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Article

Diversity and directionality: friends or foes in sustainability transitions?

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Literature on mission-specific innovation systems (MIS) highlights the crucial role of directionality when achieving sustainability transitions, while diversity literature emphasizes the need to keep diverse directions open. Like directionality, diversity is created by innovation system actors to tackle the complex and uncertain nature of transitions. While these two literature strands are presented largely independent of one another, both are deemed necessary to achieve sociotechnical transitions. We thus aim to uncover how diversity and directionality unfold in parallel in a MIS. We conduct a qualitative single-case study of the Wageningen alternative protein ecosystem to provide insights into the types of sociotechnological trajectories actors pursue and how different selection environments shape the development of each solution. We observe a mission exhibiting a clear direction toward (meat) substitutes. Underlying this mission, diversity is visible. We propose that the interplay between diversity and directionality in a MIS can be best understood by distinguishing two different sociotechnical "levels" in which they play out: the levels of transition paths ("first-order" directionality) and search directions ("second-order" directionality). We therefore call for a more nuanced understanding of the role of diversity and directionality in transitions.

Keywords: protein transition; plant-based protein; mission-oriented innovation; transformative innovation policy; diversity; directionality.

1. Introduction

The exacerbation of social, environmental, and economic challenges has prompted a shift in the innovation policy aimed at stimulating the transformative change of sectors (Weber and Rohracher 2012; Schot and Steinmueller 2018; Boon and Edler 2018; Wanzenböck et al. 2020; Hekkert et al. 2020). Innovation policy has shifted from focusing predominately on fixing market failures and promoting economic growth through technological innovation and development to focusing on "societal grand challenges" and supporting transformative change (Weber and Rohracher 2012; Boon and Edler 2018; Schot and Steinmueller 2018; Hekkert et al. 2020; Wanzenböck et al. 2020). Societal grand challenges can be defined as "wicked problems" (i.e. problems which are undeniably complex in nature, urgent, and deeply systemic), such as those related to food security, water scarcity, deforestation, and climate change (Mazzucato 2018; Wanzenböck et al. 2020).

Mission-oriented innovation policy (MIP) has recently arisen in the literature on transitions as a means to address these so-called "grand challenges" (Mazzucato 2016, 2018; Wanzenböck et al. 2020). Missions are defined as being challenge-led and thus constitute societal goals that involve transforming sectors to more desirable modes of both production and consumption. Examples of such "missions" include the 2019 Circular Economy mission initiated by the Dutch Ministry of Economic Affairs and Climate Policy, which aims to reach a fully circular economy by 2050 (Elzinga et al. 2023) and Germany's Energiewende (Mazzucato 2018). Literature on mission-oriented innovation policy has recognized the importance of a clear *direction* when tackling grand-societal challenges and, as such, the term "directionality" has been used in the literature to define this direction of change (Mazzucato 2016; Kattel and Mazzucato 2018; Schot and Kanger 2018; Yap and Truffer 2019).

The key goal of mission-oriented innovation policy is to create directionality. A well-defined mission creates a concrete direction of change in which actors can coordinate their strategic innovation activities. MIP scholars have stressed the importance of a strong direction of developments in order to direct resources, skills and competencies, and to mobilize actors toward achieving a societal goal. Further, directionality requires quick and careful prioritization of the most promising solution trajectories and the "closing down" of those that are seemingly less feasible (Mazzucato 2016, 2018; Kattel and Mazzucato 2018; Hekkert et al. 2020).

At the same time, other scholars have called for the opposite of strong directionality: the "opening-up" of the innovation process in the presence of societal grand challenges (Stirling 2011). Given the ill-defined, continuously changing, contested, and uncertain nature of societal grand challenges, literature on *diversity* in transitions stresses the need to leave options open. Contrary to the literature on directionality, diversity scholars argue for the diversification of solution trajectories in the presence of wicked problems (Stirling 2011; Schlaile et al. 2017; Termeer, Dewulf, and Biesbroek 2019; Heiberg and Truffer 2022).

A key argument in the literature on diversity is that it is necessary for dealing with the inherent uncertainty associated with grand challenges as it provides flexibility and avoids overreliance on what seems to be the most "optimal" solutions (Stirling 2009, 2011). To put it simply, scholars have argued that "we don't know what we don't know" (Stirling 2011: 5). Therefore, recent calls in the literature have acknowledged the importance of opening-up the innovation process to account for multiple ways forward (Stirling 2009, 2011; Raven et al. 2017). Aside from this, diversity scholars stress that because direction is often determined by powerful actors, it cannot be deemed representative of the heterogeneous nature of actors and their visions of progress. It has been argued that there is a need to accommodate different stakeholders' voices in shaping of directionality to balance the influence of incumbent actors and outsiders to the incumbent sociotechincal system (Parks 2022; Bergek, Hellsmark, and Karltorp 2023). Thus, fostering diversity in transitions enables recognition of diverse perspectives, visions, and values (Raven et al. 2017; Heiberg and Truffer 2022), which also has been referred to as enabling democracy in transitions (Stirling 2009; Leach et al. 2020).

This paper's point of departure hinges on the observation that notwithstanding differences, both literature strands contain several thematic overlaps and complementaries. To elaborate, we observe that both diversity and directionality are conveyed in the literature as necessary for achieving transitions (Stirling 2007, 2009, 2011; Mazzucato 2016, 2018, Kattel and Mazzucato 2018). Also, both literature strands emphasize the importance of taking a systemic perspective, i.e. assessing the interplay of actors, institutions, and the interactions among them when crafting visions for progress (Stirling 2007, 2009, 2011; Mazzucato 2016, 2018, Kattel and Mazzucato 2018). Additionally, it has been shown that there may be phases of considerable diversity of problem framings and solution directions before these are closed down and lead to a "dominant design" (Porto Vilas Boas Souza, 2020; Wanzenböck et al. 2020). Finally, it has also been conveyed that directionality in sociotechnical systems can result in a variety of disparate solution trajectories over time (Yap and Truffer 2019; Pel, Raven and van Est 2020; Andersson and Hellsmark 2024).

This raises the questions: under what conditions do diversity and directionality contradict and under what conditions can they co-exist or complement each other, or in other words when are they friends and when foes? And how can mission-oriented innovation policy best balance diversity and directionality in the pursuit of grand societal challenges?

In this paper, we aim to make a first attempt to explore these questions empirically by unraveling how directionality and diversity interplay in a societal transition pursued by a so-called "mission-specific innovation system" (MIS, see Section 2 for a definition and details). The research question is therefore as follows: *What is the interplay of diversity and directionality in a mission-oriented innovation system?*

To answer the research question, we utilize the Dutch "Protein Transition" and the associated MIS as our case of analysis. Protein transitions have been studied earlier through a transitions lens (see e.g. Mylan et al. 2019; Tziva et al. 2020; Mylan, Andrews and Maye 2023; Bulah et al. 2023a), and we deem the Protein Transition as a suitable case for several reasons. First, the Protein Transition is constituted by a clear mission: shifting the consumption and production of animal proteins to alternative proteins and therefore enables us to study the influence of mission-driven directionality on an innovation system.

However, despite this clear directionality, the transition to alternative proteins remains a widely contested arena. Ongoing discussions pertain to the problems it seeks to address, the proposed solutions, and its broader implications. Overall, the balance between directionality and diversity has been noted as an important topic in food systems transformation literature (Wojtynia et al. 2021; Kok and Klerkx 2023). For example, there is a debate regarding whether or not the transition should include animals, the role of low-tech versus high-tech solutions, and the influence of power-dynamics, particularly regarding the involvement of "Big-Tech" (Katz-Rosene, Heffernan and Arora 2023; Fairbairn and Reisman 2024). What is more, the protein transition encompasses a broad range of narratives, visions, and values making it an ideal case for also studying diversity.

We zoom in on the Wageningen science, business, and innovation ecosystem in the Netherlands, given that it is a particular ecosystem that is representative of the wider protein transition MIS. We chose to study Wageningen given its renowned research and development in alternative proteins: Wageningen is home to several prominent multinationals, research institutes, NGOs, and accelerators which are all heavily invested in the transition from animal to alternative proteins (Clarkson 2020). Furthermore, the Wageningen ecosystem encompasses a wide variety of different stakeholders, enabling us to study the diversity of interests, solutions, and development trajectories. Thus, we argue that these dynamics enable us to unravel how diverse actor and solution compilations operate and are influenced by a clear mission.

The remainder of this article is structured accordingly; Section 2 will introduce and delineate the theoretical background used in this analysis. Section 3 presents the methods used to guide this study. Section 4 outlines the results derived from this analysis. Section 5 is the discussion. And finally, Section 6 is the conclusion.

2. Theoretical background

2.1 Directionality in sustainability transitions

Transitions literature provides important insights into the factors that explain the shift to more sustainable modes of production and consumption. The most recognized frameworks to date include the multi-level perspective (MLP), the technological innovation system framework (TIS), strategic niche management (SNM), and transitions management (TM). These theoretical frameworks take a systemic perspective in order to examine how shifts toward more sustainable sociotechnical systems unfold. Further, they have been frequently utilized to inform various types of innovation policy focused on stimulating the sustainable provision of societal functions such as energy, food, and water (Markard and Truffer 2008; Markard, Raven and Truffer 2012; Köhler et al. 2019).

