TNO Vector
Anna van Buerenplein 1
2595 DA Den Haag
P.O. Box 96800
2509 JE Den Haag

www.tno.nl

T +31 88 866 00 00

TNO Report

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QUANTIFYING ECOSYSTEM CHARACTERISTICS
A quantitative approach for identifying bottlenecks in research and innovation ecosystems

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Auteur(s) Anastasia Yagafarova, Babette Bakker, Ron van Maurik, Thijmen van Bree, Finn Speijer, Marcel de Heide

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Executive summary

The term ‘research and innovation ecosystem’ has gained tremendous popularity over the past years. It is often used interchangeably with terms such as ‘local buzz’, ‘cluster’, ‘innovation systems’, ‘entrepreneurial ecosystems’, ‘technological and mission-driven innovation systems’. A research and innovation ecosystem allows for many economic benefits such as job creation, productivity increase and knowledge spillovers. It therefore comes as no surprise that many governments, including the Dutch government, have announced the desire to strengthen existing ecosystems and foster the development of new ‘exemplary’ ecosystems[1]. In this study, research and innovation ecosystems are defined as follows:

*A **research and innovation ecosystem** is a dynamic set of related actors, activities, facilities and rules that are important for the research and innovation capability of individual actors and groups of actors, where actors actively and deliberately work together to innovate and hence create value.*[2]

This report presents the results of the research aiming to link the functioning of the research and innovation ecosystems with the framework of market, system and transformation failures. The research took place between November 2021 and July 2023. Specifically, the aim of this research was to answer these questions:

1. How does an ‘ideal’ ecosystem function?
2. What types of market, system and transformation failures can occur within such an ecosystem?
3. What quantitative information and data might indicate the presence of a market, system or transformation failures?

How does an ‘ideal’ ecosystem function?
A research and innovation ecosystem is a dynamic and complex system. While there is no definition of an 'ideal' research and innovation ecosystem, vital and resilient ecosystems do exist and prosper. (TNO, 2020) suggested that a minimum configuration of various elements in an ecosystem determines whether a R&I ecosystem could be vital and resilient. Such minimum configuration forms then a **minimum viable research and innovation ecosystem** that is defined as *the minimum configuration of related actors, activities, facilities and rules in the research and innovation ecosystem that creates long term (societal) value for all actors in the ecosystem* (TNO, 2020).

A minimum viable research and innovation ecosystem consists of various actors that use knowledge, labour, capital and various facilities. The actors within this ecosystem perform various activities such as innovating, disseminating and creating knowledge, networking, acquisition of capital, lobbying among, providing leadership

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[1] (Ministry of Economic Affairs and Climate Policy, 2020).
[2] Based on (Dialogic, 2020) and (TNO, 2020) that actors actively and deliberately work with each other to innovate. Particularly the part of working actively and deliberately on innovating was added based on the practical experience of TNO as an active part of different (regional) ecosystems and an ‘ orchestrator of innovation’ by providing support to different parties in setting up partnerships and cooperation to innovate.

and steering resulting in creation of new knowledge, skills or innovation (TNO, 2020). Some of these elements are shaped and directed by the ecosystem's governance and goal.

What types of market, system and transformation failures can occur within such an ecosystem?

Within the scientific literature, three types of failures are distinguished: market, system and transformation failures. The distinction between these different types of failures reflect the scientific origins. The failures are looked at from different perspectives. At the same time, one underlying cause might lead to various types of failures. Therefore they are not mutually exclusive and could overlap. This research attempted to link these types of failures with the different aspects of a minimum viable research and innovation ecosystem as summarised in Table 1.

Table 1 – Aspects of an ecosystem where a failure mechanism might originate per market, system and transformation failure

Aspect of an ecosystem where failure mechanism might originate	Market failures				System failures				Transformation/ transition failures			
	Market concentration	Public good	Externalities	Information asymmetry	Capability failures	Interaction failures	Institution failures	Infrastructure failures	Reflexivity failure	Policy coordination failure	Demand articulation failure	Directionality failure
Key assets and factors												
Actors	x			x	x							
Market forces and access	x										x	
Institutional settings and rule of law							x			x		
Labour and talent					x							
Embeddedness in networks						x						
Key technologies					x							
Supporting infrastructure								x				
Knowledge base			x		x							
Financial capital		x		x								
Governance and goal												
Common goal, mission and vision									x	x		x
Strategies and agendas									x	x		x
Organisational structure							x		x			
Key activities												
Societal relevance and challenges		x	x							x	x	
Providing leadership and steering									x			x
Acquiring new capital				x								
Innovating		x	x	x								
Developing and disseminating knowledge			x		x							
Networking and building partnerships						x						
Developing human capital					x							
Lobbying and influencing						x						

Note: adapted from (TNO, 2020), Arrow (1962), (Klein-Woolthuis, Lankhuizen, & Gilsing, 2015), (Weber & Rohracher, 2012), authors elaboration.

Market failures focus on market imperfections and underlying mechanisms, therefore they are present mainly in the relations between the actors, how market forces and access are functioning, (access to) financial capital and the main activity taking place in an ecosystem: innovating. System- and transformation failures look at an innovation ecosystem from a broader perspective. System failures put emphasis on the systemic contexts which limits, directs or supports the innovation activities and capabilities. Thus, they are spread across factors and innovation assets, and key activities of a minimum viable ecosystem. The transformation failures framework adds a layer that is conducive to processes of transformative change, which are strategic in nature. Unlike market and system failures, transformation failures dominantly originate in the aspects of the minimum viable research and innovation ecosystem surrounding its governance and goal.

