is still relatively limited (A7). Meatable does not share details on scientific progress on their website. Preparing for commercialization, the public should be accurately informed about CM and its benefits as consumer acceptance plays a crucial part in its success (A1; A4). Sharing the scientific side of CM should be done without scaring off consumers (A1).

The knowledge sharing landscape between users, science and producers is fragmented. It is crucial to educate consumers and policy makers accordingly so that public investment is stimulated. Therefore, this indicator scores a 2 (weak)**.** The overview of the scoring of F3 can be found in Table 14.

***Table 14**. Assessment of F3*

Indicator	Score
The number conferences and workshops	2 – Weak
Network size and intensity over time	3 – Moderate
Knowledge exchange between industry, science, and users	2 – Weak
Overall score	**2 – Weak**

6.4. Function 4 - Guidance of the Search

The following section outlines the analysis of function 4 - Guidance of the Search. The indicators for F4 are regulations, visions, expectations of governments, visions, and expectations of key actors.

6.4.1. Regulations, visions, and expectations of government

The government's involvement has been minimal. Besides funding R&D projects (see section 5.4.3 '*'Financial infrastructure''*) and the CANS (Schuengel, 2022), the government did not set concrete goals for CM (A2; A3). The adopted motion to approve CM tastings, and the investment by NGF, indicates that the Dutch government beliefs in the potential of CM. The NGF acknowledges that the Netherlands has an excellent technical and starting position in agriculture and biotechnology to develop as a world leader in CA. Major developments are happening overseas and it is considered crucial for the Netherlands to undertake action (Nationaal Groeifonds, n.d.). The NGF did not invest the full requested amount to avoid raising unattainable expectations amongst the public, since there remain technological barriers that must be overcome to prove that CM is scalable (A11)**.** CM was also included in the National Protein Strategy ('‘Nationale Eiwitstrategie'') (NPS). Specifically for food production and consumption, the EC asked all member states to formulate a national protein strategy to become less dependent on protein import flows from outside the EU (Schouten, 2022). The LNV presented the NPS in 2020 with the main goal to increase the self-sufficiency level of vegetable and other new proteins over the next 5 to 10 years, contributing to the health of humans, the national environment, and animals. Increasing sustainable consumption is the primary goal (LNV, 2020). Because of the limited arable land, the strategy includes other protein sources than plant proteins like insects, microbial sources, and novel foods such as CM (Rijksoverheid, 2020). Before the NPS, CM was also part of the research program initiated by the LNV in 2009 called Innovations Protein Chains (*Innovaties Eiwitketens)* (PIEK). The focus laid on fundamental and applied research into CM insects, algae, plant foods for farmed fish and meat substitutes (LNV, 2018).

The Dutch government realizes the potential of CM and CA, and therefore invested a large sum of money into the development of CA. However, the CANS is responsible for the coordinated approach to scaling up CM and the creation and implementation of strategies. Because of the minimal government involvement in policy making, this indicator scores a 2 (weak)

6.4.2. Visions and expectations of key actors

The unfavorable regulatory landscape had slowed down CM innovation, and key actors are worried that the Netherlands will be left behind if government action is not taken quickly (A2; A3; A5; Nationaal Groeifonds, n.d.). The members of the CANS are the key actors within the TIS, and their vision for CM is aligned to a great extent. The foundation created a growth plan which covers four areas that contribute to building a developed CA ecosystem: education, research, scaling-up and knowledge sharing (CANS, 2022). The goals of the growth plan can be found in Table 15. The vision of the consortium members is to create an attractive business climate for CA companies, and to make CA an integral part of the Dutch agricultural sector. It is expected that the Netherlands will have two publicly available scale-up facilities for both CM and CA dairy production processes. A complete Dutch value chain will be created that stimulates and facilitates innovation, and in which startups, investors and industrial partners collaborate with each other. Dutch universities are actively involved in generating public knowledge and technological advancements for the sector to overcome challenges (CANS, 2022). However, there are different visions for certain aspects of CM within the consortium. For example, Ira van Eelen aspires to involve farmers into the transition (RESPECTfarms, n.d.). Consortium member Cindy Gerhardt argues that this will be almost impossible due to the technological challenge of producing CM in sterile conditions and being cost-effective at the same time (A11; Humbird, 2020). However, these discussions are considered healthy and essential, and do not form a barrier (A11).

***Table 15**. Main goals of the CANS (CANS, 2022)*

Area	Goal
Education	Educating and enthusing high-school students to CA Modules for CA for Universities and College (HBO) Developing the job-profile and education modules for MBO (community college) Postgraduate courses and career conferences for side-entry students
Research	Core program research at TU Delft, Wageningen UR and Maastricht University led by CA tenure trackers Investing in research-lab infrastructure Open call program through NOW with two rounds in 2025 and 2027 Open program for EngD's Research at HBO-institutes led by lecturers
Scaling-up	An open access scaling-up facility for precision fermentation (for CA dairy, growth media and spillover products) Open access test facility for culture media Open access scaling-up facility for cell culturing on small-scale (for CA-meat and spillover products) Open access scaling-up facility for cell culturing a product development on medium-scale (for CA-meat and spillover products)
Knowledge sharing and raising awareness	Active knowledge sharing within the CA-sector Advising and educating CA companies

Key actors have mobilized and developed the growth plan which envisions the future of CA and CM in the Netherlands. The vision of the key actors is for the most part aligned. Therefore, this indicator scores a 4 (strong). The overview of the scoring of F4 can be found in Table 16.

***Table 16.** Assessment of F4*

Indicator	Score
Regulations, visions, and expectations of governments	2 – Weak
Regulations, visions, and expectations of key actors	4 – Strong
Overall score	**3 – Moderate**

6.5. Function 5 - Market formation

The following section outlines the analysis of function 5: Market Formation. The indicators for F5 are *tax regimes for new technologies* and *the expected market size*.

6.5.1.Tax regimes for new technologies

Favorable tax regimes can create (temporary) competitive advantages (Hekkert et al., 2007). Two tax regulations for innovations could be identified in the Netherlands. The first scheme is called the ‘’innovation box’’. Through this scheme companies pay less corporate income tax. Companies are only eligible for this tax scheme under certain conditions, such as already selling the product on the market (Business.gov.nl, n.d.). Thus, this tax regime can only be used by CM companies when the products are sold on the market. The Promoting Research and Development Act (WBSO) also offers a tax scheme for R&D. Through this scheme companies can reduce the wage costs for R&D if more than 500 hours are spent yearly on R&D (RVO, 2015). The innovation box cannot be used because CM is not sold and the benefits of the WBSO are negligible considering the high costs of R&D. Subsidies can also help firms to innovate. A study was conducted by the CANS into the possibilities of additional financing from existing subsidy schemes. This research has shown that the current subsidy landscape is not appropriate with the broad CA sector developments and goals the CANS had envisioned for their growth plan (CANS, 2022). There are only two tax schemes for innovations, and they are not suitable for CM companies. Therefore, this indicator scores a 1 (very weak)

6.5.2. Expected market size

There remains uncertainty about the future market size of the Dutch CM sector (A1; A4; A5). There are no market size projections available for the Dutch and European market since CM is not allowed to be sold yet. Worldwide projections have been made, with annual sales ranging from $20 billion by 2030 to $450 billion by 2040 (Morrison, 2019; Brennan et al., 2021). Meatable predicts that CM will become a $25 billion market by 2030 (Meatable, 2022a). The industry growth is based on many drivers such as commercial and consumer trends, regulatory and government action, and scientific and technological innovation (Cohen et al., 2022; A2). CM can only enter the European market after approval by the EFSA. The expected market introduction is between 3-5 years (A1; A11; Sawers, 2022a), and the first products will be sold in high-end restaurants, butchers, and specialty shops (Idzikowska, 2018; A4; A11; Mosa Meat, 2019a). Supermarket introduction is expected to be at a later stage (A1; A11). Both Meatable and Mosa Meat have signed a partnership with CM manufacturer ESCO Aster and are introducing their products onto the Singaporean market (Hull, 2022; Meatable, 2022a). Meatable announced the introduction of their products in Singaporean restaurants by 2024, and in supermarkets by 2025 (Meatable, 2022a). Mosa Meat did not announce a concrete date for when their product(s) will be sold in the Netherlands (Mosa Meat, 2019a). Because CM is not sold on the market in the Netherlands and Europe, it is challenging to predict future market size, and predictions are based on hypothetical situations. Therefore, this indicator scores a 2 (weak). The overview of the scoring of F5 can be found in Table 17.

***Table 17**. Assessment of F5*

Indicator	Score
Tax regimes for new technologies	1 – Very weak
Current and expected market size	2 – Weak
Overall score	**2 – Weak**

6.6. Function 6 - Resource Mobilization

The following section outlines the analysis of function 6 - Resource Mobilization. The indicators for F6 are *rising volume of public funding*, *rising volume of private funding*, *changing volume and quality of human resources*, and *changes in physical resources*.

6.6.1. Rising volume of public funding

The volume of public funding has drastically increased during the past 18 years. The total public investment in CM was €5.6 million in a span of 17 years. The most recent investment by The NGF is €60 million, with a possible extra €25 million. This is increase from €5.6 to €65-85 million corresponds to an increase from 971 to 1417%. Percentage wise, the increase is high. However, noted should be that whilst this investment is large, it is rather low for a nascent industry. The initial requested amount by the CANS was €280 million. This resulted in the CANS needing to reconsider the allocation of resources. For example, at this moment regulation building has a lower priority (A11).

Thus, there is a significant increase in public funding, but considering the resource intensity of CM and it being a nascent sector with a need for more public financial resources, this indicator scored 3 (moderate)

6.6.2. Rising volume of private funding

The sector has been mainly private sector-driven since the start (A7). Mosa Meat received a total of €96 million in private investments. The company received 9.5 million in series A and a total of 85 million in series B (Crunchbase, 2022a). This is an increase of 795% between 2017 and 2021. Meatable received a total of €172.8 million. In the 2018 seed round, €3.5 million was invested. Series A raised €109.9 million, and another seed round raised €7 million. In 2021 the company did a venture round (€2 million) and another series A round raised €47 million (Crunchbase, 2022b). The total increase is 4542% between 2018 and 2021.