In recent years, the rising impacts of social, environmental, and economic challenges such as climate change and water scarcity have shifted scholars' attention toward additional frameworks. Mission-oriented innovation policy has emerged as a key tool for tackling such complex challenges (Mazzucato 2016; Boon and Edler 2018; Kattel and Mazzucato 2018; Schot and Steinmueller 2018). MIP takes a societal grand challenge as its starting point in order to *direct* innovation toward meeting a desired societal goal. Furthermore, mission-oriented innovation policy highlights the importance of directed innovation or "directionality" when tackling a mission (Mazzucato 2016, 2018; Kattel and Mazzucato 2018; Wanzenböck et al. 2020).

In line with MIP, the MIS framework has arisen in the literature on transitions as a means to address wicked problems MIS can be defined as "the network of agents and set of institutions that contribute to the development and diffusion of innovative solutions with the aim to define, pursue and complete a societal mission" (Hekkert et al. 2020). MIS are derived from the literature on mission-oriented innovation policy and highlight the importance of "temporary" innovation systems in which a broad range of stakeholders aim to steer the direction of change in an innovation system in order to elicit coordinated innovation (Hekkert et al. 2020; Wanzenböck et al. 2020; Elzinga et al. 2023).

In the literature on transitions, scholars highlight that direction comes about in several ways. First, it has been shown that direction is created by establishing shared visions and collective goals among innovation system actors, otherwise known as forming "consensus" regarding the way forward (Weber and Rohracher 2012). This usually involves actors deciding what challenges are worthwhile to pursue and how societies may best tackle grand challenges (Mazzucato 2016; Kattel and Mazzucato 2018; Hekkert et al. 2020; Wanzenböck et al. 2020). Second, directionality is shaped by targeting and aligning innovation activities across differing "levels" (Yap and Truffer 2019; Schippl and Truffer 2020). For example, Yap and Truffer (2019) highlight that directionality is shaped by innovation system actors acting as "institutional entrepreneurs" working to shape development trajectories in favor of specific alternatives by embedding and aligning their activities within a broader system's structure. In a similar manner, Schippl and Truffer (2020) highlight that directionality is shaped by interactions between two different levels, namely that of specific technological solutions and the level of the sectoral regime. In both cases, unified directionality is argued to be formed by increasing alignment between elements across levels.

Third, it has been shown that directionality may be shaped by historical contingencies in which actors follow a specific path of technological development due to their past technological capabilities, in-house knowledge, and competencies (Stirling 2009, 2011). Thus, often resulting in early "lock-in" to technologies that constrain actors' way forward (David 1985; Unruh 2000). Moreover, the literature has also shown that directionality is formed by the establishment of a "dominant" design which sets industry standards and governs actors' innovation activities across the value chain (Anderson and Tushman 1990; Porto Vilas Boas Souza, 2020). Finally, it has been argued that directionality is shaped by cultural expectations of which routes are seemingly the best to follow (Stirling 2007, 2009, 2011).

Given the complex nature of sociotechnical transitions, directionality is deemed necessary to overcome societal grand challenges for a myriad of reasons. First, literature on mission-oriented innovation policy and MIS highlights that a clear direction from the outset enables societal goals to be achieved in a timely manner as directionality allows actors to mobilize and dedicate resources to the preferred direction of change (Mazzucato 2016; Robinson and Mazzucato 2019; Hekkert et al. 2020). Because resources such as human capital, infrastructure, and R&D are inevitably limited, directionality minimizes the uncertainty associated with "betting on more than one horse" and facilitates directed innovation to complete the mission. What is more, directionality enables the prioritization of the most promising innovation activities which contribute to the chosen societal goal. Thus, enabling societies to quickly omit pathways that are deemed less suitable (Mazzucato 2018, 2016; Kattel and Mazzucato 2018; Hekkert et al. 2020).

However, shaping this so-called "unified" directionality also presents significant challenges and limitations. There may be unclarity about what is the "best bet" and too many "problem-solution spaces" that hinder a clear direction to pursue and hence stakeholder alignment toward a clear and shared goal (Wojtynia et al. 2021; Heiberg and Truffer 2022). As Parks (2022) indicates, shaping directionality is a process that can take shape through consensus building, or conversely is characterized by contestation and conflict. It may also be a process in which direction shaping is delegated to the level of projects and may turn into demand articulation with a reduced ambition level. Parks (2022) and Grillitsch et al. (2019) hence point to who is involved in the process of directionality shaping, as having actors from legacy policy structures may reduce ambitious directionality. Furthermore, Andersson and Hellsmark (2024) highlight that in circumstances where unified directionality is successfully shaped, this may result in too "'narrow" development pathways susceptible to failure due to actors' unwillingness to explore alternative trajectories. In a similar vein, Hekkert et al. (2020) highlight that overly strong directionality may drastically reduce the level of technological variety in a MIS, as winners are quickly chosen from the outset possibly resulting in the most powerful actors shaping the direction in their favor at the expense of more marginal actors. Lastly, and by way of summary, Bergek, Hellsmark, and Karltorp (2023) provide eight challenges for shaping directionality which encompass some of the aforementioned: handling goal conflicts, defining system boundaries, identifying realistic pathways, formulating strategies, realizing destabilization, mobilizing relevant policy domains, identifying target groups, and accessing intervention points. Many of the challenges of articulating unified directionality relate to handling diversity in transitions: diversity of directions and associated problem-solution spaces and diversity of stakeholders involved in defining directionality. We will discuss this in more detail in the next section.

2.2 Fostering diversity in transitions

In contrast to providing a clear and unified direction, scholars have highlighted the importance of fostering diversity in transitions (Stirling, 2007; 2009; 2010; Köhler et al., 2019). The concept of diversity has arisen from Science and Technology Studies (STS) as a critique of apolitical understandings of the governance of science, technology, and innovation. This literature brings into question "who decides" with regards to the preferred direction of change in transitions and also asks the questions of "where are we going," "why this way?," "what is 'forward'" (Stirling 2011; Parks 2022).

Diversity can be defined as "the value of nurturing more plural discourses and cultures around deliberate choice of portfolios of pathways for innovation, sustainable and development – allowing greater variety, dynamism and context-sensitivity in technological and institutional trajectories" (Stirling 2009: 5). Literature on diversity stresses that because direction is often chosen by those who hold the most power in society, it cannot be representative of the heterogeneous nature of actors and their visions of progress. Furthermore, it highlights the importance of opening-up the innovation process to the multiplicity of diverse perspectives, visions, and values (Stirling 2008, 2009; Raven et al. 2017).

At the center of the debate, diversity scholars have called attention to the fact that innovation studies and, more specifically, innovation policy underplay the role of diversity in innovation systems (Stirling 2011; Heiberg and Truffer 2022; Andersson and Hellsmark 2024). This overly condensed view of diversity may therefore lead sociotechnical systems to reinforce mechanisms such as path-dependency and "'lock-in," thus preventing transformative change (Stirling 2009, 2011). Furthermore, literature on diversity highlights that without greater attention to the attributes associated with diversity, societies can be too quick to lock-in to sub-optimal trajectories and unable to change their paths when in need due to factors, such as capabilities, routines, sunk investments, and deeply engrained habits (Stirling 2007, 2009, 2011, 2014; Andersson, Hellsmark, and Sandén 2021).

Departing from the idea that diversity is a "unitary" property of sociotechnical systems, scholars have highlighted the importance of conceptualizing diversity as an accumulation of multiple elements. Stirling (2011), for example, highlights that diversity comprises *disparity, variety*, and *balance*. *Disparity* refers to the degree to which options can be distinguished from one another. *Variety* concerns the number of types of options available. Finally, *balance* refers to how equally the options are realized and pursued. The greater the disparity, variety, and balance, the more diversity a socio-technical system displays (Stirling 2007, 2011).

Like directionality, scholars have highlighted that diversity in transitions comes about in numerous ways. First, diversity arises due to the inclusion of more marginal actors which gives room to diverse perspectives when deciding how to achieve transitions. In other words, diversity arises by "giving everyone a seat at the table" (Stirling 2007, 2009, 2011), i.e. democracy. Second, diversity arises due to uncertainty regarding the most optimal way forward thus, encouraging experimentation when devising solution pathways. Third, diversity arises through the accumulation of diverse values, political interests, and expectations, which can lead to actors pursuing different solutions based on their own normative visions of progress (Stirling 2009).

In the literature on diversity, scholars have deemed that diversity instead of a unified direction is critical to overcoming societal grand challenges. To begin, proponents of diversity in transitions highlight the inherently uncertain nature of transitions in which some things are simply "out of our control" (Andersson and Hellsmark 2024). In this way, diversity is seen as a variation in solutions and transition trajectories which gives actors space for dealing with the unpredictable and complex nature of societal grand challenges. Furthermore, diversity in solutions enables flexibility when moving forward and avoids overreliance on the seemingly most optimal solutions (Stirling 2009, 2011). As a second point, scholars have argued that fostering diversity in transitions is needed given their normatively laden and contested nature. As indicated by Klerkx and Begemann (2020) and Katz-Rosene, Heffernan, and Arora (2023) sociotechnical transitions comprise conflicting future visions, narratives, and goals from a wide variety of different actors and thus cannot be constrained to one way forward. Instead of "closing down" the innovation process, diversity is seen here as important for accounting for marginal and conflicting interests that would otherwise be disregarded. Moreover, diversity scholars condemn allowing the fate of sustainability transitions to be determined by society's most powerful actors, e.g. governments and large multinationals with "vested interests," and instead argue that uncertain and seemingly inferior development pathways must also be realized (Stirling 2008, 2009, 2010, 2014; Raven et al. 2017). Furthermore, scholars have argued that neglecting or failing to incorporate certain visions may led to contestation amongst specific actor groups and even result in entirely new problems or exacerbate their "wickedness" (Wiarda, Coenen, and Doorn 2023). Thus, fostering a diversity of visions and values helps to manage issues of representation and conflict when crafting the way forward (Andersson and Hellsmark 2024).