What quantitative information and data might indicate the presence of a market-, system- or transformation failures?
This research proposes a set of quantitative indicators and sources that might signal or refer a certain bottleneck or a failure in the functioning of an ecosystem. These suggested indicators and sources are a first attempt to create such a list, therefore it could not be considered as exhaustive. They are an indirect measurement of failure and shall be regarded as a suggestion to describe a certain aspect that could describe or signal a certain failure mechanism.

Understanding bottlenecks or issues within a research and innovation ecosystem starts with understanding the ecosystem itself and its functioning. A proper understanding of the functioning of a research and innovation ecosystem is pivotal for deciding whether a certain indicator might signal that there are any bottlenecks within such an ecosystem. Once the functioning of a research and innovation ecosystem is understood, the proposed list of indicators could be tested to determine whether they are realistic to construct from a suggested source, whether a certain indicator might signal a certain type of failure, and whether an indicator supports an initial hypothesis of an existing failure.

While the research and innovation ecosystems are being researched, there is no agreed methodology on how they should be scoped, mapped out and what quantitative information needs to be used to understand their functioning. In addition, quantitative information is not readily available for such ecosystems and has to be constructed. Therefore a pilot was conducted to research one specific research and innovation ecosystem separately from this research between May 2022 and June 2023. It focused on understanding the functioning of the research and innovation ecosystem of photonics in the Netherlands.

The results of this pilot serve as a first step to gain insights into the functioning of a R&I ecosystem. They shed light on how a research and innovation ecosystem could be mapped out and could be used as an input for the discussions with the stakeholders within the ecosystem. The results from this pilot alone are not sufficient to make definitive statements about the functioning of the R&I ecosystem. The main reason for it is that within this pilot it was not possible to get a good estimate of what part of the R&I ecosystem was captured. Therefore further research is needed to investigate it before possible bottlenecks within an ecosystem could be mapped out according to the set of indicators and sources proposed in this research. Nevertheless, the chosen quantitative approach allows us to compare ecosystems in a consistent manner, which is more difficult with qualitative information.

Concluding remarks
This paper focused on bridging the term of a (minimum viable) research and innovation ecosystem and the frameworks of market, system and transformation failures. To that end, a list of quantitative indicators and the potential sources was proposed that could signal whether a certain type of failure is present. Such list is a first attempt to do so and therefore has to be treated as non-exhaustive.

To understand whether there are specific types of bottlenecks or failures within such an ecosystem starts with understanding how the system functions. The available quantitative data and information is however limited for the ecosystems as they are spread across various sectors of economic activity. Further research is needed before the proposed set of indicators potentially signalling a specific type of failure could be tested and expanded.

Increasing availability of data through existing sources and emergence of new data sources offers possibilities to further expand the understanding of the research and innovation ecosystems. Combining these insights with the expert knowledge could further enrich understanding of the research and innovation ecosystems in general and support the development of policies and strategies.

Samenvatting

De term 'onderzoeks- en innovatie-ecosysteem' heeft de laatste jaren enorm aan populariteit gewonnen. Het wordt vaak in dezelfde context gebruikt als termen als 'local buzz', 'cluster', 'innovatiesystemen', 'ondernemende ecosystemen', 'technologische en missiegedreven innovatiesystemen'. Een onderzoeks- en innovatie-ecosysteem zorgt voor veel economische voordelen zoals het creëren van banen, het verhogen van de productiviteit en kennis-spillovers. Het is dan ook geen verrassing dat veel overheden, waaronder de Nederlandse, hebben aangekondigd bestaande ecosystemen te willen versterken en de ontwikkeling van nieuwe 'voorbeeldige' ecosystemen te willen stimuleren[3]. In deze studie worden onderzoeks- en innovatie-ecosystemen als volgt gedefinieerd:

Een **onderzoeks- en innovatie-ecosysteem (O&I ecosysteem)** is een dynamische set van samenhangende actoren, activiteiten, faciliteiten en regels die van belang zijn voor het onderzoeks- en innovatievermogen van individuele en groepen actoren, waarin de actoren actief en doelbewust samenwerken aan innovatie, en daarmee het creëren van waarde. [4]

Dit rapport presenteert de resultaten van een onderzoek waarin het functioneren van onderzoeks- en innovatie-ecosystemen wordt gekoppeld aan markt-, systeem- en transformatiefalen. . Het onderzoek vond plaats tussen november 2021 en juli 2023 en in dit onderzoek worden de volgende vragen behandeld:

1. Hoe functioneert een 'ideaal' ecosysteem?
2. Welke soorten markt-, systeem- en transformatiefalen kunnen optreden binnen een dergelijk ecosysteem?
3. Welke kwantitatieve informatie en data kunnen duiden op de aanwezigheid van markt-, systeem- of transformatiefalen?

Hoe functioneert een 'ideaal' ecosysteem?