Because the volume of private funding has increased drastically, this indicator scores a 4 (strong)

6.6.3. Changing volume and quality of human resources

The volume of human resources is relatively low and is concentrated within Mosa Meat, Meatable and several universities such as WUR, and UM[6]. Due to the fast developments within the CM IS, demand for experts is growing and Mosa Meat and Meatable are expanding their workforce. For example, Mosa Meat has recently reported a five-fold increase in production team employees in the last three months. In addition, they have the largest number of PhDs in the industry (Mosa Meat, 2022a). Meatable has also announced that their workforce is growing. The company reported investing €60 million in their production infrastructure in Singapore and are employing 50 people locally over the next five years (Meatable, 2022a).

There is a need to train qualified CA personnel (CANS, 2022). Most expertise comes from different disciplines such as tissue engineering, biomedical sciences, chemistry, biology, and food tech for example (A1). Additionally, a CM and CA scientific domain does not exist yet (A1; A7). The vision for the Dutch CM TIS is to create conditions for educational institutions to add CA skills and expertise as part of their curriculum. With this, sufficient labor potential is created that matches the required skills within the CA sector (CANS, 2022)

The number of employees within Meatable and Mosa Meat is growing, implying that the human capital is growing. However, there is still a need for skilled personnel and the creation of a labor market. Therefore, this indicator scores a 2- 3 (weak moderate)

6.6.4 Changes in physical infrastructure

Changes in physical infrastructure have been minimal up until the last quarter of 2022. Mosa Meat joined Medace's biomedical co-working space in 2020 to build a new research facility and pilot production facility (Medace, 2020; Mosa Meat, 2020). In October 2022, Mosa Meat announced the development of a new industrial production facility (Mosa Meat, 2022a). Meatable has also expanded their facility at Plus Ultra Leiden where the company doubled their laboratory and office space (Kadans, 2022). Both companies are also expanding to Singapore where they have signed a partnership with CM manufacturer ESCO Aster, because regulatory landscape is favorable for CM production (Hull, 2022; Meatable, 2022a). In addition, Meatable is building a hybrid meat innovation center in Singapore (Meatable, 2022a)

Some of the causes of limited changes are the unfavorable regulatory landscape and high investment costs of setting up pilot- and production facilities. Building a commercial plant costs around €430 million (Humbird, 2021). In addition, upscaling research is fundamental for companies before commercializing. The scale of pilot plants is bigger than laboratory scale, but smaller than commercial scale. This step is expensive, and the facilities are only temporarily used by the companies. It is therefore not attractive for private investors, as not enough products can be produced for commercialization to make the investment worth it. Thus, governmental funding is necessary, as pilot plant facilities are open access, which makes it difficult to attain private funding (A11).

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[6] A search on Scopus using the query string "cultured meat" OR "cultivated meat" OR "In vitro meat" showed that WUR, UM and TU Delft published the most scientific articles of all Dutch Universities.

For a long period, little change in physical infrastructure occurred, as CM is not allowed to be sold in the EU. However, both companies have started the assessment by the EFSA and are expanding overseas to prepare for commercialization. The CANS also plans to build open access pilot plants for small- and large-scale product development and an experiment facility for cell culture media. However, since changes only recently began to take place and there is still little infrastructure, this indicator scores a 2 (weak). The overview of the scoring of F6 can be found in Table 18.

Table 18. *Assessment of F6*

Indicator	**Score**
Rising volume of capital	3 – Moderate
Increasing volume of seed and venture capital	4 – Strong
Changing volume and quality of human resources	3 – Moderate
Changes in physical infrastructure	2 – Weak
Overall score	**3 – Moderate**

6.7. Function 7 – Counteract Resistance to Change / Legitimacy Creation

The following section outlines the analysis of function 7 – legitimacy creation / counteract resistance to change. The indicators for F7 are *rise and growth of interest groups and their lobby actions* (Hekkert et al., 2007).

6.7.1. Rise and growth of interest groups and their lobby actions

The only lobby group in the Netherlands is the CANS. The foundation has been successful in advocating for CM, as they have obtained €60 million by the NGF (Schuengel, 2022). The CANS is currently mobilizing key actors to form a strong foundation. The CANS started with 13 founding members and has added 38 new organizations to their community that are committed to the advancement of the CA sector (CANS, 2022). In addition, the political majority is in favor of CM. Political parties in the Netherlands, such as VVD, CDA, D66, GroenLinks, and PvDA see CM as a promising alternative to traditional meat consumption (Terlingen, 2020; A3; A2). The political support for CM in the Netherlands can be exemplified by a majority of the members of parliament (123 votes) voting in favor of the motion submitted by De Groot and Valstar. Experts were not aware of groups that actively lobby against CM (A1; A2; A3; A4).

There has been mild resistance, but that has not obstructed the development of CM. Parties that voted against the motion were FVD, PVV and Group of Haga (Tweede Kamer der Staten-Generaal, 2022). Party for the Animals (PVDD) also fails to see CM as an alternative, arguing that with current pressing environmental problems, the development of CM is too slow, and also uses many raw materials and energy. The new generation of plant-based alternatives already offers consumers a sufficient alternative (Partij van de Dieren, n.d.). Christen Union sees CM as an ''interference with God's creation'' (A2). Schouten, who was Minister of LNV, has blocked the tasting of CM in the past, and has also argued against government measures to stimulate innovation because ''The market can do it itself'' (NOS, 2020). The traditional meat sector is averse because CM is seen as competition, but there is no real opposition to CM. It may be observed that with sector growth, opposition from farmers will grow (A3; A4).
Resistance to CM has been low, which is likely contributed to by the fact that CM is still at an early stage.

The CM lobby has been successful in legitimizing CM as a promising technology to the government. In addition, there are no lobby groups against CM, but this is likely because CM is not widely sold and does not yet pose a threat to existing industries. Therefore, this function scores a 4 (strong)**.**

The overview of the scoring of F7 can be found in Table 19

Table 19. *Assessment of F7*

Indicator	Score
Rise and growth of interest groups and their lobby actions	4 – Strong
Overall score	**4 – Strong**

6.8. Entrepreneurial Motor

Based on the structural-functional analysis, it can be argued that the dynamics of the CM TIS come closest to the characteristics Entrepreneurial Motor. As presented in section 2.3.3., the Entrepreneurial Motor is similar to the STP motor, but additionally has a strong realization of Entrepreneurial Activity (F1) and Creation of Legitimacy/Counteract Resistance to Change (F7). For the CM TIS, the lobbying activities by the CANS have been successful, and the government now supports the technology and has awarded the consortium with the largest funding in CA worldwide. Secondly, the CM TIS development is mainly driven by the entrepreneurial activity of the two firms Mosa Meat and Meatable. The companies are two of the main actors conducting R&D and experiments. The Entrepreneurial Motor builds upon the previous motor, which is fulfilled by Knowledge Development (F2), Knowledge Exchange (F3), Guidance of the Search (F4) and Resource Mobilization (F6). In the case of CM, F3 remains weak. The function dynamics are somewhat similar to the description of dynamics of the Entrepreneurial Motor. Firstly, in the Entrepreneurial Motor, companies enter the TIS and initiate projects (F1). Mark Post from Mosa Meat introduced the first CM burger in 2013 (Boyle, 2013), and since then developments have mainly been driven by the private sector. Mosa Meat and Meatable are the main actors conducting R&D, also in collaboration with other firms and universities. In this motor, companies have positive expectations for the technology (F4). Both Mosa Meat and Meatable have not commercialized CM products in the Netherlands yet due to the NFR, but both companies are persistent and believe in the CM not only for the societal and environmental benefits, but also because it can create opportunities for commercial profits (F4). Because the technology usually resides in a pre-commercial stage during the this phase, companies must lobby for funding from governmental bodies (F7). CM is at a pre-commercial stage and CM companies had to request for funding from governmental bodies. Still, the largest part of the investments come from private investors. The funding by the NGF is the result of the lobbying activity by the CANS. Meatable and Mosa Meat have received funding from governmental bodies, see table 10 (F7). In the Entrepreneurial Motor, financial resources are used to initiate projects and conduct R&D (F1). The results impacts whether other actors will enter the TIS and start projects (F4) (Suurs, 2009).

The structural drivers and barriers described in Suurs (2009) for the Entrepreneurial Motor can also be recognized in the CM TIS. As for drivers; the CM technology is relatively well developed, but scaling-up the production process and driving down the costs remains an obstruct. The technology is still in the pre-commercial stage and not adequately aligned with the institutional structures. Secondly, key actors in the CM TIS have positive expectations for CM and believe that it has commercial potential. Investors and the government also have positive expectations, and this is exemplified by the large fundings into CM even before the product can be commercialized. Lastly, governments have supported the CM technology with the help of several funds. A structural barrier of the Entrepreneurial Motor that is applicable to CM is that government support has only been in the form of temporary funding, rather than long-term policies.

The Entrepreneurial Motor is usually weak in the beginning, but if the motor expands, several impacts strengthen the TIS. Amongst the impacts is the growing number of enactors. This creates a wide range of actors in the TIS which typically include local governments, supply-side firms and demand-side firms. Secondly, intermediary organizations often drive the mobilization of enactors, and thus the creation of networks. These networks drive the development of the TIS, however, coordination usually remains an issue. Thirdly, the demand side is stimulated, especially when it comes to its connection to the supply-side and knowledge structure. Fourthly, the large amount of experimentation results in improvement of the technology. Lastly, the technology will be further institutionalized, in the form of standards for example. Arguably, the Entrepreneurial Motor in the CM is still not strong based on the scorings of F2, F3, F4 and F6. Therefore, the focus will lay on improving F2, F3, F4 and F6 so that the Entrepreneurial Motor can be strengthened and the next motor, the System Building Motor, can be ‘’activated’’.

6.9. Conclusion functional analysis

The TIS resides in the formative phase and most functions have scored weak to moderate. The only outstanding function is F7 – Counteract Resistance to Change/ Legitimacy Creation, which scored a 4 (strong). Functions F1, F2, F4 and F6 scored 3 (moderate). Functions F3, F5 scored 2 (weak). An overview of the functions scores can be found in Table 20. Arguably, the Entrepreneurial Motor relates to the CM the most, but there are still some observed weaknesses that obstruct the full potential impact of this motor. Therefore, functions F2, F3, F4 and F6 will be discussed in the systemic problem analysis. Their scores were weak to moderate and therefore they could be strengthened further so that the Entrepreneurial Motor is stronger. Even though Market Formation (F5) scored weak, the function will not be discussed in the systemic problem analysis. Its low score is mostly due to the restrictions that the NFR poses. Once CM is commercialized, it is expected that the function will perform better. Secondly, Market Formation (F5) also does not play a prominent role yet in the Entrepreneurial Motor.