Third, diversity is also recognized as being critical for stimulating competition, innovation, and creativity. Finally, diversity is seen as important for dealing with the heterogeneous nature of "places," e.g. regions and cities. In other words, solutions that may fit in one geographical location cannot be expected to simply work in another. As indicated by Glaros et al. (2023), proposed solutions may be received differently depending on different backgrounds and the context in which a solution is introduced. Thus, directionality may lead to failure of solution implementation depending on differing spatial context conditions, e.g. culture and regional capabilities (Stirling 2009; Schippl and Truffer 2020).

Nevertheless, there are also downsides associated with too much diversity. For example, scholars have highlighted that involving too many stakeholders in the transition processes may result in a failure to meet the proposed goals. For example, Wiarda, Coenen, and Doorn (2023) highlights that while there should be diversity in project portfolios, actors and visions, too much may result in irreconcilable differences, hindering progress, and resulting in a transition "stand-still" or inertia. In similar vein, it has been argued that too much diversity may result in coordination failures in which actors are uncertain regarding the way forward and thus fail to achieve the mission in a timely manner (Hekkert et al. 2020).

Table 1. Overview of strengths, limitations, and thematic overlaps in diversity and directionality literature.

Literature	Key strengths	Key limitations	Thematic overlaps
Diversity	Multiple solution trajectories Resilience Inclusion of a wide variety of actor groups, values, and visions Context-sensitive Encourage innovation and creativity Mitigate power imbalances	Failure to meet mission in timely manner Transition inertia No consensus	Concerned with governing transitions Shift from innovation for innovation's sake (economic growth) to innovation for societal grand-challenges Systemic and multi-actor process Acknowledge transitions as contested and value-laden Acknowledge wickedness of problems
Directionality	Prioritization of most promising trajectories Consensus Targeted resources Directed innovation Transitions achieved in timely manner Coordination across value chain	Vulnerable to system shocks Power imbalances Reduced ambition Reduced technological variety	

For a summary of the aforementioned arguments, see Table 1.

In summation, these striking overlaps yet clear contradictions between the need for directionality and diversity in MIS present the focus of our paper. We aim to uncover how both diversity and directionality unfold in parallel and in a MIS.

3. Methods

To answer the research question, we conduct a descriptive qualitative single-case study of the Wageningen ecosystem. To operationalize diversity and directionality in a MIS, we utilized insights from the technological innovation systems (TIS) framework (see e.g. Hekkert et al. 2007; Bergek et al. 2015), which has also been applied recently to MIS using the same functions (Wesseling and Meijerhof 2023; Elzinga et al. 2023). The TIS approach is suitable to operationalize both directionality and diversity in transitions as it aims to understand how system dynamics contribute to specific development trajectories (Yap and Truffer 2019; Andersson and Hellsmark 2024). Specifically, the framework enables insights into how a complex array of actors, institutions, infrastructure, and networks influence and shape different development trajectories.

We specifically zoom in on function four, namely, guidance of the search (GS) in order to operationalize directionality and diversity in an innovation system at a concrete level. In the TIS framework, guidance of the search captures the shared collective visions and expectations regarding the way forward, which guide actor's activities and decision-making in an innovation system. Moreover, guidance of the search has been deemed a critical driver in shaping the direction of change in a sociotechnical system. Recently, this has led scholars to recognize guidance of the search as a fruitful tool to examine direction in an innovation system (Yap and Truffer 2019; Wanzenböck et al. 2020; Elzinga et al. 2023). Similarly, a multitude of search directions shows the diversity in a transition process.

To this end, we define "directions of search" as both the visions and expectations and activities that innovators undertake for exploring, developing, and pursuing solutions in order to solve particular problems that they deem most pressing (Hekkert et al. 2007). Hence, this also deals with matching problems to different "solution spaces" that enact broader missions such as protein transitions (Wanzenböck et al. 2020; Wojtynia et al. 2021; Elzinga et al. 2023). To analyze the potential impact of these search directions in the Wageningen ecosystem on the direction of the protein transition they were assessed in terms of their dominance in the regional ecosystem as well as related to an earlier study on the more general emerging transition pathways (see Van Mierlo and Klerkx 2023).

3.1 Case selection and boundaries

We selected the Wageningen innovation, business, and research ecosystem (i.e. the food research and innovation hub around WUR, with connected actors from the direct vicinity and the wider region within the Netherlands) as a case to study the interplay of diversity and directionality in transitions for several reasons. First, the "Protein Transition" exhibits a clear mission, i.e. shifting the production and consumption of animal proteins to alternative proteins, and therefore enables us to examine the influence of directionality on an innovation system. Second, Wageningen is seen as a hotspot for alternative protein research and development and is representative of a broad range of actors in MIS. Moreover, Wageningen is home to an elaborate food innovation cluster that includes research institutes, network organizations, global food firms, start-ups, scale-ups, non-governmental organizations, and the like which all undertake activities aimed at accelerating the Protein Transition (i.e. the Wageningen ecosystem is strongly linked to the broader Protein Transition MIS) (Clarkson 2020). Third, this presence of a variety of actors, with different technological capabilities, political interests, and cultural expectations, suggests that the Wageningen ecosystem can give insights into the microdynamics associated with both directionality and diversity. Concluding, this makes Wageningen a vibrant location to examine the interplay of diversity and directionality, and it connects to ideas that a technology-oriented MIS which has a global orientation can also be strongly located within particular regions (Rohe and Mattes 2022).

Regarding the relevance of our case for the rest of the world, the Wageningen ecosystem relates to similar developments in alternative proteins in the Global North, such as that of the USA and the UK (see e.g. Bulah et al. 2023a, 2023b; Mylan et al. 2019). These regions share a similar consensus that there is a need to shift our diets toward alternative proteins, resulting in a plethora of novel innovations aimed at replacing traditional meat and dairy products. However, this is not a transition that only takes place in the Global North, as countries in the Global South such as Chile and Singapore are also home to innovation ecosystems working on alternative proteins (Klerkx and Villalobos 2024), and hence the case can also be deemed relevant for those contexts.

Our case boundaries include actors in the Wageningen ecosystem, i.e. those actors located in and in the vicinity of Wageningen and all those (f)actors that contribute to the respective search directions within the Wageningen ecosystem.

3.2 Data collection and analysis

The first step in our analysis included mapping out the structural components of the Wageningen ecosystem, i.e. the actors, networks, and institutions. Data on the structural components were collected using secondary sources, such as organization websites, gray literature, industry reports, and government documents. This included the names of specific actors and organizations working on alternative proteins in the Wageningen ecosystem.

Thereafter, we conducted thirty-one semistructured interviews with actors in the Wageningen innovation cluster. Semistructured interviews were chosen as they allow for a mix of closed and open-ended questions on the chosen phenomena and in-depth analysis of both concrete events/activities as well as personal motivations and values, i.e. factors underlying search directions.

We utilized the system mapping to contact interviewees, ensuring that we did not exclude any search directions from our analysis. Thereafter, we used a snowball sampling approach in which we received recommendations for other relevant interviewees. Actors gave recommendations based on their networks and who they knew to be working in the domain of alternative proteins. Each interview lasted 45 minutes to 1 hour and took place between November 2020 and June 2021. To gain a comprehensive overview of all search directions present in Wageningen, we aimed to spread out the number of interviewees per actor type, e.g. ingredient producer, non-governmental organization (NGO), policymaker, etc. The complete overview of actor types and their related characteristics can be found below (Table 2)

Interview questions were informed by the concept of "guidance of the search," as elaborated above. Questions thus related to the organization's current innovation activities, e.g. developing a new protein source, and what influenced their innovation activities, e.g. personal/organization future visions, market-based factors, regulations, etc. The questions were also tailored based on the actor type. The complete interview protocol can be found in Appendix A. After the interviews were recorded, they were transcribed and anonymized.

The qualitative data analytics software Atlas.Ti was used to code the transcriptions. Atlas.Ti is a software program that allows one to store transcripts and code segments of text. Codes can then be grouped, removed, and added. In order to identify different directions of search, we conducted an inductive, open coding approach to identify themes based on the content of the data. Codes were first created based on challenges actors were working to solve, innovation activities, and their factors of influence, e.g. future visions (attributes of search directions).

In the initial stage, codes were specific, e.g. *identifying new strains of fava beans* (activity), *limited sources of protein ingredients (challenge to be solved), consumer expectations for different ingredients (factor of influence)* and later grouped into larger thematic categories. For example, the code *identifying new strains of fava beans* was then added to the overarching group *developing new protein sources*. In like manner, the code *consumer expectations for different ingredients* were *grouped to Factor(s) of influence: market-based*, and finally, into the overarching search direction, e.g. *developing new protein sources*.

Table 2. List of Interviewees.