Een onderzoeks- en innovatie-ecosysteem is een dynamisch en complex systeem. Hoewel er geen definitie is van een 'ideaal' onderzoeks- en innovatie-ecosysteem, bestaan er wel degelijk succesvolle, vitale en veerkrachtige ecosystemen. Eerder onderzoek (TNO, 2020) suggereert dat een minimale configuratie van verschillende elementen in een ecosysteem bepaalt of een O&I-ecosysteem vitaal en veerkrachtig kan zijn. Een dergelijke configuratie vormt dan een ‘minimum viable’ onderzoeks- en innovatie-ecosysteem dat wordt gedefinieerd als de minimale samenstelling van gerelateerde actoren, activiteiten, faciliteiten en regels in het onderzoeks- en innovatie-ecosysteem die op lange termijn (maatschappelijke) waarde creëert voor alle actoren (TNO, 2020).

Een **’minimum viable’ onderzoeks- en innovatie-ecosysteem** bestaat uit verschillende actoren die gebruik maken van kennis, arbeid, kapitaal en verschillende faciliteiten. Daarnaast voeren deze actoren verschillende activiteiten

[3] (Ministry of Economic Affairs and Climate Policy, 2020).
[4] De definitie is samengesteld op basis van twee definities van een onderzoeks- en innovatie ecosysteem: Dialogic. (2020). Onderzoeks- en innovatie-ecosystemen in Nederland, TNO. (2020). Regionale innovatie-ecosystemen: Onderzoek naar optimale vormgeving van en dynamiek in regionale ecosystemen, TNO 2020 R11137.

uit, zoals innoveren, verspreiden en creëren van kennis, netwerken, kapitaal verwerven, lobbyen, leiding geven en sturen die leiden tot het creëren van nieuwe kennis, vaardigheden of innovatie (TNO, 2020).

Welke vormen van markt-, systeem- en transformatiefalen kunnen optreden binnen een dergelijk ecosysteem?

Binnen de wetenschappelijke literatuur worden drie soorten falen onderscheiden: markt, systeem en transformatie falen. Het onderscheid tussen deze verschillende soorten falen weerspiegelt de wetenschappelijke oorsprong. Daarom zijn de verschillende soorten falen in deze studie bekeken vanuit verschillende perspectieven. Eén onderliggende oorzaak kan tegelijkertijd leiden tot verschillende soorten falen. Daarom sluiten ze elkaar niet uit en kunnen ze elkaar overlappen. In dit onderzoek is geprobeerd om deze soorten falen te koppelen aan de verschillende aspecten van een ’minimum viable’ onderzoeks- en innovatie ecosysteem, zoals samengevat in Tabel 1.

Tabel 2 – Aspecten van een ecosysteem waar een faalmechanisme kan ontstaan per markt-, systeem- en transformatiefalen

Aspect of an ecosystem where failure mechanism might originate	**Market failures**				**System failures**				**Transformation/ transition failures**			
	Market concentration	Public good	Externalities	Information asymmetry	Capability failures	Interaction failures	Institution failures	Infrastucture failures	Reflexivity failure	Policy coordination failure	Demand articulation failure	Directionality failure
Key assets and factors												
Actors	x			x	x							
Market forces and access	x										x	
Institutional settings and rule of law							x			x		
Labour and talent					x							
Embeddedness in networks						x						
Key technologies					x							
Supporting infrastructure								x				
Knowledge base			x		x							
Financial capital		x		x								
Governance and goal												
Common goal, mission and vision									x	x		x
Strategies and agendas									x	x		x
Organisational structure							x		x			
Key activities												
Societal relevance and challenges		x	x							x	x	
Providing leadership and steering									x			x
Acquiring new capital				x								
Innovating		x	x	x								
Developing and disseminating knowledge			x		x							
Networking and building partnerships						x						
Developing human capital					x							
Lobbying and influencing						x						

Bron: (TNO, 2020), Arrow (1962), (Klein-Woolthuis, Lankhuizen, & Gilsing, 2015), (Weber & Rohracher, 2012).

Marktfalen richt zich op marktimperfecties en onderliggende mechanismen, en is daarom vooral aanwezig in de relaties tussen actoren, hun toegang tot markten en het functioneren daarvan,(toegang tot) financieel kapitaal en de belangrijkste activiteit die plaatsvindt in een ecosysteem: innoveren. Systeem en transformatie falen bekijken een innovatie-ecosysteem vanuit een breder perspectief. Systeem falen legt de nadruk op de systemische context die de innovatieactiviteiten en -capaciteiten kan beperken, sturen en of ondersteunen. Ze zijn dus verspreid over factoren en innovatiemiddelen en sleutelactiviteiten van een ’minimum viable’ ecosysteem. Het raamwerk voor transformatiefalen voegt een laag toe die zich richt op processen van transformatieve verandering, welke strategisch van aard zijn. In tegenstelling tot markt en systeem falen, vindt transformatie falen zijn oorsprong voornamelijk in de aspecten van het ’minimum viable’ onderzoeks- en innovatie-ecosysteem die betrekking hebben op het bestuur en het doel ervan.

Welke kwantitatieve informatie en data kunnen duiden op de aanwezigheid van markt, systeem of transformatiefalen?