***Table 20**. overview of scores*

Indicator	Score
F1 Entrepreneurial Activity	3 (moderate)
F2 Knowledge Development	3 (moderate)
F3 Knowledge Exchange	2 (weak)
F4 Guidance of the Search	3 (moderate)
F5 Market Formation	2 (weak)
F6 Resource Mobilization	3 (moderate)
F7 Counteract Resistance of Change / Legitimacy Creation	4 (strong)

7. Systemic problems analysis

In the following chapter, the underlying systemic problems of Knowledge Development (F2), Knowledge Exchange (F3), Guidance of the Search (F4) and Resource Mobilization (F6) will be analyzed. First, the functions and their blocking mechanism, systemic problem(s) and corresponding goals are presented. Then, reasons for why specific instrument tools were chosen for the systemic problem are explained. The second section elaborates on the interactions between the functions.

7.1. F2– Knowledge Development

The indicators *number of R&D projects* scored a 3 (moderate) and *number of patents* scored a 1 (very weak). There are only three filed patents. Thus, the lack of producing actors present within the TIS is the systemic problem. Because of the NFR, potential producing actors lack incentive to start a CM company since it is resource intensive, and uncertainty remains regarding the duration of the EFSA assessment procedure. Expected is that when CM has been approved as a food group by the EFSA, more actors will enter the TIS (A4). The corresponding goal is to 1) *stimulate and organize the participation of relevant actors*, and 7) *stimulate physical, financial and knowledge infrastructure* to provide key actors the necessary resources to develop knowledge. An overview of the systemic problem analysis of F2 can be found in Table 21.

Table 21. *Systemic problem analysis F2*

Function	Functions evaluation (absent/ very weak, etc.)	Reason why the specific function is absent/weak/strong etc. ('blocking mechanism')	Systemic problem(s) (presence/capabilities) + corresponding goal	Instruments
F2	3 - Moderate	Solely two companies and two universities are actively developing knowledge, therefore the number patents is low and the number of R&D projects is moderate.	Actors: presence (1) Stimulate and organize the participation of relevant actors Infrastructure: presence (7) Stimulate physical, financial and knowledge infrastructure	(1) Clusters; new forms of Public Private Partnerships, interactive stakeholder involvement techniques; public debates; scientific workshops; thematic meetings; transition arenas (7) Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs

Corresponding to goal 1, the recommended policy instruments are clusters and new forms of Public Private Partnerships (PPP). Clusters encompass interrelated economic actors, firms and institutions that are in the same area to stimulate innovation, specialized expertise, patent filing and create employment (European Commission, n.d.). PPPs are long-term cooperation between the government and the private sector and can be beneficial for parties. A partnership enables public actors to focus on policy, planning and regulation. Increased public funding can be invested into building relevant infrastructure (Worldbank, 2009). For CM, this could mean building open-access pilot plants for R&D and further expanding knowledge infrastructure by integrating CM into educational curriculums or training qualified personnel. Collaborations between governmental bodies, universities, and private parties may speed up the innovation progress. Such programs (e.g., Profetas and PIEK) have been implemented for PBMAs and were considered an influential part of the innovation progress. As for goal 7, knowledge development (F2) can be stimulated through instruments like funds, loans, and grants for R&D. By creating a financial infrastructure, the obtaining of funds and grants for R&D should be made more accessible so that independent research and entry of new entrepreneurs is stimulated.

7.2. F3 – Knowledge Exchange

F3 scored 2 (very weak) for the indicators *knowledge exchange between users, industry and science*, and *number of workshops/conferences*. Knowledge exchange is compartmentalized because Mosa Meat and Meatable are concerned with IP, since the largest part of the funding originates from private investors. Additionally, lack of public funding (F6) could also be attributed as a systemic problem. If more public funding were available, then likely more research would be made open access. Although F6 scored 3 (moderate) for the indicators *increase in public funding* and 4 (strong) for *rising volume of private funding*, more funding is needed. Because CM is a young sector, deeper governmental involvements is needed to stimulate open access and independent research, which will likely speed up the innovation process. Additionally, informing the public on CM should be done accordingly to increase consumer awareness and acceptance. Thus, financial infrastructure should be strengthened so that independent researchers may access funding for research, which could in turn strengthen knowledge infrastructure and knowledge sharing. The goals are to 5) *secure presence of (hard and soft) institutions* and to 7) *stimulate physical, knowledge and financial infrastructure.* An overview of the systemic problem analysis of F3 can be found in Table 22.

Table 22. *Systemic problem analysis F3*

Function	Functions evaluation (absent/ very weak, etc.)	Reason why the specific function is absent/weak/strong etc. ('blocking mechanism')	Systemic problem(s) (presence/capabilities) + corresponding goal	Instruments
F3	2 - Weak	Lack of public investment and favorable financial and knowledge infrastructure	Institutions: presence (5) Secure presence of (hard and soft) institutions Infrastructure: presence (7) Stimulate physical, knowledge and financial infrastructure	(5) Awareness building measures; information and education campaigns; public debates; lobbying, voluntary labels; voluntary agreements (7) Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs

Instruments corresponding to goal 5 include awareness building measures, information and education campaigns, public debates, and lobbying. It is necessary to share knowledge to the public so that consumers make well-educated purchases and incorporate CM into their diet. Tools such as awareness building measures, information and education campaigns, and public debates are intended to increase awareness and trust from the public, but also from more authoritative actors such as policy makers and ministers. Instruments corresponding to goal 7 are classical R&D grants, funds, subsidies, and public research labs. At this pre-competitive stage, public pilot plants and research labs are crucial for knowledge development. Therefore, building this infrastructure is necessary to stimulate knowledge dissemination and improve the lack of knowledge sharing the sector is currently enduring. Public funds, R&D grants, and subsidies could stimulate independent researchers to start conducting research. These instruments could also be used by companies, with the condition that more information and scientific findings should be made public.

7.3. F4 – Guidance of the search

Overall, this function scored a 3 (moderate) because of the strong and aligned vision of key actors. Governmental involvement has been rather limited, besides funding in the development of CA and legalizing CM tastings. Therefore, the indicator *regulations, visions and expectations of the government* scored 2 (weak). Policy makers have not yet set concrete goals or expectations, and thus have not implemented specific instruments and policies for CM. It is left to the CANS to further advance the development of CA. The underlying obstructs are the lack of knowledge sharing (F3) and technological barriers. Lack of knowledge sharing slows down the innovation process and leads to uninformed policy makers who are less likely to push for increased public funding, or to implement favorable policies. Technological barriers also hinder the government to set expectations and goals. Since the technology has not yet been widely applied, it remains challenging to set concrete expectations and implement policy tools and instruments. Therefore, the goal is to 2) *create space for actor's capability development* and 3) *stimulate the occurrence of interactions.* An overview of the systemic problem analysis of F4 can be found in Table 23

Table 23. *Systemic problem analysis F4*

Function	Functions evaluation (absent/ very weak, etc.)	Reason why the specific function is absent/weak/strong etc. ('blocking mechanism')	Systemic problem(s) (presence/capabilities) + corresponding goal	Instruments
F4	3 - Moderate	Technology still needs to prove that larger-scale production is possible and economically viable on a large-scale before government will invest more money and implement policies. Lack of knowledge sharing due to IP concerns results in a slowed-down innovation process and uninformed policy makers, and thus lack of direction.	Actor: capacity (2) Create space for actor's capability development Interactions: presence (3) Stimulate the occurrence of interactions	(2) Articulation discourse; backcasting; foresights; road-mapping; brainstorming; education and training programs; technology platforms; scenario development workshops; policy labs; pilot projects (3) Cooperative research programmes; consensus development conferences; cooperative grants and programmes; bridging instruments (centres of excellence, competence centres); collaboration and mobility schemes; police evaluation procedures; debates facilitating decision-making; science shops; technology transfer

Several instruments corresponding to goal 2 aim to increase positive visions and expectations of the government, and to stimulate the composing of regulations. Firstly, CM still faces technological challenges regarding the scaling-up of production processes and simultaneously being economically viable (Humbird, 2022). Therefore, more R&D must be conducted to explore how barriers can be overcome. Pilot plants are pre-commercial production centers essential for R&D. They are needed at this phase, as they assess the feasibility of CM industrial-scale production (Cohen et al., 2022). Backcasting is a valuable method that begins with establishing a desired future, then identifying which policies and programs will help achieve that desired future (The Natural Step, n.d.). This is useful because governments need to be involved in the process of setting expectations and visions, leading to the creation and implementation of suitable policies and programs. Instruments corresponding to goal 3 include bridging instruments (e.g., competence centers) and programs. Competence centers provide infrastructure for knowledge organization and transfer, with the aim of creating competitive advantage for a specific industry (4CH, n.d.). National and regional programs initiated by governmental bodies and in collaboration with CM industry actors can accelerate the institutionalization of CM and strengthen the collaboration between industry actors and governments.

7.4. F6 – Resource mobilization

The indicators *changes in physical infrastructure* scored 2 (weak) and *changing volume and quality of human resources* scored 3 (moderate). The underlying systemic problem is a lack of financial resources. More (public) funding is needed for R&D to overcome technological barriers, and to develop the entire CM sector. In addition, funding must be allocated to integrating CM and CA into educational curriculums and starting research programs at universities to increase human capital. Thus, the systemic goal is to (7) *stimulate physical, knowledge and financial infrastructure.* An overview of the systemic problem analysis of F6 can be found in Table 24.

Table 24. *Systemic problem analysis F6*

Function	**Functions evaluation (absent/ very weak, etc.)**	**Reason why the specific function is absent/weak/strong etc. ('blocking mechanism')**	**Systemic problem(s) (presence/capabilities) + corresponding goal**	**Instruments**
F6	2 - Weak for changes physical resources 3- Moderate for changing volume and quality of human resources	More (public) financial resources are needed to conduct R&D to overcome technological barriers, and to stimulate the development of physical infrastructure and human capital.	Institutional: presence (7) Stimulate physical, knowledge and financial infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs

The instruments corresponding to goal (7) are classical R&D grants, loans, funds, subsidies, and public research labs. Building open access pilot plants and public research labs is recommended to stimulate R&D and speed up the innovation process. In addition, financial instruments can be used to fund the integration of CM into educational curriculums to cultivate experts and qualified personnel, thus increasing the quality and volume of human capital.