Type of actor	Characteristic	Code
Incumbent	Multinational Meat Substitute Producer[a]	Incumbent #1
Incumbent	Multinational Food & Beverage Producer	Incumbent #2
Incumbent	Multinational Meat Producer	Incumbent #3
Incumbent	Multinational Technology Company	Incumbent #4
Incumbent	Multinational Ingredient Producer	Incumbent #5
Incumbent	Global Protein Supplier	Incumbent #6
Incumbent	Multinational Meat Substitute Producer[a]	Incumbent #7
Research	Research	Research #1
Research	Research	Research #2
Research	Research	Research #3
Research	Research	Research #4
Research	Research	Reseach #5
Research	Research	Research #6
Industry organization	Networking Organization	Industry Organization #1
Non-profit	International Food Advocacy Organization	Non-profit #1
Non-profit	International Food Advocacy Organization	Non-profit #2
Non-profit	Networking Organization	Non-profit #3
Knowledge Institute	University	Knowledge Institute #1
Knowledge Institute	Research Institute	Knowledge Institute #2
Knowledge Institute	Research Institute	Knowledge Institute #3
Start-up	Meat Substitute Producer	Start-up #1
Start-up	Meat and Dairy Substitute Producer	Start-up #2
Start-up	Meat and Dairy Substitute Producer	Start-up #3
Start-up	Meat and Dairy Substitute Producer	Start-up #4
Government	Policymaker	Government #1
Government	Policymaker	Government #2
Government	Strategic Advisor	Government #3
Government	Regional Program Manager	Government #4
Farmer	Ecofarmer	Farmer #1
Firm	Food Extruder	Firm #1
Firm	Ingredient Wholesale and Producer	Firm #2

[a]Indicates if a company is owned by a meat producer or has previously been in the meat industry.

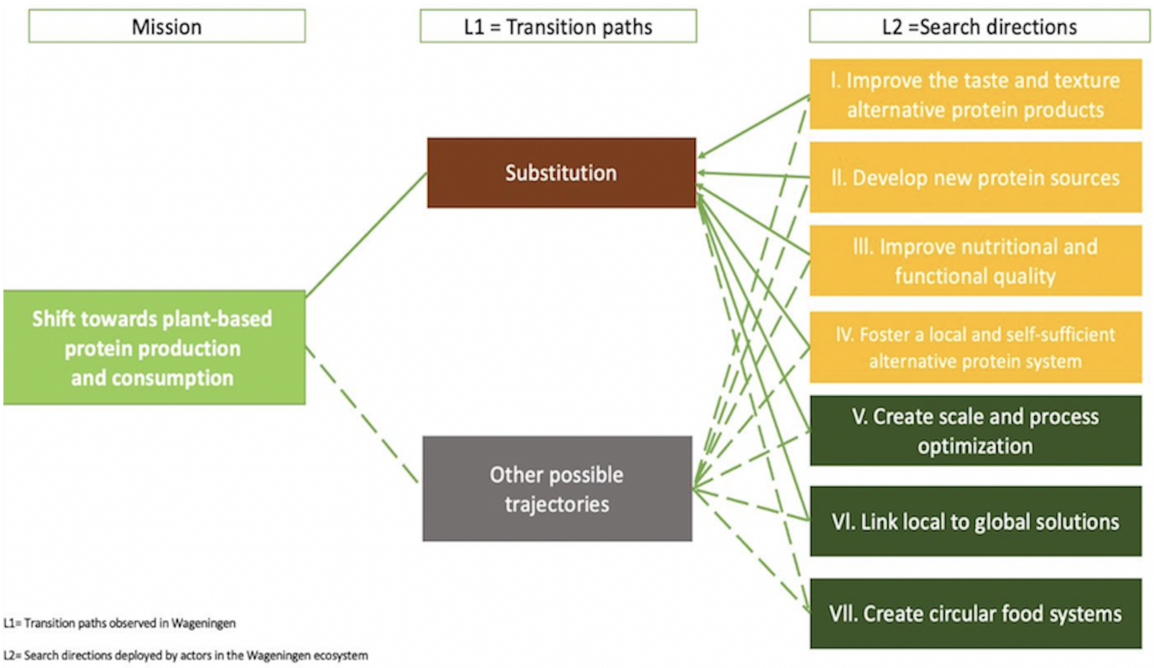

Figure 1. Levels of directionality and diversity found in the Wageningen ecosystem. The solid lines represent strong linkages to the dominant transition pathway and overarching mission. The dotted lines represent weak linkages. See Sections 4.1 and 4.2 for elaboration.

Once saturation of the data was reached, 10 per cent of the data were sent to an independent researcher and an intercoder reliability check performed. Approximately 90 per cent of the codes were validated. Any discrepancies or other interpretations of the codes were then discussed and changed if deemed necessary by both researchers. During the coding process, the research team frequently met to discuss and interpret the data to ensure the reliability of the codes created. Coding resulted in seven search directions, each comprising distinct sets of innovative activities and their factors of influence.

4. Results

Our empirical findings are structured as follows: first we outline the general levels of diversity and directionality found in the Wageningen ecosystem. Furthermore, we propose the interplay between directionality and diversity can best be understood by distinguishing different *levels* at which directionality and diversity play out. Thereafter, we describe the state of the Protein Transition in the Netherlands along with the current directionality toward substitution in Wageningen. Subsequently, we outline the seven directions of search observed in the Wageningen ecosystem. In addition, we describe the dominant factors of influence guiding each direction of search. Finally, we conclude by unraveling the interplay between diversity and directionality in the Wageningen ecosystem.

Overall, actors in the Wageningen ecosystem are influenced by the general mission of a "Protein Transition" *(see Fig. 1, mission)*. In recent years, the shift of societies from animal-based products to products made from alternative proteins, e.g. soy, fava bean, and quinoa have been increasingly investigated in Wageningen, the Netherlands. This mission provides a strong direction to the entire Wageningen innovation system.

At the same time, there are different transition pathways for realizing this mission, for example, meat substitution and alternative farming systems *(see Fig. 1, L1)* (see e.g. Broad 2019; Van der Weele et al. 2019; Lonkila and Kaljonen 2021; Mylan, Andrews, and Maye 2023; Van Mierlo and Klerkx 2023). This constitutes the first sociotechnical level in which diversity and directionality coexist. Within these pathways we, in turn, observe seven directions of search under which actors organize their innovation activities. This constitutes a second level that displays significant diversity, yet that also contributes to the overall direction provided by the mission *(see Fig. 1, L2)*. Within this level, we observe that most of the innovation activities actors deploy are confined to technological solutions that aim to stimulate rapid market growth and the diffusion of meat analogs. In the regional ecosystem around Wageningen there are four dominant search directions (yellow-colored boxes, I–IV) and three sub-dominant search directions. The latter are only deployed by a small number of actors who work on their own directions of search (green-colored boxes, V–VII).

4.1 The "Protein Transition" and directionality toward meat substitution

The Wageningen ecosystem is strongly guided by the mission to shift toward alternative protein consumption and production. In December 2020, the Dutch Ministry of Agriculture issued the National Protein Strategy (NPV) of the Netherlands. The National Protein Strategy aims to encourage sustainable production and consumption of alternative proteins and focuses on stimulating the Dutch alternative protein innovation system by, for example, advocating for the cultivation of alternative protein crops in the Netherlands and promoting research and development into alternative proteins. In addition, the Netherlands is home to over 250 companies and

50 collaborative initiatives, which support the transition to alternative proteins in the Netherlands (Future Protein NL, 2022).

In the Wageningen ecosystem, we observe that the general mission is realized by a strong directionality toward meat substitution *(see* Fig. 1, *L1)*. Meat analogs, i.e. products that aim to mimic the structure, taste, and texture of animal meat have been present on the market since the late 1900s; however, in recent years, they have witnessed exceptional growth in the Dutch market (Tziva et al. 2020; Bulah et al. 2023a). Prior to the early 2000s, the meat substitute market was populated by mostly first-generation alternative protein producers and products. These products, predominately made from textured vegetable proteins (TVP), were seen by consumers as meat substitutes that did not perfectly mimic meat and were associated with having a hard texture and a chewy consistency. Thus, many of these products were undervalued by consumers given that they were highly distinguishable from real meat (Lin, Huff and Hsieh 2000; Tziva et al. 2020). Furthermore, these products remained rather stagnant in the market and were mainly the target of vegetarian consumers.

In recent years, actors in the Wageningen ecosystem have increasingly directed their innovation activities toward improving meat analogs and the related production system. This is largely driven by the expectation that *if* individuals were to transition to consuming plant-based products these products had to closely resemble meat. For example, one interviewee stated:

> "The response of the consumers was, you can do everything you like, but it has to look like meat. So that was quite a disappointment because we were actually really trying to get away from meat as the source of inspiration. But it was also clear that consumers would not buy that… it had consequences in the sense that we, therefore, needed to go into a direction that the research was focusing on meat alternatives rather than completely new products."—Research #6

These emerging aspirations were further realized by the appearance of high-moisture extrusion technology (HME) around the 2010s, with which alternative protein products could now have a similar taste, bite, and appearance to animal meat. In addition, the rise of a new market segment namely "flexitarians" contributed to the growing enthusiasm surrounding meat substitutes and the rise in the number of meat analogs on the market (Tziva et al. 2020).

In the midst of a growing market and the novel opportunities provided by HME technology, actors in the Wageningen ecosystem have increasingly latched on to the meat substitute trend. This directionality is reinforced by the presence of large corporations such as Unilever, Schouten, and Vion, which have recently entered the alternative protein space and are seen developing a plethora of novel meat substitute products. Also, Wageningen is home to several research institutes, NGOs, networking organizations, and start-ups which also contribute to the growing innovation system around meat analogs.

4.2 Search directions

Nevertheless, within the strong "first-order" directionality toward meat substitution in the Wageningen ecosystem, we found that there are seven directions of search that both reinforce the direction towards meat analogs and may also contribute to other possible transition trajectories. See Table 3 below for an overview of the main empirical findings.