In dit onderzoek worden kwantitatieve indicatoren gepresenteerd die kunnen wijzen op een bepaald knelpunt in het functioneren van een ecosysteem. Deze voorgestelde indicatoren zijn een eerste poging om een dergelijke lijst op te stellen en kunnen daarom niet als volledig worden beschouwd. Het gaat om indirecte metingen van falen en moeten dan ook worden beschouwd als een suggestie om een bepaald (aspect van) een faalmechanisme te beschrijven of signaleren.
Het begrijpen van knelpunten of problemen binnen een onderzoeks- en innovatie-ecosysteem begint met inzicht in het ecosysteem zelf en de werking ervan. Een goed begrip van het functioneren van een onderzoeks- en innovatie ecosysteem is van cruciaal belang om te beslissen of een bepaalde indicator een signaal kan geven dat er knelpunten zijn binnen een dergelijk ecosysteem. Zodra het functioneren van een onderzoeks- en innovatie-ecosysteem wordt begrepen, kan de voorgestelde lijst van indicatoren worden getest om te bepalen of deze indicatoren gebruikt kunnen worden om een realistisch beeld te geven van een bepaald type falen en of een indicator een initiële hypothese van een bestaand falen ondersteunt.

Hoewel onderzoeks- en innovatie-ecosystemen worden onderzocht, is er geen overeengekomen methodologie over hoe deze moeten worden afgebakend, in kaart gebracht en welke kwantitatieve informatie moet worden gebruikt om hun werking te begrijpen. Bovendien is kwantitatieve informatie voor dergelijke ecosystemen niet direct beschikbaar en moet deze worden geconstrueerd. Daarom werd tussen mei 2022 en juni 2023 een pilot uitgevoerd om los van dit onderzoek één specifiek onderzoeks- en innovatie-ecosysteem te onderzoeken. De pilot richtte zich op het begrijpen van het functioneren van het onderzoeks- en innovatie-ecosysteem van fotonica in Nederland.

De resultaten van deze pilot dienen als een eerste stap om inzicht te krijgen in de werking van een O&I-ecosysteem. Ze werpen licht op hoe een onderzoeks- en innovatie ecosysteem in kaart gebracht zou kunnen worden en kunnen als input dienen voor de gesprekken met stakeholders binnen het ecosysteem. De resultaten uit deze pilot alleen zijn niet voldoende om definitieve uitspraken te doen over het functioneren van het O&I ecosysteem. De belangrijkste reden hiervoor is dat het binnen deze pilot niet mogelijk was om een goede inschatting te krijgen van welk deel van het O&I ecosysteem is vastgelegd. Daarom is verder onderzoek nodig om dit te onderzoeken voordat mogelijke knelpunten binnen een ecosysteem in kaart kunnen worden gebracht volgens de in dit onderzoek voorgestelde set van indicatoren en bronnen. Desalniettemin maakt de gekozen kwantitatieve aanpak het mogelijk om ecosystemen onderling te vergelijken, wat met kwalitatieve informatie moeilijker gaat .

Conclusies

Dit onderzoek richt zich op het overbruggen van de theorie van (’minimum viable’) onderzoeks- en innovatie ecosystemen en de kaders van markt, systeem en transformatie falen. Daartoe werd een lijst van kwantitatieve indicatoren en mogelijke bronnen voorgesteld die kunnen aangeven of er sprake is van een bepaald type falen. Deze lijst is een eerste poging daartoe en moet daarom als niet-uitputtend worden beschouwd.

Om te begrijpen of er specifieke soorten knelpunten zijn binnen een dergelijk ecosysteem, moet men eerst begrijpen hoe het systeem functioneert. De beschikbare kwantitatieve gegevens en data zijn echter beperkt voor de ecosystemen, aangezien ze verspreid zijn over verschillende sectoren van economische activiteit. Er is verder onderzoek nodig voordat de voorgestelde reeks indicatoren die op een specifiek soort falen kunnen wijzen, kan worden getest en uitgebreid.

De toenemende beschikbaarheid van gegevens via bestaande bronnen en de opkomst van nieuwe gegevensbronnen biedt mogelijkheden om het begrip van de onderzoeks- en innovatie-ecosystemen verder uit te breiden. Het combineren van deze inzichten met de kennis van experts kan het begrip van de onderzoeks- en innovatie-ecosystemen in het algemeen verder verrijken en de ontwikkeling van beleid en strategieën ondersteunen.

1 Introduction

Research and innovation (R&I) ecosystems have been increasingly studied over the past decades. Their policy relevance is also researched with the focus on how to strengthen and promote ecosystems while increasing prosperity and tackling societal challenges. A research and innovation ecosystem creates new knowledge, skills, and innovations. Such a system allows for many economic benefits such as job creation, productivity increase and knowledge spillovers. In some cases, the ecosystem revolves around social innovations regarding societal relevancies and challenges such as the current energy transition. It therefore comes as no surprise that governments, including the Dutch government, have announced that they desire to strengthen existing ecosystems and foster the development of new 'exemplary' ecosystems[5].

In order to develop a strategy that sets out to do this, a proper understanding of the functioning of a research and innovation ecosystem is needed. Academic and policy discussions have concentrated so far mainly on understanding how innovation ecosystems are organised and how they could be structured. There is however little research done on assessing quantitative indicators of these ecosystems because the data on ecosystems is spread within the current structures of statistics of economic activity.

This study contributes to this important strand of research by linking the functioning of research and innovation ecosystem with the framework of market, system and transformation failures using quantitative information. Before potential failures or bottlenecks can be identified, the functioning of an ecosystem must be assessed. Understanding what is happening and what mechanisms are triggering certain responses from actors are pivotal to understanding any potential underlying issues that might occur within an ecosystem and lead to a certain type of failure. Only then, a proper response could be formulated to tackle the underlying issue.