7.5. Feedback loop

A negative feedback loop has been identified (see Figure 10). The CM sector has been predominantly private sector driven since the start (A7). Companies are mainly dependent on private funding to conduct R&D, and independent and open access research is limited since public and private funding is difficult to obtain at this pre-competitive stage (F6). Because most companies are heavily funded by private investors, they are concerned with IP, which stop companies from sharing scientific findings. As a result, most generated knowledge stays within companies (F3). Policy makers remain mis- or uninformed and therefore concrete visions, goals or policies created for CM are scarce (F4). Uninformed policy makers are less likely to push for further public funding or for creating favorable tax- or subsidy regimes (F6). Lack of knowledge sharing (F3) and public funding (F6) also slows down knowledge development and innovation (F2). Resources are wasted as private developers reproduce the same experiments, including failed lines of research. Secondly, it is usually difficult to obtain financial resources (F6) for open-access research facilities, as they are temporary and not used for commercial scale production. However, they play an important role in producing the necessary knowledge for commercial up-scale production (F2).

Figure 9. Feedback loop

7.6. Conclusion systemic problem analysis

In this section, sub-question one ''*What systemic problems are causing obstruction within the Dutch cultured meat TIS?''* is answered. Systemic problems within functions F2, F3, F4 and F6 hinder the TIS from entering the next stage. The main knowledge producers are Mosa Meat, Meatable, UM and WUR (F2). Because of this small number of knowledge producing actors, there are only three patents and a moderate number of R&D projects. Therefore, goal (1) *stimulate and organize the participation of relevant actors* is the appropriate goal for this systemic problem. Specific systemic instruments that help realize this goal are, for example, Public Private Partnerships, classical R&D grants, and public research labs. Independent research and entry of new entrepreneurs could be stimulated through instruments corresponding to goal (7) *stimulate physical, knowledge and financial infrastructure* such as funds, R&D grants, subsidies, and loans. Knowledge sharing (F3) is limited due to IP concerns, and therefore, more public funding is needed to stimulate open access research. Financial infrastructure (7) should be created so that independent open access research is stimulated, resulting in decompartmentalization of knowledge sharing

The Dutch government is minimally involved and has not set concrete goals or implemented policies for CM (F4). Two blocking mechanisms were identified: the technological obstacles of CM, and the lack of knowledge sharing (F3). Therefore, goal (2) *create space for actor's capability development* with corresponding instruments like pilot plants, policy labs and backcasting encourage the cooperation and knowledge sharing between government and CM producers. In addition, goal (3) *stimulate the occurrence of interactions* should be set to increase interactions between key actors. Suitable instruments are, for example, cooperative research programs, and collaboration and mobility schemes. While the amount of private capital is high, it is not sufficient for a nascent industry such as CM, and physical and human resources have remained relatively low (F6). The construction of pilot plants and production plants is expensive, but necessary, asbarriers remain regarding upscaling the production process. In addition, resources should be allocated to create education modules and train a specialized CM workforce.

A feedback loop was identified. Funding for independent and open access research is difficult to obtain and companies are heavily dependent on private investors (F6), which makes them concerned with IP and stops them from sharing scientific findings. Most knowledge creation stays within companies (F3). When information is not publicly shared, policy makers remain uninformed, and are less likely to advocate for further public funding, create policies (F4) or creating appropriate financial infrastructure (F6). Lack of knowledge sharing (F3) and public funding (F6) slows down knowledge creation and innovation (F2).

Lastly, an underlying barrier that influences virtually every function is the NFR. This regulation has slowed down the innovation and the market introduction of CM. It influences many functions, including F2, F4 and F6. Because companies cannot commercialize and profit from CM, no new entrants are entering the TIS. This undermines the potential knowledge development that could occur if new entrants would be incentivized to develop CM products. Mosa Meat and Meatable are carrying the burden of investing time and money by fulfilling EFSA procedures. Expected is that after CM is approved as novel food, more actors will enter the TIS (A4). It also influences F4, as policy makers are not yet incentivized to set expectations, construct goals, and implement policies for CM, because there remain uncertainties concerning whether the product is safe and when it will be introduced into the market, and whether large-scale production will be technologically possible. Less money can be directed to creating human capital and physical infrastructure. Thus, F6 is also affected by the consequences of the NFR. Whether CM will ever be produced on a large scale and simultaneously be economically viable also remains uncertain. Before more public money will be invested, companies worldwide must prove that CM can in fact be produced on a larger-scale, and can be price- competitive.

8. PBMAs analysis

The following section outlines the analysis conducted for research question three: *''Are there insights that can be drawn from the PBMAs sector to improve the performance of the TIS?''.* The first subsection describes the emergence and development of PBMAs from the 1990's until present, including drivers and barriers. The second subsection outlines the similarities and differences between CM. The third section outlines the recommendations from PBMAs experts for the development for CM, followed by a conclusion. An identified goal is indicated with the number between brackets, for example: (2) or (3).

8.1. The emergence and development of PBMAs

The development of the PBMAs market in the Netherlands started at the beginning of the 90's with a few players such as Vivera, Schouten Europe and Quorn dominating the market (A10; van Woensel Kooy, 2020; Schouten Food, n.d.; Geijtenbeek, 2021). In the early phases of market development, the products generally did not appeal to consumers due to the inferior quality or because consumers were simply unaware of their existence. PBMAs have struggled with having the ''geitenwollensokken'' (treehuggers) reputation (A8; A10). The poor quality of PBMAs and consumer acceptance have been the biggest barriers and has taken many years to be overcome. PBMAs are now considered to be ''mainstream'' after 30 years of continuous R&D to improve the quality of the product (A8; A10). Clever branding of quality products reached specific target groups that could identify with the products. While taste and experience are important factors, the identity and feeling that consumers can resonate with is also essential for purchasing PBMAs (A8).

Besides conducting R&D, other important (external) factors led to the success of PBMAs in the Netherlands. Creating awareness of the impact that is created for personal health and the environment was another driver that contributed to the popularity (A8). Livestock supply chain crises and disease outbreaks have also been favorable for increasing awareness, as consumers became concerned about health issues related to livestock production (A8; Tziva et al., 2020). The outbreak of zoonotic diseases such as Bovine Spongiform Encephalopathy crisis (mad cow's disease) and African Swine Fever led to a decline in consumption of the particular meat type and increased the sales of meat alternatives (Verbeke et al., 1999; Joppen, 2011; Directorate-General for Agriculture and Rural Development; 2021). The COVID-19 pandemic increased consumer awareness of health and safety risks related to livestock farming, which led to a further interest in alternative protein sources (A8; Rzymski et al., 2021; NL Times, 2021). Environmental concern started increasing with the publishing of environmental reports and policy plans such as the Brundlandt report in 1987, the first Dutch National Environmental Policy Plan and FAO's Livestock's Long Shadow in 2006 (Keeble, 1987, Straaten, 1992; Aiking et al., 2006; Steinfield et al., 2006, Tziva et al., 2020). This activated the discourse around the negative consequences of livestock farming. Environmental organizations, animal welfare and health organizations started to promote PBMAs and the consumer demand for PBMAs increased. A feedback loop was activated wherein more resources were allocated (F6), leading to knowledge development (F2) and thus positive results that strengthened the legitimacy of PBMAs (F7). Consequently, more resources were allocated to perform R&D (F6) and entrepreneurial experimentation (F1) (Tziva et al., 2020).

A second contributor to the success of PBMAs was that The Netherlands was one of the first countries that anticipated the problems that came forth from the production and consumption of animal proteins. The Netherlands created a favorable business climate for protein production, which improved the country's reputation (A8).

''The Netherlands has built a reputation when it comes to the development and knowledge of protein innovation, further than just meat and dairy. And what you also see happening now is that in addition to the young, smaller companies in the Netherlands, there are also many large companies that have grown from meat and dairy, also use their protein knowledge, expertise, infrastructure, and network on a global scale to create impact outside the Netherlands as well. And the Netherlands plays a very credible part in this.'' (A8)

The Dutch government-initiated programs to set the agenda and showcase the urgency for change (F4) (A8; Aiking et al., 2006). The development of new business activities has been facilitated and financed at an early stage by national and regional governments (1, 7). This set the breeding ground for entrepreneurs and academia to start developing PBMAs (F1) (A8). The Dutch government has been actively funding research over the past 30 years. In 1999, the multidisciplinary research initiative Profetas (Protein Foods, Environment, Technology and Society) was established, with the aim of researching what the role of alternative proteins could be in developing a more sustainable food system (Aiking et al., 2006). In the early 2000's, the national and regional governments started large public-private programs. Between 2010-2017, 61 projects were funded with regards to the protein transition (RVO, 2018). Examples of programs are: ''towards a next generation of meat analogues'' (€ 2.88 million), ''digestibility and quality of vegetable proteins'' (€ 1.3 million) and ''chickpea-based products (€ 200,000).). From 2009-2012, the LNV launched the innovation and research program ''Innovations in Protein Chains'' (PIEK), which focused on the applied research into algae, insects, meat substitutes, CM, and vegetable food for farmed fish (RVO, 2018; LNV, 2020; A8). The SBIR (Small Business Innovation and Research) instrument was a part of the PIEK and challenged entrepreneurs to develop new innovative market-ready products based on vegetable proteins. Another important factor was the political mindset of policy makers (A8). For example, former minister of LNV Gerda Verburg had pushed PIEK and SBIR (A8; NU, 2009). Lastly, the importance of provinces and municipalities should not be overlooked, as they have also been active in the protein transition. For example, the province of Gelderland established the Food Valley NL, The Green Protein Accelerator, and The Protein Community together with Overijssel (Foodvalley, n.d.; World Food Innovations, n.d.; The Protein Community, n.d.).

In 2015, the Dutch Nutrition Centre adjusted the dietary guidelines and promoted a shift towards a more plant-based diet for health (CR, 2015). The mobilization of key actors also strengthened the PBMAs sector (F3) (3). The Planet (Het Planeet) was initiated by Jeroen Willemsen and unified meat substitute firms to collaborate and create a shared vision for the future of PBMAs. In 2017, The GPA came forth from The Planet, and is an alliance between meat substitute firms, the NGO Nature and Environment (''Natuur & Milieu'') and the Dutch Nutrition Centre. Their goal is to equalize the current ratio of plant-based protein to animal protein ratio from 37:63 to 50:50 by 2025 (A8; Green Protein Alliance, n.d.). The alliances between industry, governmental agencies and NGOs further strengthened the legitimacy of PBMAs (F7). The growing legitimacy led to higher consumer demand for PBMAs, which in turn increased positive expectations (F4), which eventually led to further investments in R&D (F6) (Tziva et al., 2020). With rising popularity, resistance to PBMAs emerged. For example, The Vegetarian Butcher was ordered to change several product descriptions on their website after an NVWA investigation (Van Leeuwen, 2017). Incumbent actors also started to lobby against PBMAs. Farmers requested to ban names such as ''veggie burger'' and ''vegan sausage'' to avoid misleading consumers (Blenkinsop, 2020). This proposal was rejected (Kwai, 2020). In sum, continuous R&D, increased health and environmental awareness, and active governmental involvement were the main drivers that led to the success of PBMAs.