4.2.1 Improving the taste and texture of alternative protein products The first dominant search direction found in the Wageningen ecosystem is *improving the taste and texture of alternative protein products*. In this direction, there is much attention towards enhancing and producing diverse types of meat alternative products and as a result this search direction links directly to the overarching directionality towards substitution.

The primary motivation behind this search direction stems from market-driven factors, such as the growing global market for alternative proteins and consumer expectations that meat substitutes must taste like animal meat. Major multinational corporations are actively invested in this search direction recognizing the immense growth potential and opportunities within the alternative protein market.

> "I mean ten years ago no one could imagine themselves making money in this field. The market growth that plant-based food products have seen has just… you know… completely wowed the food industry right… when you find something that is growing a category growth of 6 up to even 12 percent year on year it's just its mind blowing to a lot of food companies who are used to a very stagnant and sort of stable business."–Research #3

> "The second pillar is about being very close to customers and being a company which was in the meat industry before, made us pretty close to customers and listening to customers so we also listen very much to what customers are indicating that they believe are categories that have an opportunity."—Incumbent #1

Overall, activities in this search direction are largely aimed at minimizing consumers' need for behavioral change by making the transition to alternative protein consumption as effortless as possible. Furthermore, the main aim is to improve the taste and texture of different types of meat substitutes in order to target traditional meat eaters or "flexitarians":

> "We really believe that it's difficult for people to change their eating patterns…So…. what we strive for is a meat replacer that looks like meat, that smells like meat, touches like meat, but also cooks like meat. So that, in the end, makes it a small step for a consumer to go from a traditionalist, as we call it, or a meat lover, towards a flexitarian."—Incumbent #3

> "It's definitely a group that has a conscious consideration of not eating meat for personal health, for our planet, and for animal welfare and is to a certain degree willing to make other choices. And that group (flexitarians) is the prime target group."—Incumbent #1

Actors in this search direction focus both on improving first-generation textured vegetable protein products and also on developing second- and third-generation products made from processes such as HME. In the current market, some of the

Table 3. Overview of search directions, activities, and main factor(s) of influence.

Search direction	Description (based on identified challenge)	Factor(s) of influence (e.g. future-visions, market-driven, regulation-driven)	Dominant versus emerging	Activities
Improving the taste and texture of alternative protein products	All activities related to improving the sensory aspects of plant-based proteins. This includes, for example, mouthfeel, taste, and bite. This can be improving first generation, second-generation, and third generation protein products.	Market driven (e.g. growth of "flexitarians")	Dominant	Plant-based products for: 1. Indulgence 2. Every "type" of consumer 3. Mimic popular products in the meat market 4. Convenience Technology development e.g. improved extrusion technologies
Developing new protein sources	All activities related to researching and/or commercializing new products with new protein sources. This includes for example, fava bean, insects, and duckweed.	Future-vision driven (e.g. personal motivations) Market driven (e.g. consumer expectations for "clean-label" products)	Dominant	Protein from side-streams Developing new protein sources Redesigning products made from soy to newer protein sources e.g. fava bean, quinoa Fermentative biomass Technology development
Improving nutritional and functional quality	All activities related to improving protein nutritional and functionality. Improved protein functionality differs from improved taste and texture as this transition pathway focuses on aspects such as protein solubility, protein content, clean-label, and nutritional properties of proteins.	Market-driven (e.g. consumer expectations for more nutritional products) Regulation-driven (e.g. Novel Food Regulation)	Dominant	Producing protein concentrates Clean-label formulations Clinical trials on protein digestibility, solubility, etc. Breeding protein crops for improved functionality Technology development
Fostering a local and self-sufficient alternative protein ecosystem	All activities aimed at linking initiatives across the chain and ensuring self-sufficiency of the Dutch alternative protein ecosystem.	Mission-driven e.g. National Protein strategy Future vision- driven	Dominant	Field labs for innovation valorization Living labs Shared facilities network Facilitating and up-scaling new businesses Local chains Local infrastructure development and reuse Earning models for farmers
Scaling up and process optimization	All activities aimed at optimizing the current ways in which alternative proteins are produced. This includes, for example, implementing new production methods, scaling-up to meet rising demand, minimizing energy use in production processes, etc.	Market-driven (e.g. scaling up to enhance market competitiveness) Future-vision driven	Emerging	Maximizing throughput through editing machine processes Up-scaling Funding and facilitating protein development and production processes Developing modular insect production technologies
tagmcend **Linking local to global solutions**	All activities aimed at linking small-scale solutions oriented towards the Netherlands to more global initiatives e.g. connecting actors and spreading industry knowledge and research.	Future-vision driven (e.g. of a 'Global Protein Transition')	Emerging	Building 'Protein pathways' Connecting partners around the globe Sharing and assimilating knowledge through platforms
Creating a circular food system	All activities aimed at creating a more circular food system. This includes solutions for both food and feed.	Mission-driven (e.g. reaching a fully Circular Economy by 2050)	Emerging	Circular innovation programs e.g. Fascinating 2020 Growing local plant-based protein sources e.g. lupin Increasing availability of new crops Valorizing waste streams

most popular meat substitutes include schnitzels, burgers, and minced products. Multinational corporations, however, aim to gain a competitive edge and expand this variety by pursuing products for different cultural cuisines and popular seasonal activities.

For example, some actors are observed creating meat substitutes for the Dutch summer barbecue season and introducing products that can be prepared on the BBQ like popular meat products. This includes, for example, niche products like satay and spareribs:

> "We look into trends… What is new? What are people looking for or what do they expect? What are they using when they go for a barbecue, for instance? So that's why we came up with the boneless spare rib because we see that spareribs are one of the most wanted products on the barbecue."—Incumbent #3

Actors in this trajectory also innovate other ways supporting the directionality towards meat substitutes. For example, start-ups are seen developing disparate production methods with which they can mimic whole cuts of animal meat. In comparison to products made from HME, whole-cuts require shear-cell technology to create. With shear-cell technology, actors can replicate more complex flesh structures and thus can create layered, thick, and tough structures such as chicken breasts and steaks.

Researchers also work in this search direction but mainly at the request of large multinational organizations. These innovation activities are also influenced by market-driven factors such as dominant consumer preferences for meat mimicry products.

> "The projects that are bilateral tend to be pretty close to market…. pretty applied. You know company x wants to develop a new burger on the basis of chickpeas, and they need help with it…. You know very very practical and very short to market type of questions happening there."—Research #3

4.2.2 Developing new protein sources The second search direction found is focused on *developing new protein sources*. The main drivers behind this search direction are future-vision and market-based. Currently, plant-based protein products mainly make use of ingredients like soy due to its exceptional qualities and performance in mimicry formulations. However, soy cannot easily be grown in the Netherlands and is often imported from North and especially South America, where soy cultivation is said to exacerbate adverse environmental impacts such as deforestation. Also, this strong reliance on such a small number of sources limits the possibilities of creating meat and dairy replacements. Thus, actors in this search direction focus on finding and developing new sources of protein which can help to uncover new traits and tastes to mimic meat, decrease the environmental impacts associated with alternative protein consumption and production, and reduce the reliance on foreign imports.

Unlike the prior search direction, here actors work to increase the variety of the types of protein sources available on the market. This includes novel sources such as potato, duckweed, fava bean, rapeseed, algae, insects, and seaweed. These sources require different activities to be suitable as sources of alternative proteins. For example, in fava bean, researchers are working to develop new varieties that can be resistant to pathogens and produce high-quality and consistent seeds, whereas in insects, knowledge institutes focus on improving the supply chain which includes assessing and modeling of the most sustainable insect chains.

Multinationals and ingredient producers that are active in this search direction develop new protein sources in order to pursue ingredients to be later used in meat mimicry formulations, similar to that of the previous search direction. This is reinforced by market-driven influences regarding consumer preferences for diverse sources and perceived market opportunities.

> "Soy is actually a very good product if you look into the protein set up as well... but we need to look at alternatives as well because the consumer might be asking for that. And that is why we are, for instance, looking into fava beans in the Netherlands to see what the possibilities of growing them are and making it into a healthy but also very tasteful meat replacer."—Incumbent #3

> "Because we're a company that imports and exports, we're really in the center of the market. We also are able to see what's being requested from the market… and we have this idea that we should jump into one of those opportunities once the right opportunity arises."—Firm #1

Here we see that the activities of many industry actors reinforce the overall directionality towards substitution driven primarily by the market. However, it is important to note that this search direction can potentially also contribute to different directions the Protein Transition may take. For example, researchers that work on duckweed do not pursue the direction of mimicking strategies and instead strive to make these new protein sources into suitable products that do not necessarily resemble meat. Duckweed has superior qualities as a plant-based protein in that it grows exceptionally fast, is accessible worldwide, and has a high protein level. Thus, researchers work to develop duckweed to be eaten raw or incorporate it into a number of recognizable dishes, e.g. soups and risotto.

Notably, researchers are driven by their personal motivations and visions of a desired future state highlighting pressing issues, such as not having enough proteins to feed a rising global population, food insecurity, and climate change as a driver behind their work. What is more, researchers note that here they are able to do research based on their own visions and not at the request of industry actors.

> "I started to work on duckweed because what I see is a very important upcoming problem… that we will not have enough plant proteins to feed the world and that we need to change."—Research #5

> "I think that's very important that we also show our vision. And that we do research, what we think is, is important and not only the research where industry is also involved…"—Research #4

4.2.3 Improving nutritional and functional quality The third direction of search focuses specifically on improving the *nutritional and functional quality* of alternative proteins.