The main aim of this research is to explore how the different aspects of the functioning of research and innovation ecosystems could be captured by various indicators and quantitative measures and, if so, how this information can provide insight on different types of failures. Specifically, the following research questions are being studied here:

1. How does an 'ideal' ecosystem function?
2. What types of market, system and transformation failures can occur within such an ecosystem?
3. What quantitative information and data might indicate the presence of a market, system or transformation failures?

This report starts by defining the scope of the research. Chapter 2 defines the a research and innovation (R&I) ecosystem and discusses the first research question.

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[5] (Ministry of Economic Affairs and Climate Policy, 2020).

Chapter 3 reviews the functioning of such an ecosystem and when it functions properly. Specifically, it relates the various types of failure to different elements of a research and innovation ecosystem, thereby answering the second research question. Chapter 4 then continues by summarising the quantitative measures or indicators that could be potentially used to hint or signal towards a specific type of failures outlined in Chapter 3. Thereby it provides an answer to the third research question.

Understanding bottlenecks or issues within a research and innovation ecosystem starts with understanding the ecosystem itself and its functioning. It is challenging as (quantitative) information on ecosystems is not readily available. Moreover, there is no agreed methodology on how an ecosystem could be scoped in practice nor how the problems or issues within an ecosystem could be quantitatively assessed. Therefore a pilot was conducted to research one specific research and innovation ecosystem. The pilot explored how this certain ecosystem functions using quantitative information and microdata. This pilot was conducted separately from this study between May 2022 and June 2023. It focused on assessing the demographic and economic profiles and cooperation between the actors or players within the research and innovation ecosystem of photonics in the Netherlands. The lessons from this pilot are outlined in Chapter 5.

Chapter 6 ends this paper with a concluding summary.

2 What is a research and innovation ecosystem?

The term ‘research and innovation (R&I) ecosystem’ has gained tremendous popularity over the past years[6]. It is often used interchangeably with terms such as ‘local buzz’, ‘cluster’, ‘innovation systems’, entrepreneurial ecosystems, ‘technological and mission-driven innovation systems’. For the purposes of this research, we define a research and innovation ecosystem combining the definitions of (Dialogic, 2020) and (TNO, 2020):

*A **research and innovation ecosystem** is a dynamic set of related actors, activities, facilities and rules that are important for the research and innovation capability of individual actors and groups of actors, where actors actively and deliberately work together to innovate and hence create value.*[7]

A R&I ecosystem is not just a ‘network’ or a ‘cluster’. It is a ‘nonlinear complex adaptive system’,[8] which is formed between actors or entities with a common goal to enable (technological) development and innovations. Instead of individual goals, actors within a successful research and innovation ecosystem have a common goal. It could be imposed on the players by a dominant player (e.g. ASML pushing the limits of its suppliers), it could take form of a common vision (e.g. to become world leading in a technology) or it could be imposed by a necessity to address societal challenges (e.g. a green chemical industry).

By having a common goal and moving towards it, actors and elements are aligned with one another. The focus of these actors in an innovation ecosystem is not just on competition, but on collaboration in reaching this common goal. All players within an innovation ecosystem form the lay of the land and simultaneously influence the landscape. Over time, an innovation ecosystem morphs, adapts and evolves. All this, and much more, makes it that an innovation ecosystem is much greater than the sum of its parts.

There is currently no definition of an ‘ideal’ research and innovation ecosystem or how an ideal R&I ecosystem functions. At the same time, R&I ecosystems exist and prosper. (TNO, 2020) suggested that a minimum configuration[9] of various elements in an ecosystem determines whether a R&I ecosystem could be vital and resilient. Such minimum configuration forms a minimum viable research and innovation ecosystem:

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[6] See for example in (Gu, Zhang, & Hou, 2021).
[7] This definition is primarily based on the one used in (Dialogic, 2020), with an addition from (TNO, 2020) that actors actively and deliberately work with each other to innovate. Such a crucial part of working actively and deliberately on innovating was added based on the practical experience of TNO as an active part of different (regional) ecosystems and an ‘ orchestrator of innovation’ by providing support to different parties in setting up partnerships and cooperation to innovate.
[8] (Phillips & Ritala, 2019).
[9] TNO’s experience gained in orchestrating multi-stakeholder innovation processes and the notion of a ‘minimum viable product’ as described in (TNO, 2020).

A **minimum viable research and innovation ecosystem** is defined as *the minimum configuration of related actors, activities, facilities and rules in the research and innovation ecosystem that creates long term (societal) value for all actors in the ecosystem* (TNO, 2020).

An ecosystem consists of various actors that use and have access to knowledge, labour and capital and various facilities, that perform various activities resulting in creation of new knowledge, skills or innovation. The presence and functioning of these aspects, an intentional interaction between actors, determine whether there is a minimum viable ecosystem (TNO, 2020). The way collaboration is shaped through activities and governance is therefore as important as the presence of, for instance, actors and facilities. Such a minimum viable ecosystem forms a basis for a vital and sustainable research and innovation ecosystem.

We have conceptualized the dynamics of a **minimum viable research and innovation ecosystem** in Figure 1. This conceptual framework of a research and innovation ecosystems is based on previous work from Erik Stam (Stam & Cloosterman, 2020) (2018), Teece (1986), (2018), Dialogic (2020) and TNO (2019), (2020).