8.2. Similarities and differences

This section outlines the inherent and trajectory differences and similarities between CM and PBMAs.

8.2.1 Similarities

Several similarities can be identified. Firstly, the drivers to purchase CM and PBMAs come from the same ideals: environmental awareness, health concerns and ethical considerations (A4; A8; A10). The increasing awareness of sustainability issues led to positive expectations with scientists and governmental bodies for the potential benefits of PBMAs and CM for the mitigation of livestock related climate problems. Legitimacy creation (F7) played an important role in the early stages of both technologies. Vegetarians and vegans were advocating for PBMAs, which created niche markets (Tziva et al., 2021). For CM, consumers did not drive the development, and niche markets are lacking due to the NFR. However, the legitimacy of CM is relatively strong and created by CM advocates such as Ira van Eelen and Mark Post. CM is recognized as a legitimate technology and has created positive expectations within private investors and the NGF (F4), hence the large fundings. The growth plan presented by the CANS solidified the €60-85 million funding, which kickstarts the sector development, in coordination with the LNV (F2, F6). A similar trajectory took place for PBMAs. Positive expectations led to the start of research programs such as PIEK and Profetas initiated by the LNV. Both PBMAs and CM also initially lack consumer acceptance (A4; A8; A9; A10). Taste, familiarity, attitudes, food neophobia and social norms can act as barriers for consumers to try alternative proteins such as PBMAs or CM (Onwezen et al., 2021; Jahn et al., 2021). Food neophobia is the reluctance and/or avoidance of consumers to novel foods (Pliner & Hobden, 1992; Siegrist, 2020). To increase the legitimacy for consumers towards CM, it is important that quality CM products are introduced to the market so that consumers experience a positive first impression (A1).

8.2.2. Differences

While both are an alternative protein, there are also differences that can be observed regarding regulations and technological obstructs. Firstly, the CM technology is inherently more complex than PBMA's. The challenges CM faces with regards to production price and scalability are larger barriers than PBMAs have ever faced (A8). The technology of PBMAs is well established and the main goal is to tweak the products to mimic meat to the greatest extent possible (A7). Secondly, CM is not yet commercially available in Europe due to the NFR. This regulation is scientifically demanding and expensive, especially for start-ups and SMEs (Lähteenmäki-Uutela et al., 2021). The creation of niche markets (F5) by vegetarians and vegans was important in the early phase of PBMAs because it drove entrepreneurial experimentation (F1) (Tziva et al., 2020). CM has no niche market because of the NFR, and consumers can therefore not drive the creation of niche markets and potentially drive entrepreneurial experimentation. Entrepreneurial experimentation is mainly driven by the investments of private investors and the Dutch government (NGF) who have positive expectations for CM (F4).

Another difference is that the threshold for entering the CM TIS for new entrepreneurs is high since products cannot be commercialized yet. This slows down the rate of innovation of CM. The NFR presented a barrier for PBMAS, because it obstructed producers with experimenting with certain ingredients such has leghaemoglobin (Tziva et al., 2020; Lähteenmäki-Uutela et al., 2021). Leghaemoglobin is derived from the roots of leguminous plants and has similar properties as hemoglobin found in meat. This is an example of an ingredient that must go through European legislation before it is approved safe for consumption (Lähteenmäki-Uutela et al., 2021). Still, PBMAs arguably had a better starting position than CM, because the regulatory barriers only prevail for specific ingredients compared to the entire production process of CM. Therefore, it is highly possible that public and private investments were made with less hesitation for PBMAs, which likely resulted in faster innovation.

Thirdly, the main concern for PBMAs producers during the formative stage was to develop products that would satisfy consumer preferences. For CM, the biggest challenges are the upscaling of the production process (A1), reducing the price and receiving approval by the EFSA (A1; A2; A3; A4; A5; A11). Whether CM will be bought by consumers is difficult to predict. This likely gives policy makers and private investors less incentive to fund companies or the CANS. While the public investment by the NGF is high, it is still insufficient considering how young the industry is. As described previously, the CANS had initially requested a €280 million investment. The NGF only awarded €60 million due to (technological) uncertainties.
In addition, investing such large amounts can create expectations which could possibly not be reached, which would be damaging for the acceptation process amongst consumers (A11).

8.3. Insights

Two interviews were held with key actors from the PBMAs sector: Jeroen Willemsen from GPA and Robin Haakmat, Senior Product Developer at Vivera. The aim of these interviews was to inquire about the drivers and barriers of the PBMAs transition, strategies, and guidance for CM. Their advice is outlined in the following section, and if available, also complemented with advice from the CM interviewees.

Mobilize actors and create a common vision
The mobilization of actors, such as the establishment of The Planet and GPA, indicated that goal (3) *stimulate occurrence of interactions* was being realized. Bringing key actors together and creating a shared vision will strengthen the CM TIS. Reluctance might arise due to IP concerns and self-interest; however, the goal is to establish concrete goals for the future direction of the sector that all actors can identify with. Common dividers are the direction of the market, how the government can assist, and consumer perception. Important is to include numbers for volumes, quantities, and kilograms to showcase the commercial potential of CM. Educating oneself on the transition theory and in which transition stage the technology is ''located'' could also aid in establishing effective measurements (A8).

Find a spokesperson
The presence of one spokesperson on behalf of the entire sector can be beneficial as this person exceeds the underlying competition, gains public confidence, and communicates the vision clearly. The CM sector in the Netherlands has Ira van Eelen and Mark Post as spokespersons. The next step for CM is to mobilize and communicate from a sector-wide background with a sense of politics, communication, marketing branding and positioning, and not necessarily from a scientific background. This is still missing in the CM sector (A8). Thus, goal (5) *secure the presence of hard and soft institutions* could improve the institutionalization of CM.

Work on the provincial level
The start of large public-private programs indicates that goal (1) *stimulate and organize participation of actors* was being fulfilled. The national and regional programs that were being implemented could be assigned to goal (2) *create space for actor's capability development* and (7) *stimulate physical, financial and knowledge infrastructure,* because the government funded research projects which allowed industry actors to research and develop their products. Young innovative companies are more likely to be helped and supported financially by regional development programs. These programs are less tied to national politics and sensitivities surrounding it (A8).

Increasing consumer acceptance
A combination of price, taste and identity is important to consumers (A1; A8; A9; A11). Whilst taste and texture of CM will most likely not be an issue, price remains one. It is important for both PBMAs and CM to reach price-parity with conventional meat (A10). Several developments took place which indicate that goal (5) *secure presence of hard and soft institutions* was being fulfilled, such as the implementation of the NPS and the adjustments of the dietary guidelines by CR.

Funding research projects at universities:
According to Willemsen, excessively funding research projects at universities is not effective. There is a risk that a large sum of the money will be allocated to the university department and not the R&D project. This strategy is ingrained in the Dutch IS. Innovations within the food domain are still very much associated with universities and knowledge institutes. Entrepreneurs play a greater role in the practical applicability of food innovations, however, the government wants to prevent the perception that public money is being invested in private companies; something that is not allowed for competitive reasons. There is a split between public and private, and therefore money is usually invested into universities. However, with most of the CM research happening within companies, it would presumably be more effective to establish private-public partnerships. This is especially important if the aim is to be competitive with other countries such as Israel, the USA and Singapore, where CM is developing at a faster rate. This implies that the instrument ''new forms of Public Private Partnerships'' from goal (1) *stimulate and organize participation of actors is beneficial.*

Hybrid models
Hybrid models could play a part in the future alt-protein landscape (A1; A9; A9; Vegconomist, 2022). These products consist of both plant-based ingredients and CM (Asioli, 2022; A1; A9). Hybrid models share more of the meat-like characteristics than the fully plant-based options, the latter often not fully satisfying consumers (Spencer et al., 2018). Hybrid models can fulfill what is missing in contemporary PBMAs such as animal fat (A9; Southey, 2021). Furthermore, the end-product will also have a more similar nutritional profile to conventional meat. Moreover, there are additional environmental benefits, such as reducing the need for plant-based oils which usually originate from crops grown as monocultures (Southey, 2021). However, hybrid models have failed in the past and are expected to fail in the future. Consumers either want to eat fully plant-based or a good quality sourced piece of meat, and not something in-between (A8).

8.4. Conclusion PBMAs
This concluding section will answer sub-question 3: '*'Are there insights that can be drawn from the PBMAs sector to improve the performance of the TIS*?

PBMAs have been steadily rising in popularity since the 90's and the Dutch are now the biggest consumers in Europe. Several forces have driven the development of PBMAs, including increased governmental involvement and the heightened public awareness of negative consequences of livestock farming. PBMAs and CM are both alternative proteins and share several (trajectory) similarities and differences. By identifying similarities and interviewing experts from the PBMAs sector, several insights could be drawn that could possibly benefit CM's transition into the growth phase. Experts from the PBMAs sector provided several insights based on their experience with building their sector that could aid the development of the CM sector. In the following section, goals, instruments, and functions are indicated with their respective numbers.

Several systemic goals and tools were identified that aided PBMAs from transition from the formative phase into the growth phase. To increase governmental involvement, support, and funding (F4), it is crucial to mobilize key actors (3) and establish concrete goals for the future trajectory of the sector through, for example, backcasting and roadmapping (2). Secondly, goal 3 was implemented by mobilizing key actors through an alliance or network such as The Planet and GPA. Key actors created shared visions, goals, and expectations that made the growth plan of PBMAs concrete with numbers through volumes, quantities, and kilograms to showcase the potential. Thirdly, collaborations between the private sector and formal authorities continued the institutionalization of PBMAs as part of a sustainable food system and part of a healthy diet (5). The start of big public-private programs like PIEK and Profetas funded by governmental agencies such as LNV and EKZ, gave producers the capacity to conduct R&D and experiment with the technology (1, 2, 7), which ultimately improved the quality of the products and increased consumer acceptance. Therefore, experts recommend initiating public-private programs and/or partnerships, as most R&D is conducted within companies. Recommended was also to work on the provincial level because there is a higher chance of receiving support. Lastly, whilst not necessarily linked to any of the functions, pushing hybrid products was not recommended. Hybrids tend to fail because consumers either want to eat plant-based or eat good quality meat, and not something in-between.