Here, actors are influenced by market-based factors such as consumer preferences for healthier and minimally processed meat substitutes and regulation pertaining to the off-tastes and negative digestive affects associated with several new protein sources.

Actors in this search direction focus primarily on protein sources that are not as well established as soy. Moreover, actors work on new protein sources that we saw in the previous search direction, but they do not focus on identifying new proteins and making them more suitable but specifically focus on improving their functionality and making plant-based products more nutritional.

Activites in this direction are mostly technical. These activities are different from that of the first search direction in that actors do not predominantly work on semi-finished or finished products but work to, e.g. enhance plant-specific qualities at the plant breeding site. Researchers, for example, work to remove the off-tastes of new protein sources through various plant breeding techniques:

> "The project at the moment that I personally supervise is on breeding legumes in specific pulses to remove off-flavors so that they can be further used for processing."—Research #1

To market new protein sources actors must be able to convey that consumers are able to digest them with no side effects. Therefore, unlike the previous directions, this search direction is highly influenced by the Novel Food Regulation. The Novel Food Regulation requires that all new foods marketed after 1997 present an extensive dossier that proves a new protein source's suitability as a safe protein source for human consumption. Therefore, the goal of many actors operating in this search direction is to legitimize new protein sources through clinical trials:

> "A lot of new proteins are coming on the market, but they are not always suitable for human consumption yet because they are new….in Europe we have strict regulations on new products. So, people need to file a Novel Food Dossier…So these [clinical trial] results can help build a novel food dossier that your protein source is safe for human consumption, and you can enter the European markets."—Research #4

Also, like the first two search directions, large multinational companies in this search direction work to create mimicry products that are "clean-label." This is driven by consumer expectations that plant-based substitutes should also be healthy to consume. Thus, companies in the Wageningen ecosystem work on creating clean-label products that aim to reduce the number of additives in meat alternative products such as burgers without compromising taste.

> "People have the idea if they buy a meat replacer that it would be more healthy… but if you start comparing the backsides of two products, you might be surprised by the outcome. So that is something, for instance, we are working on with our product development to have low saturated fat levels, low salt levels..."— Incumbent #3

4.2.4 Fostering a local and self-sufficient alternative protein ecosystem The fourth dominant search direction is *fostering a local and self-sufficient alternative protein ecosystem*. In the Netherlands, actors working on the Protein Transition are inhibited by the amount of available arable land. This makes producing alternative protein products increasingly difficult and as a result, actors outsource for several steps of the alternative protein production chain. This, however, results in significant environmental impacts and drastic reliance on foreign imports of proteins outside the Netherlands. Thus, actors in this search direction are focused on creating and improving the national supply chain. The main drivers behind this search direction are future-vision and mission-based.

Here actors focus primarily on stimulating alternative protein chains in the Netherlands. For example, networking organizations in the Wageningen ecosystem focus on transforming existing infrastructure to also accommodate the production of alternative protein products. Unused and rundown facilities, e.g. former meat-processing factories are turned into so-called "shared facilities networks," where actors can reuse factories for parts of the alternative protein chain:

> "..What I also give great importance to is the redesign of existing infrastructure that is already there…, to make it usable for the production of raw materials or semi-finished products for the protein shift."—Industry Organization #1

Alongside transforming facilities, networking organizations also work to create larger initiatives that promote hands-on learning spaces where consumers, companies, research institutes, and governments can come together to experiment in creating local chains. These field labs promote quick innovation valorization and work to create a zero-carbon footprint by keeping innovation "close to home."

In comparison to the prior search directions, these activities also adhere to the directionality towards meat substitution as actors work on creating semi-finished products which can later be used in end-product formulations. Also, actors work on food application trials directed toward analog products.

The motivations behind this search direction are largely influenced by the National Protein Strategy. One of the strategic goals of the NPS is to increase the number of protein-rich crops harvested and produced within the Netherlands. Thus, actors use this strategy as a means to stimulate their "local" innovation activities:

> "Well, the strategic agenda (NPS), in any case, includes the goal of converting that ratio from 60-40 animal- vegetable protein consumption to 40-60. That is actually the objective in all kinds of regional and national documents. So, we want to set up actions to try to achieve this in the region as well."—Government #4

Another distinct characteristic of this search direction is that government actors work to create payment schemes for Dutch farmers to grow locally. To become fully self-sufficient, farmers in the Netherlands must be incentivized to grow protein sources on Dutch soil. However, these "home-grown" proteins do not guarantee consistent yields as farmers in the Netherlands are accustomed to. Thus, actors also work to create earnings models which provide farmers guaranteed earnings when growing proteins in the Netherlands.

4.2.4.1 Sub-dominant search directions Although the aforementioned directions of search are the most dominant in the Wageningen ecosystem, we also observe three up-and-coming search directions. These search directions are deployed by only a small number of actors in the Wageningen ecosystem, yet serve as their own independent directions of search.

4.2.5 Scaling-up and process optimization Actors in the first emerging search direction work specifically to scale-up novel technology concepts and to improve the efficiency of production processes for meat substitutes. The main activities in this search direction include optimizing production processes, enhancing technological capabilities, and creating scale. Many of the start-ups in Wageningen develop novel technologies with the potential to contribute to the mission of the Protein Transition. However, these technologies are created from a research standpoint and thus, are often difficult to scale up and mass produce. Thus, some actors in this search direction work to ensure that their novel innovations have "impact" and can compete against other alternative protein products on the market.

Other actors recognize that in order to increase consumer uptake of meat substitute products, these products must be lower in price than their animal meat counterparts and therefore work to optimize their production processes. The main factors of influence in this search direction are market and future-vision based.

Start-ups, for example, focus on enhancing their product technologies to become commercially attractive. Thus, they focus on aspects such as cost-efficiency and process. For example, one interviewee stated:

> "To make it commercially interesting, we need to be able to scale-up. So… especially the research that I did myself, we were mainly concerned with 100 grams. Well, there we have made a scaling step within the university to 7 kilos. But to make it commercially interesting, we really need to go to hundreds and thousands of kilos per hour."—Start-up #3

Global technology developers also take a similar approach. While they have already acquired mass-market distribution channels, they focus on increasing throughput and becoming even more process efficient so that the price of plant-based meats can be reduced to that of traditional meats. A traditional HME extruder, for example, can produce up to 500 kg of product per hour, however, after full-processing meat substitutes are often more expensive than real meat. Therefore, to increase consumer access, technology producers focus on increasing the maximum number of kilograms produced per hour.

Notably, this search direction also exhibits directionality as the start-ups focused on scaling-up mostly produce meat analogs. Also, the technologies being optimized are mostly focused on creating competitive meat alternative products:

> "But right now, I'd say probably 90 per cent of my time is spent on the meat analogs."—Incumbent #4

Nevertheless, this search direction is also influenced by visions of creating more environmentally conscious technologies, mainly pursed by smaller companies and researchers:

> "Well, one important one [goal] is how to minimize the energy and what we use during processing. And that's one that we're very, very heavily involved in."—Firm #2

> "The topic is sustainable technology and what I'm actually trying to do is develop new process concepts to make products or ingredients in a more sustainable way."—Research #2

4.2.6 Linking local to global solutions Actors working in this search direction aim to scale-up solutions created in the Netherlands to the rest of the world. Notably, the actor constellation in this search direction includes strictly intermediary organizations such as networking organizations, non-profits, and NGOs. These actors realize that to stimulate a "global" Protein Transition, local initiatives may also be beneficial for dissemination to other locations across the globe. Therefore, this search direction involves creating "global reach" with regard to the transfer of knowledge, technologies, and people to tackle the mission of a global Protein Transition. The main factors driving this search direction is future visions.

This search direction adheres to the overall directionality towards substitution as actors strive to gain "global reach" through the creation of a wide variety of global platforms, websites, and white papers, which disseminate key industry knowledge on meat alternatives to other places around the world. Notably, actors do not create their own technological solutions or conduct research themselves but work to compile and share key information:

> "We specifically focus on meat alternatives, for most of our work… So, really trying to build a community of scientists and entrepreneurs and innovators who have interest and expertise that will be valuable for this field."—Non-profit #3

Networking organizations, for example, work to build "protein pathways." Protein pathways are channels between regions that promote sharing novel technologies, human and physical capital, and knowledge between the Wageningen ecosystem and high-protein consuming regions, e.g. China. Actors are thus, motivated by their own personal future visions of a "global protein transition" which incites them to:

> "'…capture all of that expertise that exists and bring it together in a way that's going to be helpful for everyone' in order to aid visions such as 'feeding a world population that is expected to be close to ten billion people by the year 2050'."—Non-profit #3

4.2.7 Creating a circular food system The final up-and-coming search direction is focused on *creating a circular food system*. In order to create circular food systems, actors in this search direction work to create closed-loop systems, which involve maximizing the use of all biomass. Actors focus on integrating animal and plant-based supply chains. This ideally means that the waste streams created from one supply chain can be used as input to another. Actors in this search direction develop solutions for both food and feed. The main drivers behind this search direction are mission-driven.

Also, here we see activities that aim to connect and coordinate the efforts of different actors. However, these are not aimed at connecting local activities to the global level but at creating circular food systems. Government actors, for example, focus on coordinating regional programs. The project Fascinating 2020, otherwise known as Food Agro Sustainable Nature Technology is an agricultural program from the National Program in Groningen. In this program multinationals, companies, research institutes, and networking organizations work to create closed-loop nitrogen systems and to minimize $C0_2$ emissions.