In analysing research and innovation ecosystems we distinguish between two sub-parts: the 'Characterization of the ecosystem' and the 'Modus operandi of the ecosystem'. Under the 'Characterization of the ecosystem' we include the ecosystem's factors and (innovation) assets and to a more impalpable degree the ecosystem's governance and goal. 'Factors and (innovation) assets' refer to networks and actors and the access they have to technological assets (knowledge or infrastructure) and complementary assets (resources needed to bring innovations successfully to the market, such as facilities, labour, etc.) (Teece, 1986, 2006, 2018). The factors and (innovation) assets thus include what is present in the ecosystem at a certain moment in time, of which some are shaped, directed and/or focussed by the ecosystem's governance and goal. The 'governance and goal' include intentional collaboration on innovation, based on a common goal and understanding; joint innovation agenda; strategic leadership and coordination to realise the joint agenda, mission and vision.

Under the 'Modus operandi of the ecosystem' we include how the ecosystem is organized, including the ecosystem's key activities and to a more impalpable degree the ecosystem's governance and goal. With 'key activities' we refer to things and occurrences that are 'happening' within an ecosystem, of which some are shaped, directed and/or focussed by the ecosystem's governance and goal.

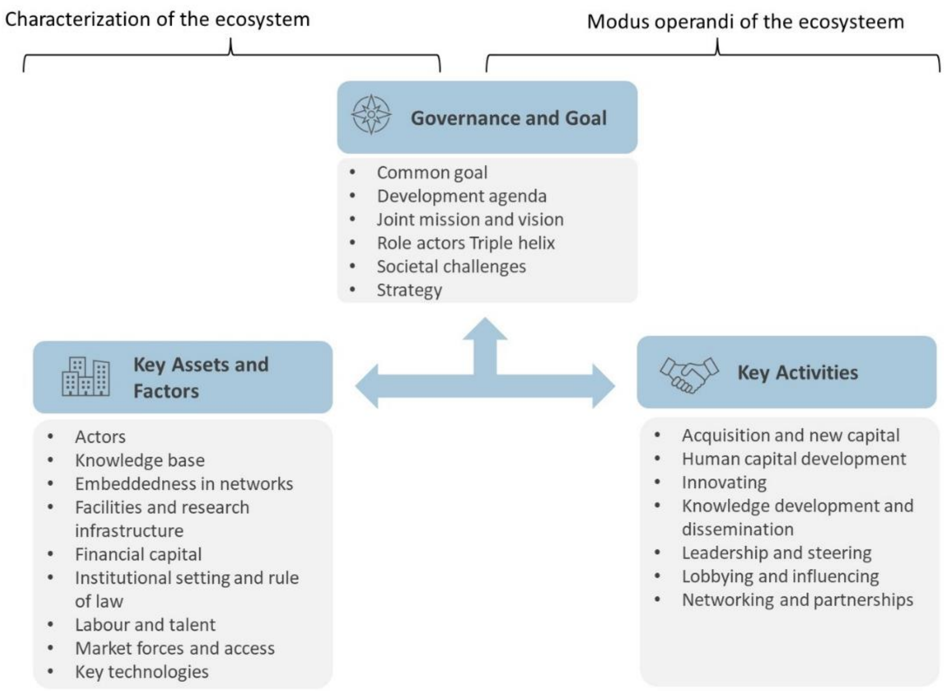

Figure 1 – Conceptual framework of a minimum viable research and innovation ecosystem, Source: (TNO, 2020).

By nature ecosystems are dynamic ‘entities’ of which the size and shape is continuously changing. Although we define the ‘Factors and (innovation) assets’ as something that can be fixed at a certain time, they do change over time. They form the input for the key activities and through the key activities they are shaped and expanded (e.g. external players are involved through new networks, projects have been financed, human capital has been developed). Hence, many of these key activities impact the factors and (innovation) assets, which subsequently influence the key activities.

Through these dynamics, this mixture of the ‘factors and (innovation) assets’, the ‘key activities’, and the ‘governance and goal’ form a nonlinear complex system that changes and adapts over time. However, an ecosystem does not always operate optimally due to specific failures. Such failures will be discussed in the following section, but first we will discuss the sub-aspects that are part of a **minimum viable research and innovation ecosystem**. Insight in the functioning of these sub-aspects, based on data or qualitative research, provides points of references for identifying failure.

We include the following ‘Factors and (innovation) assets’ sub-aspects:
- Actors: this includes all ‘players’ or actors within an ecosystem (firms, public sector) and hence also captures the ecosystem’s GDP contribution.
- Knowledge base: refers to the knowledge base that is available within the ecosystem.
- Embeddedness in networks: this refers to the degree to which networks are ingrained within the ecosystem.

- Facilities and research infrastructure (supporting infrastructure): refers to all kinds of infrastructures (physical/financial/digital/research) and how they are supported.
- Financial capital: refers to the amount of financial capital that is available for use and already in use within the ecosystem.
- Institutional setting and rule of law: refers to the established institutional setting (culture; norms and values) and to rule of law (e.g. intellectual property rights protection).
- Labour and talent: refers to the labour supply within an ecosystem and their talent.
- Market forces and access: refers to the power-settings within an ecosystem (e.g. oligopoly, monopoly) and to which degree newcomers can access the ecosystem.
- Key technologies: refers to the technologies that most profoundly impact the ecosystem (e.g. quantum; cybersecurity).