Finally, it should be recognized that PBMAs had a significantly more beneficial starting point than CM. The CM technology is far more complex than PBMAs. Still, there are several technological barriers that make scaling-up production while simultaneously being cost-effective difficult Secondly, the regulatory hurdles that CM faces are blocking companies from bringing products onto the market. This makes it extremely difficult to raise positive expectations through, for example, consumer demand, which could signal policy makers to create policies that stimulate the building of physical, financial and knowledge infrastructure. Thus, CM has significantly bigger barriers to overcome than PBMAs.

9. Recommendations

The results provide a basis for recommendations for policy makers and companies to stimulate the development of the CM sector in the Netherlands. To transition into the next stage several recommendations are proposed:

Stimulate open access research and knowledge sharing
The lack of knowledge sharing due to IP concerns slows down the innovation progress of CM and can leave policy makers and the public not educated enough about the technology. Uninformed policy makers are less likely to push for public funding and create favorable policies, tax regimes and subsidy regulations. Therefore, knowledge sharing between producers, government and users should be stimulated. Because most of the research happens within companies, it is necessary to also stimulate open access- and independent research. It should be avoided that lines of (failed) research are repeated, as this slows down the speed of innovation. Open-access research facilities must be built, as they are important at this pre-competitive stage. CM still faces some technological barriers related to scaling-up the production capacity, while also reducing the producing costs. However, it is difficult to obtain private funding for open access research infrastructure as these facilities are temporary and cannot produce products at a commercial scale. Thus, increased public funding should be invested in open access research.

Deepen governmental involvement
Governmental involvement has been limited in terms of setting goals, expectations and creating corresponding policies and regulations. Firstly, involvement of formal authorities could possibly increase the legitimization CM. Public-private partnerships or programs have proven to be successful for the innovation, development, and institutionalization of PBMAs, especially on the regional level. Programs such as PIEK and Profetas stimulated R&D and entrepreneurial activity, and thus increase knowledge development. However, because the CM sector is very much private-sector driven and concerned with IP, these public-private arrangements need to have certain conditions with regards to knowledge sharing. For example, findings coming from joint research programs must become available for the public.

Secondly, whilst an allocation of €60 million could be interpreted as a large sum, CM is a nascent sector and challenges regarding the scaling up of production and cost reduction remain Thus, eventually more public funding will be needed. This funding could be in the form of R&D grants, loans, and subsidies, and is recommended to be invested in the construction of open-access test and scaling-up facilities, pilot plants and other relevant physical infrastructure. Publicly available research centers will produce findings that will increase the performance of the CM technology, and possibly overcome existing technological barriers. Public funding will also break the negative feedback loop (see Figure 10). Governmental financing can stimulate open access research and therefore increase the exchange of knowledge between key actors. In turn, governmental actors, such as policy makers and ministers, are more informed on CM and can better set expectations and goals. Policy makers with positive expectations could potentially increase the availability of funds, and implement favorable tax- and subsidy regimes. This in turn will likely stimulate the entry of new entrepreneurs, and thus the development of new knowledge and speed innovation.

Stimulate institutionalization of CM
The growth stage is characterized by the increased structurization of technology related institutions. The institutions of CM can be strengthened by implementing soft and hard measures to stimulate the emergence of technology specific institutions and strengthen the existing ones. Technology specific institutions include hard measures such as safety procedures and standards, interoperability standards and technical norms. This is an important aspect because CM currently is going through the NFR procedure, in which CM companies must prove that products are safe for consumption, and that production processes are safe and reliable. However, most companies are presenting their own safety procedures as there is a lack of independent research conducted on safety assessment procedures. Thus, more research must be conducted on standard risk assessment procedures. When more is known on standard safety procedures of CM, a standardization committee for CM on European Union level should be established.

Soft measures include information and education campaigns, and awareness building measures. This will increase the knowledge on CM amongst the public and policy makers. Secondly, creating CA/CM specific educations, or integrating CM/CA knowledge into existing educational curriculums, will stimulate the formation of qualified personnel and workforce. Because the CM sector was initially mainly private sector-driven, it lacks the academic foundation that many other innovations had established. Expertise comes from several different domains such as tissue engineering, biomedical sciences, biology, and food science. Therefore, it is the right timing to orchestrate the foundation of a CM/CA academic field and workforce.

10. Discussion

The following section outlines a discussion of the results and elaborates on the limitations of the research

10.1. Discussion of the results

The results of the structural and functional analysis indicate that the CM TIS appears to be driven by the Entrepreneurial Motor. For example, the functions Counteract Resistance to Change/ Legitimacy Creation (F7) and Entrepreneurial Activity (F1) are sufficiently fulfilled. Entrepreneurial activity by CM firms and the strong lobby are important drivers of the development of the CM TIS. Market Formation (F5) was not functioning well, which is also in line with the typology by Suurs (2009) as this function usually plays a more significant role in the next motor. The aspects that correspond with the Entrepreneurial Motor identified in the CM TIS are discussed under section 6.8 ''Entrepreneurial Motor''. There are aspects of the CM TIS that align with the typology of the Entrepreneurial Motor, but the motor appears to be weak in the CM TIS, and thus is not completely identical to the motor. There are still several barriers that likely obstruct the full potential impact the motor can have on the CM TIS. There obstructs can be found within Knowledge Development (F2), Knowledge Exchange (F3), Guidance of the Search (F4) and Resource Mobilization (F6) because they scored weak to moderate, and are not strongly fulfilled, as stated in Suurs (2009). The observed barriers are also different than the barriers of the Entrepreneurial Motor (Suurs, 2009). This possibly gives new insights of potential barriers that can hamper the functioning of the Entrepreneurial Motor.

Another novel finding is related to the systemic goals. The recommended set of goals for CM are (1) s*timulate and organize the participation of actors,* (2) *create space for actor's capability development,* (3) *stimulate the occurrence of interactions,* (5) *secure the presence of hard and soft institutions* and (7) *stimulate physical, financial and knowledge infrastructure.* Analyzing the PBMAs transition provided additional insights into how the CM can transition into the growth phase. Planned comparisons revealed that the same systemic goals (1, 2, 3, 5 and 7) were also identified in the transition of PBMAs from the formative stage into the late formative stage. The results possibly imply that these systemic goals should be implemented for a food related TIS to transition from a formative stage into the late formative stage, which could possibly be a future research topic. Another finding related to the systemic problems was that they were mostly presence problems, meaning that there is a lack of present actors, institutions, infrastructure, or interactions. This could likely be explained by the fact that CM is a nascent sector and therefore many structural elements still need to be established or grow. The characteristics of the formative stage include low institutional structuration, loose networks, and a small number of actors (Markard & Hekkert, 2013, as cited in Bento & Wilson, 2016), which is somewhat in line with the finding of the absence of the structural elements. Future research could investigate questions on the nature of the systemic problems per lifecycle stage. For example, is the formative stage identified with presence related systemic problems and the growth stage possibly with capacity related problems? These avenues of research could possibly deepen the understanding which policy goals and instruments are suitable per lifecycle stage.

Guurink (2020) conducted a structural-functional analysis, a Multi-Level Perspective (MLP) analysis and researched strategies of involved actors to analyze how the Dutch CM TIS was developing, and under which circumstances the TIS could grow. This research concluded several findings with regards to the functional analysis, which also resulted in different recommendations compared to this research. Entrepreneurial Activity (F1) and Knowledge Development (F2) were scored as moderate in both research papers. This identical finding is most likely because the number of knowledge-producing actors barely changed in the past two years. No new CM producing actors entered the TIS. The number of patents increased by one, and the number of published articles has steadily grown. This low number of patents is likely attributed to the NFR, which has given new players no incentive to enter the market. Because the networks are small and have high intensity, Knowledge exchange (F3) scored moderate according to Guurink. With the establishment of the CANS, I argue that the network size has grown and is in proportion given the stage of the TIS. However, I scored F3 as weak because companies are reluctant in sharing technological developments due to IP concerns. In addition, the number of workshops and conferences is scored as moderate by Guurink, but her research states that they are rare. Based on my findings, I argue that this indicator scores weak, because there are still not many conferences and workshops in the Netherlands. Guidance of the search (F4) scores weak according to Guurink, which I partially agree with. Because key actors have mobilized through the CANS and established goals for the CA sector, I argue that their vision is strong. Corresponding to Guurink's findings, governmental involvement remains limited. Market formation (F5) scored high, which is in contrast to the findings of this research. Market size and potential are difficult to predict because the product cannot be sold on the market yet, and expectations are therefore only based on hypothetical situations. Furthermore, a different indicator was used in my research (the presence of beneficial tax regimes) instead of ‵′efforts to create market′′, which could also have resulted in a different scoring of the function. Resource mobilization (F6) scored similar with regards to the financial resources, however, I disagree with the high score for physical resources. Guurink argues that the CM sector can benefit from the farmed meat infrastructure. Based on the interviews with experts and my analysis, I argue that this is not possible given that CM production is extremely technological and production facilities must be aseptic. Therefore, it will not be easy to simply use the livestock infrastructure. Secondly, the availability of human resources has increased as the companies have grown in number of employees, thus the lower score for this indicator is not accordant anymore. Lastly, Counteract Resistance to Change/ Legitimacy Creation (F7) scored weak according to Guurink, contrary to this research. Lobby activity scored strong since they have increased since 2020 with the establishment of the CANS consortium. The CANS has been successful in acquiring large funding and support from the government.

The variety in scoring can be caused by a few reasons: Firstly, the CM TIS has inevitably progressed since 2020, which results in different assessments of some functions. Secondly, sometimes other indicators were used which can cause a different end-scoring based on the performance of an indicator. Thirdly, the interviews and results are ultimately subject to the interpretation of the researcher. A critique from the researcher was that it was difficult to determine what was considered weak or strong during the assessment of the functions. For example, when assessing quantitative indicators such as ‵′numbers of new entrants′′ and ‵′number of workshops′′, there is no pre-determined number of what constitutes as weak or strong. This lack of guidance emphasizes that qualitative research is context specific and subject to varying interpretations. Another factor to keep in mind is that different publications on the TIS contain different indicators.