Notably, this search direction exhibits some directionality as it also promotes upcycling waste streams, e.g. sugar beet leaves to be useful in meat mimicry formulations. However, this search direction is disparate in that, unlike the other search directions, actors primarily work on using alternative proteins to develop animal feed. When processing raw materials, for example, a large majority of the plant is not used in processing. Actors thus work to upcycle the remaining raw materials into cow feed.

Strikingly, actors in this search direction do not focus on the mission of a Protein Transition in itself but as a means to reach the mission of a Circular Economy:

> "… a Circular Economy implementation program was established in the province. And it is based on the largest raw material flows that existed in Gelderland… And that has led to us… We have invested heavily in the protein transition in Gelderland."—Government #2.

Furthermore, actors see the Protein Transition as a necessary component to reach this goal.

5. Analysis and discussion

Overall, we observe two distinct sociotechnical "levels" in which both diversity and directionality coexist in the activities and developments related to the Protein Transition. At the first level of transition pathways, we observe that there is a strong directionality toward substitution in the Wageningen ecosystem. This clear "first-order" directionality reduces the diversity present in achieving the "Protein Mission." We observe that both the dominant and subdominant search directions consist mostly of activities that are centered around the production and consumption of (meat) substitutes. Further, while actors do create a variety of different types of analogs, processing technologies, and ingredients, the focus is predominantly limited to technological innovations that aim to contribute to the substitution pathway.

We, however, fail to observe a significant number of activities that aim to provide socially and institutionally diverse solutions, such as those that would stimulate novel ways of cooking and thinking about food or question the role of "animals" in their entirety (see e.g. Lonkila and Kaljonen 2021; Van Mierlo and Klerkx 2023). On the second level of search directions, we found diversity ("second-order" directionality) in the form of seven directions of search in the Wageningen ecosystem. These search directions came about due to factors such as researchers' personal interests (e.g. developing fava bean as a novel source of protein) and also consumer preferences for meat substitutes that are less processed.

On the basis of these findings, we develop three hypotheses about the interplay between diversity and directionality in a MIS. First, it can be hypothesized that diversity at the level of search directions may *strengthen* the directionality of an innovation system. Although the seven search directions form distinct innovation activities with disparate goals, they simultaneously each contribute strongly to the "first-order" directionality toward (meat) substitution, see Fig. 1. In other words, we observe diversity *within* the substitution transition pathway.

Our findings echo that of Yap and Truffer (2019) and Schippl and Truffer (2020) who highlight that alignment across elements (or activities) in different levels may result in stronger directionality. To elaborate, in our case we observe that while actors deploy diverse search directions, the activities they encompass are widely complementary. For example, the activities in the search directions *developing new protein sources* and *improving taste and texture* may go hand-in-hand, e.g. developing fava bean to be used in a meat mimicry formulation, and therefore, more strongly shape the directionality towards the meat substitution pathway. Further, this resonates with ideas coined by Klerkx and Begemann (2020) that a larger mission may constitute smaller "sub-missions," which represent a particular transition pathway and way of operationalizing the larger mission in terms of the search directions and the sociotechnological solution spaces that are explored. Nonetheless, it is important to note that despite the observed *technological* diversity within a singular transition pathway like meat substitutes, the diversity observed remains rather limited. Furthermore, the search directions that complement (or align) with each other are predominately pursed by multinational corporations who arguably possess greater agency in shaping directionality, potentially stifling the development of emerging search directions and excluding the values of and visions of fringe actors (El Bilali 2019; Dueñas-Ocampo, Eichhorst, and Newton 2023).

Second, while at first glance strong directionality at the first level seems to restrict the solution space for the Protein Transition, we hypothesize that diversity at the second level of search directions could contribute to other pathways as well. For example, the search direction *developing new protein sources* does not focus solely on developing proteins for meat substitute products but included activities related to promoting unprocessed plant-based protein consumption, e.g. duckweed. Likewise, in the search direction *creating a circular food system*, actors do not only focus on upcycling waste streams to be useful in mimicry formulations but also focus on activities dedicated to the transition pathway of stimulating alternative farming systems.

In this search direction, we observe knowledge being created that challenges the current food system in its entirety by, for example, using what was once seen as waste as an input for cow feed. Even if innovation ecosystems display strong directionality at the level of transition paths, diverse search directions may stimulate competition and create space for including marginal and conflicting interests (see e.g. Klerkx and Begemann 2020). This shows that diversity and directionality are not necessarily opposites. Hence, connecting to and deepening Parks (2022), "first-order" directionality may be based on the consensus that alternative proteins are needed and serve as a guiding vision for the Wageningen Ecosystem with one clear transition pathway. On the other hand, "second-order" directionality is based on contestation and divergence, hence multiple search directions, and its articulation is delegated to MIS stakeholders at the

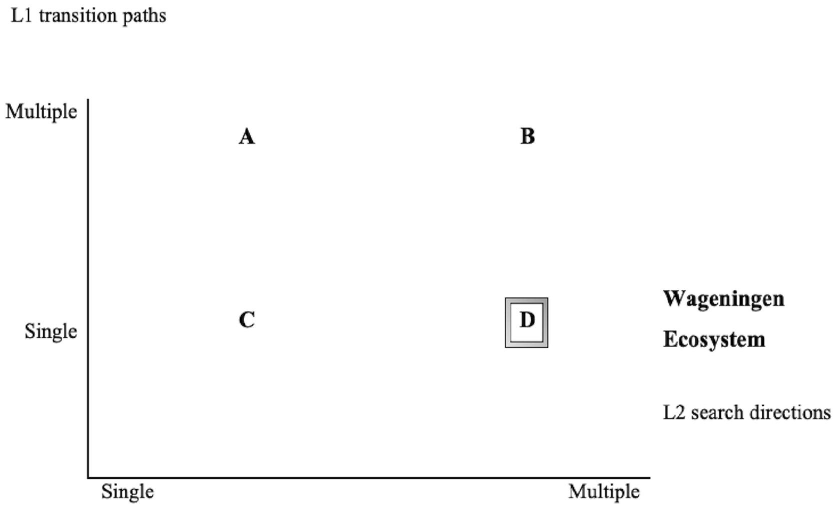

Figure 2. Different constellations of directionality and diversity based on the different levels emerging from this study.

micro-level of enterprises and research projects. Nevertheless, the issues of potential power imbalances also plague the optimism of this hypothesis. Furthermore, power asymmetries may affect the prioritization of certain search directions over others, ultimately hindering their fruition and ability to contribute to more novel transition pathways (Yap and Truffer 2019).

A related observation is that the diversity of search directions may support ecosystems in responding to emerging issues. For example, an emerging problem in the meat substitute transition pathway is that analogs do not contain as many nutritional benefits as previously assumed, which has resulted in court cases against popular meat substitute producers (Wile, 2023). However, we observe that despite Wageningen's strong directionality toward meat substitution, the work on clean-label products in the search direction of *improving nutritional and functional quality* more easily enables actors in the system to respond to such complex challenges. In that sense, we posit that search directions may increase flexibility in the face of the unpredictable and complex nature of societal grand challenges, and—again—that diversity and directionality are not necessarily at odds with one another. In this way, diversity at the level of search directions ensures that some of the downsides of strong directionality, such as premature lock-in due to a dominant design or what turns out to be a lack of transformative potential (see e.g. Porto Vilas Boas Souza, 2020; Parks 2022) that were also identified in diversity literature are avoided (see e.g. Stirling 2009, 2011). This may help address several of the challenges for enacting effective directionality as identified by Bergek, Hellsmark, and Karltorp (2023), such as defining clear system boundaries of sub-missions and their search directions within the overall MIS, identifying realistic pathways and strategies for concrete innovations, and identifying target groups for them.

The distinction between the level of the transition pathway and the level of the directions of search that emerged from our study, suggests that there are different possible constellations of diversity and directionality (see Fig. 2). Besides mission-driven innovation systems with single dominant transition paths and multiple search directions like the Wageningen ecosystem (quadrant D), there may also be MIS's with a single transition path and a single search direction (C), multiple transition paths and multiple search directions (B), and even with multiple transition paths and a single search direction (A).

Thus third, we hypothesize that each constellation of diversity and directionality has its own strengths and weaknesses in achieving societal grand challenges. The combination of multiple transition paths and multiple search directions (quadrant B) may be especially open to marginal and conflicting interests and may also increase resilience in the face of uncertainties and complexities. Furthermore, this combination of diversity and directionality has the potential to shield the mission from becoming centralized and concentrated where only the powerful steer the direction of change (Klerkx and Rose 2020). Nevertheless, this potential is contingent on whether or not a broad range of actor groups are sufficiently represented and included in the processes of directionality shaping, as has been noted elsewhere for the protein transition, in particular cellular agriculture (Chiles et al. 2021). This would require addressing issues of power imbalances, making space to deliberate, and fostering controversy (Duncanet al. 2022). As a final note, a downside associated with this specific constellation is that it runs the risk of providing too little direction to innovation activities, and therefore, results in unmet goals, which from a MIS perspective may undermine a mission's time-bound and temporary nature (Mazzucato 2016; Hekkert et al. 2020; Elzinga et al. 2023).