We include the following ‘Key activities’ sub-aspects:
- Acquiring new capital: the act of acquiring new capital from existing or new financial networks/flows.
- Developing human capital: the act of developing human capital, for example through workshops or trainings.
- Innovating: the act of innovating incremental or radical products and/or services, including new business creation and entrepreneurship.
- Developing and disseminating knowledge: the act of developing and disseminating knowledge. E.g. through academic research, applied research or experimental research.
- Providing leadership and steering: the act of providing leadership and steering. We often see that a specific corporations or group of actors have made the vitality of the ecosystem part of their strategy plan. They make sure goals are set and all actors are aware of this and steered into a certain direction. So in essence, much of the ‘governance and goal’ aspects are materialized through the act of providing leadership and steering.
- Lobbying and influencing: the act of lobbying and influencing with the attempt to shape decisions made by legislators and official.
- Networking and building partnerships: the act of strengthening existing or creating new networks and partnerships with either internal or external actors.

The ecosystem’s ‘governance and goal’ is what makes an ecosystem an ecosystem. Without it, it would be an unaligned group of actors. It could be either formally institutionalised but it could also be informally present. The ‘goal’ aspect is what makes the actors within an ecosystem be in symbiosis. Therefore the ecosystem’s ‘governance and goal’ aspect has an overlap with both sub-parts.

Such a goal could be institutionalised for instance in an innovation program or through arrangements by the government but it could also be informal. We see that it characterizes the ecosystem through its common goal, mission, vision and agenda. This is also what makes the established actors within an ecosystem face the same direction. This, in turn, determines what the actors ‘do’ (their ‘key activities’), which, because of ecosystem’s goal, are focussed. Their actions have become purposeful by being in alignment with the ecosystem’s greater good, which is to develop, diffuse and apply technologies and innovations for economic and societal goals. The governance and goal aspects, of course, are not static, and can change and adapt over time. This would be an activity on itself. As it changes so does the orientation of the actors, and hence their activities.

We include the following ‘ Governance and goal’ sub-aspects:

- Common goal, mission and vision: refers to the common goal, mission and vision that is shared by all actors within the ecosystem.
- Strategies and agendas: refers to the strategies and agendas that are laid out for the relevant participants within the ecosystem.
- Organizational structure: refers to the formalization of actors in a governance structure and the role of the Triple Helix.
- Societal relevance and challenges: some ecosystems are driven by a societal reverence and challenges, other’s might not be driven by it but are heavily linked to them. Such societal reverence and challenges could exist because of economic reverences such as job-provision, but also because of their link to national goals and agenda’s, such as the current energy-transition. Currently, we see that ecosystems are often driven by societal reverences and challenges. This could either be that existing ecosystems adapt their common goal in services of such societal references and challenges, or completely new ecosystems come to life in purpose of it.

3 When does a R&I ecosystem not function properly?

An ecosystem consists of various actors that use knowledge, labour and capital and various facilities, that perform various activities resulting in creation of new knowledge, skills or innovations as explained in Chapter 2. All the various aspects of an ecosystem could be captured with factors and innovation assets, governance and goal. Within such an ecosystem, various key activities are performed. The presence and functioning of these aspects determine whether there is **a minimum viable ecosystem** (TNO, 2020). Such a minimum viable ecosystem forms a basis for a successful research and innovation ecosystem, where successful means that it is vital and sustainable.

However, a research and innovation ecosystem might not be successful and may show signs of not properly functioning. There might be various underlying reasons for that, that could be described through market, system or transformation failures. The existence of a significant failure can be seen as a key condition for determining whether a government intervention, for example in a form of state aid, has the potential to enhance welfare[10]. The current policies mostly rely on the market failures as a justification for a government intervention.

The goal of this chapter is to link the various types of failures to the elements of a minimum viable ecosystem, established in Chapter 2. Understanding the mechanisms behind this problems results in understanding how these mechanisms could be assessed quantitatively (these are proposed in Chapter 4).

Typically, the following failures are distinguished within the literature: market-, system- and transformation failures (Figure 2**Error! Reference source not found.**). These types of failures are usually presented separately mainly due to their different scientific origins (Weber & Rohracher, 2012). Given their different scientific origins, they look at failures from different perspectives while not being mutually exclusive to each other. Moreover, different types of failures could be intertwined and caused by the same underlying problem or issue.

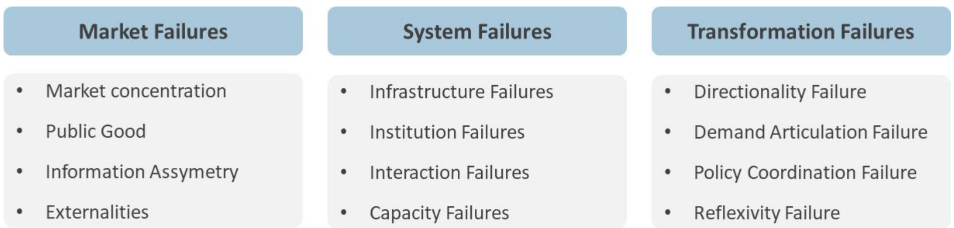

Figure 2 –Different types of failures used to legitimise innovation policy interventions

Market failure is a situation in which the allocation of goods and services by a free market is not efficient. The neo-classical market failure framework was introduced by Arrow (1962)[11]. Currently, the market failures theory is used to determine the basis for government intervention. While market failures reflect 'the situations in

[10] The economic analysis of state aid: some open questions (europa.eu)
[11] Expertwerkgroep Effectmeting / Cimmussue Theeuwes (2012). Durft te meten

which markets left to their own devices, are unlikely to produce efficient outcomes'[12], they do not take into account the nature and the functioning of the institutions and networks surrounding the firm-based innovation processes within an ecosystem.