A second difference between this research and the work of Guurink was that her research centered many recommendations on external influences and actors, because her research included the MLP framework and actor strategies. The recommendations are more so created to adapt to the developments occurring on the landscape- and regime-level. For example, two of the recommendations are ‵′develop long-term vision for the meat sector′′ and ‵′cooperate with the conventional meat system′′. Secondly, some of the listed bottlenecks are not relevant anymore, such as the limited lobby activity and low human resources, because the TIS has progressed ever since. The differences in indicator and function assessment also indicate that the recommendations need alternations and additions, because the TIS is at a further stage in the formative stage. In conclusion, the CM TIS has progressed since 2020 which has resulted in several different assessments of functions and indicators. Additionally, Guurink's research describes the symptoms (bottlenecks) of the TIS, and her recommendations are more focused landscape- and regime-level developments. This research focuses more micro-level dynamics and on the underlying systemic obstructs of the CM TIS.

This variation of findings and lack of TIS research on CM in the Netherlands suggests that further research is required for a better understanding of the systemic problems of the Dutch CM sector. Alternations had to be made frequently, leading to different findings and conclusions throughout the research. This highlights the fact that the CM TIS is dynamic and constantly changing. It is therefore crucial to continuously research CM, so that systemic problems are identified, and appropriate goals and instruments are implemented. After CM develops from the formative stage into the growth stage, the next step would be to identify which systemic problems obstruct the TIS from moving into the mature stage. The findings of this research contribute to the increasing body of knowledge on CM, CA, and alternative proteins. The recommendations serve as a guidance for policy makers to implement suitable policies that will stimulate the consumption of alternative proteins, thus contributing to the mitigation of environmental problems caused by livestock production.

10.2. Limitations

The findings of this study must also be seen in the light of its limitations. Limitations of the present study include the sample size, the interview structure, the research scope, and researcher interpretation. Firstly, the sample size of interview participants was limited (11). For the CM participants, this issue was addressed by choosing at least one interviewee to represent each actor group. Due to lack of response, only two interview participants represented the PBMAs sector. One or two more actors from the PBMAs sector would have strengthened the external validity. Secondly, conducting semi-structured interviews may deliver biased results because only a select group of people is interviewed that have their own opinions and interpretations. The interpretations of the results are also subject to the perception of the researcher. Analyzing relevant literature, reports, websites, and newspaper articles has accounted for the gaps of knowledge and was also a means to confirm the interview results. Because of time limitations and the semi-structured nature of the interviews, not all questions from the interview guide could be asked. Questions were selected prior to the interview and based on the expertise of interviewee to try to ensure that substantive answers were given. Therefore, some structural elements and function assessments were based on only one or two interviewees.

The third limitation is related to spatial aspects and the context of the TIS. As discussed in section 3.6.1. '*'Notes on the TIS framework''*, these are two limitations of the TIS. This research did not extensively account for spatial aspects of the context of the TIS as the boundaries were set within the Netherlands. Developments in other countries influence the direction and speed of innovation in the Netherlands. Outside influences, such as the possible effects that the expansion of Mosa Meat and Meatable to Singapore has on the Dutch TIS and the first FDA approval for CM (Reiley, 2022), were not included. However, developments like these likely influence developments in the Netherlands. How these developments influence the Dutch CM sector could be a topic for future research. The fourth limitation concerns the scoring of the functions and determining of systemic problems, goals, and instruments, which is based on the interpretation of the researcher.

11. Conclusion

The aim of this research was to identify systemic problems within the Dutch CM sector, and thereupon propose recommendations that could aid the development of the TIS. The main research question ''*How can the cultured meat sector in the Netherlands transition into the next stage of development?''* was researched by using the TIS framework, the Motors of Innovation typology and the concepts derived from the systemic policy scheme by Wieczorek & Hekkert (2012) to identify weak functions and their underlying systemic problems. Afterwards, systemic goals were assigned to the systemic problems including corresponding policy tools. Lastly, the development and transition of the PBMAs sector from the formative into the late formative stage was analyzed to determine whether useful insights from this similar sector could aid in the development of recommendations.

Extensive qualitative research, including interviews with key actors from within the industry, revealed that functions F2 – knowledge development, F3 - knowledge exchange, F4 – guidance of the search, and F6 – resource mobilization scored weak to moderate. In addition, a feedback loop was identified between functions F3, F4 and F6. The lack of public funding and financial infrastructure (F6) has forced companies to resort to private investors for funding, with the consequence that companies are now concerned with IP and are restrictive in the knowledge they share (F3). Policy makers remain relatively un- or misinformed and therefore concrete visions, expectations and policies remain rather absent (F4). In turn, policy makers are less likely to push for more public funding or to create favorable tax and subsidy regimes (F6). Lastly, the limited knowledge sharing (F3) and access to public funding (F6) also slows down knowledge development (F2)

The second finding was that most systemic problems were presence related, meaning that in general there is an absence of necessary actors, institutions, interactions, and infrastructure. The assigned goals to the systemic problems were (1) *stimulate and organize the participation of actors,* (2) *create space for actor's capability development,* (3) *stimulate occurrence of interactions,* (5) *secure presence of (hard and soft) institutions,* and (7) *Stimulate physical, financial and knowledge infrastructure*. The PBMAs analysis showed that similar to what was identified in the analysis of CM, goals (1), (2), (3), (5) and (7) were also important for the PBMAs to develop. Thus, the insights from the PBMAs analysis confirmed that these were suitable systemic goals and policy instruments to implement.

While each function has one or two underlying obstructs and systemic problem(s), two common denominators hinder to the development of the TIS: the NFR and the technological barriers as described in section 4.5 ''technological barriers''. There remains a degree of uncertainty as to whether CM can be produced on a larger scale while also being economically feasible at the same time. Secondly, the NFR regulation has made it impossible for producers in Europe to bring products onto the market. This leads to the conclusions that 1) the NFR makes it increasingly difficult for companies to obtain funding (F6) as it is not proven that CM will be commercially successful, 2) regulators are therefore less inclined to create and implement favorable policies (F4) and (3) this explains the low number of actors in the TIS, affecting the amount of knowledge development (F2).

The structural-functional analysis, the systemic problem analysis and the PBMAs sector comparison provided the basis for several recommendations. The first recommendation is to stimulate open access research and knowledge sharing through the means of public funding. Secondly, deepening governmental involvement by for example starting large public-private programs and increasing financial aid through R&D grants, funds, and loans. Intensifying the connection with the government will likely strengthen knowledge exchange and consequently stimulate policy makers push for favorable policies. Secondly, the alliance with authoritative bodies strengthens the legitimacy of CM, which can potentially create positive expectations amongst policy makers, the public and investors. Lastly, stimulate the institutionalization of CM through the establishment of safety standards, and soft measures such as information and education campaigns to increase awareness. To conclude, the CM sector is rapidly developing in the Netherlands. Positive developments such as the approved motion for tastings, and the investment from the NGF emphasize that there are positive expectations for CM. However, CM remains in the formative stage and there are several interrelated barriers that must be overcome to transition into the growth stage. With thoughtful planning and collaboration between governments, private actors and researchers, and careful allocation of resources, CM has the potential to play a significant part in the transition to a sustainable food system.

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Appendix

Appendix A – Interview guide CM

Dutch version

<u>Interview deel I – Structuur-analyse</u>

Actoren
• Wie zijn volgens u de belangrijkste actoren in de Nederlandse kweekvlees sector op het gebied van kennisontwikkeling/regelgeving/bedrijven/organisaties?
• Met welke van deze actoren heeft uw het meeste contact gehad?
• Heeft u contact met Europese actoren? Zo ja, met wie?
• Wat zijn de belangrijkste ontwikkelingen voor de Nederlandse kweekvlees sector op het gebied van kennisontwikkeling/regelgeving/bedrijven/organisaties?
• Wat zijn de huidige ontwikkelingen binnen uw/het bedrijf?

Instituties
• Zijn er op dit moment Nederlandse en/of Europese regelgevingen die de ontwikkeling van kweekvlees bevorderen of belemmeren?
• Wat is volgens u de huidige publieke opinie over kweekvlees?

Infrastructuur
• Is er voldoende kennis infrastructuur/ fysieke infrastructuur/ financiële infrastructuur?
• Wat zijn de grootste technologische obstakels?
• Wat is er nodig voor het verbeteren en uitbreiden van de fysieke infrastructuur?
• Wat is er nodig voor het verbeteren en uitbreiden van de kennisinfrastructuur?
• Wat is er nodig voor het verbeten en uitbreiden van de financiële infrastructuur?
• Wat is er volgens u nodig om de marktintroductie van kweekvlees te versnellen?

Interacties
• Welke interacties kunnen er worden herkend op netwerkniveau
• Welke interacties kunnen er worden erkend op individueel niveau?

<u>Interview deel II – Functie-analyse</u>

1. Experimenten en productie van entrepreneurs

- Wie zijn de meest relevante actoren?
- Zijn er voldoende industriële actoren/ondernemers in het innovatiesysteem?
- Innoveren industriële actoren voldoende op grootschalige productie?
- Zou u in vergelijking met andere landen zeggen dat er in Nederland veel wordt geëxperimenteerd en geïnnoveerd?

2. Kennis ontwikkeling

- Is de hoeveelheid en kwaliteit van kennisontwikkeling voldoende voor de ontwikkeling van het IS, of vormt het een barrière voor de TIS?
- Welke kennis is nu nodig voor deze fase van ontwikkeling van kweekvlees?

3. Kennis uitwisseling

- Vindt u dat er voldoende kennisuitwisseling is tussen wetenschap en bedrijfsleven? En tussen gebruikers en industrie?
- Vindt u dat er voldoende kennisuitwisseling is over geografische grenzen heen?
- Is er een gebrek aan kennisuitwisseling en zo ja, vormt dit een barrière voor het innovatie systeem om naar de volgende fase te gaan?
- Ziet u goede mogelijkheden voor samenwerkingen?

4. Sturing van de zoektocht

- Vindt u dat er een duidelijke visie is op hoe de industrie en markt moeten ontwikkelen? Bijvoorbeeld door middel van regeringsdoelen?
- Denkt u dat er duidelijke en haalbare beleidsdoelen zijn? Zo nee, welke beleidsdoelen zou u graag zien?
- Wat is uw visie voor kweekvlees?
- Denkt u dat uw visie aansluit bij de visie van andere actoren of denkt u de visie meer op één lijn zou kunnen liggen?
- Wat zijn de grootste drijfveren en belemmeringen voor de ontwikkeling van kweekvlees?