In turn, the combination of a single transition path and a single search direction (quadrant C) offers the most direction not only to innovation activities but is also most vulnerable to undesirable lock-in that may hamper a system's ability to maneuver in the face of changing circumstances. What is more, this quadrant also warrants the dominance of hegemonic power structures in which the few may benefit at the expense of many (Klerkx and Rose, 2020). Further, the constellation of multiple transition paths and a single search direction (quadrant A) may be a special case that may not be encountered often in MIS. One situation in which this constellation may occur is when missions revolve around the development of an enabling technology, such as artificial intelligence or nanotechnology. In such cases, there may be a single search direction in order to improve an enabling technology that can later be used in a variety of transition paths and missions. As such, the distinction between "first-order" (transition path) and "second-order" (search directions) directionality may help to shed new light on the interplay between diversity and directionality.

Regarding the limitations of our research, it is ever more important to highlight the plurality of food system transitions, particularly the diverging visions and values in the transition to alternative proteins (Katz-Rosene, Heffernan, and Arora 2023; Duncan et al. 2022). While our case looked at the search directions present in the Wageningen ecosystem and their impact on diversity and directionality, it is clear that there are other potential directions of search encompassing diverging views (see e.g. Van Mierlo and Klerkx 2023). One key point of attention is the transition's impact on farmer livelihoods, as the substitution pathway may displace these actors (Burton 2019; Glaros et al. 2023). Furthermore, in future studies we call for the inclusion of broader perspectives, namely those of small farmers, social movements, and other fringe actors, as including these actors and their visions is necessary to ensure a just and equitable transition (Broad 2019; Chiles et al. 2021; Dueñas-Ocampo, Eichhorst, and Newton 2023; Glaros et al. 2023; Newell and Glaros 2024).

6. Conclusions

In this paper, we aimed to address a key issue regarding sustainability transitions and transformative and mission-specific innovation policies: whether to foster diversity or directionality in the presence of societal grand challenges. We utilized the "Protein Transition" as our case of analysis as it signifies a clear mission and there is a strong directionality with regards to the direction of change within a MIS pursuing a particular transition pathway (in our case toward technological innovation focused on meat substitution) (see also Tziva et al. 2020; Bulah et al. 2023a, 2023b). We zoomed in on the Wageningen ecosystem given that Wageningen is a hotspot for alternative protein research and is also home to a myriad of actors active in the Protein Transition MIS. Our findings show that contrary to what literature suggests (see e.g. Stirling 2009, 2011; Mazzucato 2016, 2018) directionality and diversity are not mutually exclusive.

We contribute to the literature on diversity in transitions and directionality in MIS and show that both can coexist in the pursuit of societal grand challenges. Furthermore, we propose that the interplay between diversity and directionality can be best understood by distinguishing different sociotechnical "levels" at which they play out: namely, the levels of transition paths (level 1) and search directions (level 2). Our case illustrates that while, on the one hand, "first-order" directionality may restrict the opportunities for diversity in a MIS as it strongly favors one particular transition pathway, on the other hand, factors such as researchers' personal motivations, the expected consumer preferences, and capabilities, may still involve "second-order" directionality regarding the search directions and therefore provide diversity within a mission-specific transition process. Search directions thus may nurture opportunities for societies to reorient to other transition pathways in the future.

Literature on diversity states that strong directionality when tackling grand challenges may lead to premature "lock-in" and therefore limit opportunities to diversify in unforeseen circumstances (Stirling 2011), but this is one of the main premises of MIP and MIS (Mazzucato 2016, 2018; Kattel and Mazzucato 2018; Hekkert et al. 2020; Elzinga et al. 2023). Our case highlights, that while at first glance, strong "first-order" directionality seems problematic to the future development of the MIS in view of constraining diversity, when we dig deeper, other mechanisms such as diversity in values and future visions may still present opportunities to explore alternative pathways (see e.g. Schlaile et al. 2017). Our findings also speak to Schlaile et al. (2017), who highlight that the process of shaping the direction of a transition is not a "straightforward" matter and that diverse expectations, conflict, and uncertainty (i.e. the normative aspects associated with transitions) are inherent in the pursuit of any complex challenge and may ultimately lead to diversity. We therefore argue that a more nuanced perspective is needed when aiming to understand the role of diversity and directionality in the pursuit of societal grand challenges (see also Van Mierlo, Beers, and Hoes 2020), which echoes other recent work in this area (Parks 2022).

Nevertheless, regarding the case of the Protein Transition MIS, whether there is a good balance between "first-order" directionality and diversity cannot be judged at this point in time. It is hard to foresee to what extent the substitution pathway could meet the goals of the mission to shift the production and consumption of proteins, and how it compares to alternative protein transition pathways (or sub-missions), such as cultured or cellular meat, or veganism. Notwithstanding an increasing network and awareness among consumers, market sales of meat alternatives have been remaining stagnant and are even dropping. Also, the consumption of meat has remained rather stable in the Netherlands (Dagevos and Verbeke 2022).

Critical sociologists point to the risk of reinforcing skewed power relations in the agri-food system with the current focus on meat substitution (Broad 2019; Lonkila and Kaljonen 2021). Currently, the search directions supporting alternative pathways or sub-missions seem to be less dominant in the Wageningen ecosystem. Moreover, they do not complement each other as well as the search directions supporting the meat substitution pathway do. Hence, once the latter have become dominant designs the risk of an early lock-in, may re-appear. Finally, the emerging search directions in the Wageningen ecosystem are only pursued by a small number of actors, begging the question if these will ever fully come to fruition and underscoring the need for the inclusion of broader perspectives. What is more, our case highlights the need for constant reflexivity when moving forward in both the policy realm and in practice.

Nevertheless, given our focus on a single case, we warrant further research on the role of diversity and directionality in other sectors which have displayed strong directionality for a longer period such as energy and transport as these sectors might display different constellations of diversity and directionality (as suggested in Fig. 1). An interesting avenue of research would be to further investigate diversity and directionality in different contexts such as the Global South and also explore what may be an optimal balance between the two in different phases of a transition.

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Appendix A

Interview Guide
Research Aim:

The purpose of this research is to gain insight into the factors that determine the "direction of search" of Wageningen-based plant-based innovators. Direction of search is defined as the type of solutions that plant-based innovators are exploring, developing, and pursuing in order to solve particular problems that they deem most pressing. Thus, direction of search is both about the perceived problem (e.g. we need a better texture) and the solutions that are considered (e.g. microbial transglutaminase).

In the interview guide, we use the word "innovation activities." You can also use the word R&D activities. For a knowledge institute, the term "research activities" can be used.

Delineation: plant-based proteins to replace meat, dairy, and other products which come from animals like eggs and egg products; the related technical, social, and institutional innovations.

Research Question

I. Interviewee background

1. Could you tell me about your function and the organization you work for?
2. Could you tell me about your daily role in the context of your organization?

II. Organization's direction of search

Note for interviewee: This section can be tailored to the person/organization you interview. Based on that you can decide if you begin with the specific organization's motivations, goals, and activities and then move to how this connects to other developments or vice versa.

We have witnessed an exceptional market growth for plant-based proteins in recent years. Also, we notice a lot of new products and new product characteristics. Apparently, there is a lot of innovation going on.

1. Can you describe the innovation activities in plant-based proteins, why are you doing this?

a. What are the main challenges or problems firms and knowledge institutes try to solve within these innovation activities/trajectories?

b. What are the most dominant solutions that are pursued to solve these challenges/problems and how do they work alongside each other?

c. Where do these solutions come from (geographically)?

d. How do you see the future of the industry and what do you think could be improved in order to accelerate the transition?

2. How do your organization's innovation activities fit within the wider field of innovation?

a. In terms of main challenges or problems, what is it that drives you and/or your organization?

Below a set of potential problems that can be used to prompt interviewee.

- Environmental consequences	- Search for healthier alternatives
- Improved texture and taste of alternative proteins	- Sustainable resource use/better crops as input
- Lowered cost of alternative proteins	- Other

b. What is the solution that you are working on? (Or in plural)

Follow-up if needed: Can you elaborate what you do exactly in terms of innovation activities (R&D activities)?

What happens where?

Have these activities changed overtime? If so, how?

How have you seen the industry change overtime?

c. How do you foresee the development and implementation of the solution? Which applications and at what time frame?

d. Are there major obstacles to overcome? Which?

e. What is the main market your organization targets and why?

lll. Network characteristics

1. Who are your organization's most important collaborators that influence your innovation activities and why are they so important?

When unclear: you may explain that collaborators can be knowledge partners but also clients that demand certain quality aspects

Follow-up if needed: What do they contribute?

2. Why do you collaborate with these organizations and for what purpose(s)?
3. Where are these organizations located? Geographically and in the supply chain?

I am interested in how your organization manages collaboration and knowledge exchange across scales.

4. How does your organization do this, and do you encounter difficulties when cooperating with actors in different places?

lV. Other factors of influence

1. What would you describe as the most influential factors to your organization's innovation choices and why?

(*create a list of factors and probe on each, use the list below to check whether certain influences are important but overlooked, the sub-questions may be used when a factor is considered important)*

2. You did not mention the following factors ______ can you elaborate a bit on their influence?

Factor	Questions
Finance/investment	- How are your projects financed and by whom? - Where are they situated? - How does this influence your innovation decisions?
Past choices/ technological preferences	- How do past choices/technological preferences influence what your organization does? - Why does your organization choose to continue on this path?
Consumer preferences/ trends	- What do you see as the most important consumer trend and where does it come from? - How does this influence your innovation decisions?
Regulation	- What regulations influence your organizations activities? - How does this influence your innovation decisions?
Other	- What other factors influence your organization's innovation activities and how?

3. I now have a set of factors that you mention as important for your organization's innovation choices. Can you rank them from most important to least important?

VI. Closing question

Is there anything else you would like to add that has not yet been covered?

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