5. Marktvorming
- Hoe groot verwacht u dat de toekomstige marktomvang zal zijn?
- Wat zijn volgens u de grootste belemmeringen voor de groei van de marktomvang?
- Denkt u dat kweekvlees een aparte markt nodig heeft of denkt u dat het in bestaande markten kan worden geïntegreerd?
- Wat is er volgens u nodig om de marktintroductie van kweekvlees te versnellen?

6. Mobilisatie van middelen
- Denkt u dat er een gebrek is aan middelen (financieel/menselijk/fysiek)?
- Zo ja, hoe denkt u dat dit verbeterd kan worden?
- Op welke manieren kan de fysieke infrastructuur worden verbeterd?

7. Tegengaan van weerstand tegen verandering/ legitimiteitscreatie
- Is er weerstand tegen de technologie? Zo ja, van welke kant komt deze weerstand?
- Bent u op de hoogte van lobbygroepen tegen of voor kweekvlees?

Interview deel III - PBMAs
- Denkt u dat er overeenkomsten zijn tussen de sector van plantaardige vleesvervangers en de kweekvlees sector? Zo ja, kunt u uitleggen welke?
- Denkt u dat er overeenkomsten zijn tussen de geschiedenis van sector van plantaardige vleesvervangers en de kweekvlees sector? Zo ja, kunt u uitleggen welke?
- Denkt u dat er inzichten en lessen uit deze sector kunnen worden toegepast tot kweekvlees? Zo ja, welke?
- Wat is volgens u het grootste verschil tussen kweekvlees en plantaardige vleesvervangers? Bijvoorbeeld in termen van regulering/ consumenten acceptie/ marktdynamiek.
- Zijn er wetten en/of beleidsinstrumenten die moeten worden geïmplementeerd zodat kweekvlees de groeifase in kan gaan?

English version

Interview part I – Structural analysis

Actors
- Who do you think are the most important actors in the Dutch cultured meat sector in the field of knowledge development/regulations/companies/organizations?
- Which of these actors have you had the most contact with?
- Do you have contact with European actors? If so, with whom?
- What are the most important developments for the Dutch cultured meat sector in the field of knowledge development/regulations/companies/organizations?
- What are the current developments within the/your company?

Institutions
- Are there currently Dutch and/or European regulations that promote or hinder the development of cultured meat?
- What do you think is the current public opinion on cultured meat?

Infrastructure
- Is there sufficient knowledge infrastructure/physical infrastructure/financial infrastructure?
- What are the biggest technological obstacles?
- What is needed to improve and expand the physical/knowledge/financial infrastructure?
- What do you think is needed to accelerate the market introduction of cultured meat?

Interactions
• What interactions can be recognized at the network level
• What interactions can be recognized at an individual level?

Interview part II – Functional analysis

1. Experiments and production of entrepreneurs
• Who are the most relevant actors?
• Are there sufficient industrial actors/entrepreneurs in the innovation system?
• Do industrial actors innovate sufficiently on large-scale production?
• Compared to other countries, would you say that there is a lot of experimentation and innovation in the Netherlands?

2. Knowledge development
• Is the amount and quality of knowledge development sufficient for the development of the IS, or is it a barrier for the TIS?
• What knowledge is now required for this stage of cultured meat development?

3. Knowledge exchange
• Do you think there is sufficient exchange of knowledge between science and industry? And between users and industry?
• Do you think there is sufficient knowledge exchange across geographical borders?
• Is there a lack of knowledge exchange and if so, is this a barrier for the innovation system to move to the next stage?
• Do you see good opportunities for collaborations?

4. Guidance of the search
• Do you think there is a clear vision on how the industry and market should develop? For example through government targets?
• Do you think there are clear and achievable policy goals? If not, what policy goals would you like to see?
• What is your vision for cultured meat?
• Do you think your vision is in line with the vision of other actors or do you think the vision could be more aligned?
• What are the main drivers and barriers to the development of cultured meat?

5. Market formation
• How big do you expect the future market size to be?
• What do you think are the biggest barriers to market size growth?
• Do you think cultured meat needs a separate market or do you think it can be integrated into existing markets?
• What do you think is needed to accelerate the market introduction of cultured meat?

6. Mobilization of resources
• Do you think there is a lack of resources (financial/human/physical)?
• If so, how do you think this could be improved?
• In what ways can the physical infrastructure be improved?

7. Countering resistance to change/creation of legitimacy
• Is there resistance to the technology? If so, where does this resistance come from?
• Are you aware of lobby groups against or for cultured meat?

Interview part III - Plant-based meat alternatives
• Do you think there are similarities between the plant-based meat substitutes sector and the cultured meat sector? If so, can you explain which ones?
• Do you think there are similarities between the history of the plant-based meat substitute sector and the cultured meat sector? If so, can you explain which ones?
• Do you think insights and lessons from this sector can be applied to cultured meat? If yes which one?
• What do you think is the biggest difference between cultured meat and plant-based meat substitutes? For example in terms of regulation/consumer acceptance/market dynamics.
• Are there any laws and/or policies that need to be implemented so that cultured meat can enter the growth stage?

Appendix B – Interview guide Plant-based meat alternatives
Dutch version

1. Introductie
• Kunt u zich kort voorstellen alstublieft? Wat is uw rol binnen [*naam*]?
• Kunt u alstublieft kort vertellen hoe [*naam*] tot stand is gekomen?
• Waarom is Nederland ideaal voor de productie van plantaardige vleesvervangers?
• Wat is [*naam*] positie ten opzichte van kweekvlees?
• Wat voor rol denkt u dat kweekvlees gaat spelen in de aankomende 10 jaar?

2. Drijfveren en hindernissen
• Wat zijn de belangrijkste drijfveren geweest voor de ontwikkeling en groei van plantaardige vleesvervanger sector als u kijkt naar de afgelopen 30 jaar?
• Wat zijn volgens u de belangrijkste mijlpalen geweest voor plantaardige vleesvervangers?
• Wat zijn de barrières die de sector heeft overkomen? En hoe zijn deze barrières overkomen?
• Welke actoren hebben een belangrijke rol gespeeld in de ontwikkeling van plantaardige vleesvervangers?
• Wat zijn de strategieën die u gebruikt om de ontwikkeling en verkoop van plantaardige vleesvervangers te versnellen?

3. Doelen en instrumenten
• Heeft de overheid bijgedragen aan de groei van de plantaardige vleesvervanger? Zo ja, hoe?
• Kunt u mij vertellen of er bepaald beleid is ingevoerd die de sector heeft bevorderd?
• Zijn er bepaalde beleidsinstrumenten of andere strategieën geweest die *niet* succesvol zijn geweest voor de bevordering van plantaardige vlees alternatieven?
• Zijn er volgens u bepaalde beleidsinstrumenten die ook toepasselijk zijn voor de kweekvlees sector? Zo ja, welke?

4. Vergelijking met kweekvlees
• Zijn er volgens u overeenkomsten tussen kweekvlees en plantaardige vleesvervangers? Zo ja, welke?
• Zijn er volgens u verschillen tussen kweekvlees en plantaardige vleesvervangers? Zo ja, welke?
• Kunt u mij vertellen of er bepaalde inzichten zijn vanuit de plantaardige sector die kunnen worden aanbevolen voor de bevordering van kweekvlees?

English translation

1. Introduction
• Can you briefly introduce yourself please? What is your role within [name]?
• Can you briefly tell how [name] came about?
• Why is the Netherlands ideal for the production of plant-based meat alternatives?
• What is [name]'s position with regards to cultured meat?
• What role do you think cultured meat will play in the next 10 years?

2. Drivers and barriers
• Looking at the past 30 years, what have been the main drivers for the development and growth of the plant-based meat alternatives sector?
• What do you think have been the most important milestones for plant-based meat alternatives?
• What are the barriers the sector has encountered? And how were these barriers overcome?
• Which actors do you think have been most important in the development?
• What strategies are you using to accelerate the development and sale of plant-based meat substitutes?

3. Goals and instruments
• Has the government contributed to the growth of the plant-based meat substitute? If so, how?
• Can you tell me if any policies have been put in place that have benefitted the sector?
• Are there any policy instruments and/or other strategies that have not been successful in supporting plant-based meat alternatives?
• Do you think there are similar policy instruments that could be implemented to the cultured meat sector?

4. Comparison with cultured meat

- Do you think there are similarities between cultured meat and plant-based meat alternatives? If yes, could you elaborate please?
- Do you think there are differences between cultured meat and plant-based meat alternatives? If yes, could you elaborate please?
- Can you indicate whether certain insights from the plant-based meat alternatives sector are advisable for the promotion of cultured meat?

Appendix C - Coding

System functions:
F1
F2
F3
F4
F5
F6
F7

Structural elements:
Actors
Infrastructure
Interactions
Institutions

PBMAs:
Drivers
Barriers
Systemic goal 1,2,3,4,5,6,7,8
Systemic instrument
Similarities PBMAs vs CM
Differences PBMAs vs. CM

Other:
Barriers CM
Benefits CM*
CM Technology
Consumers
About interviewee

System functions	Other	PBMA related	elements
F1	Barriers CM	Insights PBMAs	Actors
F2	Benefits CM*	Barriers PBMAs	Infrastructure
F3	CM technology*	Other PBMAs*	Interactions
F4	Consumers	Similarities PBMAs vs CM	Institutions
F5	About interviewee	Differences PBMAs vs CM	
F6			
F7			

***CM technology:** Answers related to the technology of CM
***Benefits CM:** Answers related to the perceived benefits of CM
***Other PBMAs:** Answers on other PBMA related topics

Appendix D – Consent form

INFORMED CONSENT FORM for participation in:

An analysis of cultured meat TIS in The Netherlands

To be completed by the participant:

I confirm that:

- I am satisfied with the received information about the research;
- I have been given opportunity to ask questions about the research and that any questions that have been risen have been answered satisfactorily;
- I had the opportunity to think carefully about participating in the study;
- I will give an honest answer to the questions asked.

I agree that:

- the data to be collected will be obtained and stored for scientific purposes;
- the collected, completely anonymous, research data can be shared and re-used by scientists to answer other research questions;
- video and/or audio recordings may also be used for scientific purposes.

I understand that:

- I have the right to withdraw my consent to use the data;
- I have the right to see the research report afterwards.

Name of participant: ___________________________________

Signature:______________________________________ Date, place: ____/____/, ___