In the past decades the innovation literature has focused on further developments of guidelines and rationales for policy makers: the system failures[13]. **System failures** are the imperfections in the character of the entire research and innovation ecosystem such as the functioning of institutions and networks.

Even more recent developments in innovation policy and it's orientation towards societal challenges, have led to the development of another type of failure framework: **transformation or transition failure**[14]. This type of failure occurs if the innovation ecosystem experiences strategic challenges related to innovation, production and consumption.

While market failures are largely studied and widely used, there is much less empirical evidence on how system and transition failures could be measured and applied. In the next section we link each type of failure with the different elements of a minimum viable ecosystem [15], while Chapter 4 proposes different measures or empirical indicators of these failures.

3.1 Market failures within a minimum viable ecosystem[16]

The market failures refers to the situations where markets, left to their own devices, are unlikely to produce efficient outcomes.[17] Most commonly these types of market failures are distinguished within a research and innovation ecosystem: market concentration, public goods and externalities and information asymmetry. These types of market failures are briefly described below linking them to the specific element of a research and innovation ecosystem (in blue).
One of the forms of a market failure is the presence of substantial market power or **market concentration**. An efficient market consists of a large number of **actors**:

[12] Communication from the Commission Framework for State aid for research and development and innovation 2022/C 414/01, C/2022/7388, OJ C 414, 28.10.2022, EUR-Lex - 52022XC1028(03) - EN - EUR-Lex (europa.eu)
[13] See for example Smits, R., Kuhlmann, S., Teubal, M., 2010. A system-evolutionary approach for innovation policy. In: Smits, R., Kuhlmann, S., Shapira, P. (Eds.), The Theory and Practice of Innovation Policy: An International Research Handbook. Edward Elgar, Cheltenham, pp. 417–448; OECD 1998. New Rationale and Approaches in Technology and Innovation Policy. STI Review, 22, OECD, Paris.
[14] Weber & Rohracher (2012). Legitimizing research, technology and innovation policies for transformative change. Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. Research Policy.
[15] More elaborated explanation and examples could be found for example in (Bryan & Williams, 2021), (Klein-Woolthuis, Lankhuizen, & Gilsing, 2015), (Weber & Rohracher, 2012).
[16] This sub-chapter summarises the neoclassical economics argumentation introduced by Arrow (1962): Arrow, Kenneth. (1962). Economic Welfare and the Allocation of Resources for Invention. 1962. 5. 10.1007/978-1-349-15486-9_13.
[17] Communication from the Commission Framework for State aid for research and development and innovation 2022/C 414/01, C/2022/7388, OJ C 414, 28.10.2022, EUR-Lex - 52022XC1028(03) - EN - EUR-Lex (europa.eu)

buyers and sellers[18]. If there is market concentration, a certain player or number of players have the power to influence market prices, output, the variety or quality of products and services or other parameters of competition for a significant period of time (**market forces and access**), to the detriment of consumers[19]. This usually leads to a lower level of investments in R&D. In addition, it might also result in the reduction of innovating activity.

Research and innovation have **public goods** properties as the use of it by one party does not reduce the stock of understanding that might be used by another[20]. Public goods have specific characteristics: they are non-excludable and non-rivalrous in consumption. Non-rivalrous goods are those that cannot be consumed at the expense of somebody else. While non-excludability refers to the fact that consumers cannot be prevented from consuming such a good. Usually, consumers are able to benefit from public goods without paying for it (free-riding). Therefore, private parties are discouraged from investing in research and innovating. Therefore the failure occurs at the level of **financial capital**. In addition, **innovating** in itself is negatively affected. This becomes a market failure particularly in situations when the benefits of such goods exceed their costs. Therefore, usually government controls production of such goods. For example, results of fundamental research are usually considered as a public good, and therefore are usually fully funded by government. This could lead to over-exploitation of commons however, meaning that public resources are over-used in the absence of institutional rules that limit their exploitation[21]. Other typical examples of public goods are technical innovations, sustainable transport infrastructure, defence and national security. In other words, these are goods that relate to society as a whole or the societal challenges (**societal relevance and challenges**).

R&D&I often generate benefits for society in the form of positive **externalities** or spill-over effects[22], for example available **knowledge base** leads to the creation of complementary products and services by other economic actors. At the same time, the original innovator might decide not to invest as much in R&D as they would not necessarily profit from increased productivity of other actors. Anticipating this, the actors might be rethinking their key activities within an ecosystem: **developing and disseminating knowledge** and **innovating**. This creates a negative externality as the level of new knowledge does not reach socially optimum level. Such an

[18] It is possible that market concentration is not a failure in certain markets. This specific argumentation stems from Arrow (1962).

[19] Communication from the Commission Framework for State aid for research and development and innovation 2022/C 414/01, C/2022/7388, OJ C 414, 28.10.2022, EUR-Lex - 52022XC1028(03) - EN - EUR-Lex (europa.eu).

[20] Winston, C. (2006). Government Failure versus Market Failure: Microeconomics Policy Research and Government Performance. Washington D.C.: AEI-Brookings Joint Center for Regulatory Studies; Communication from the Commission Framework for State aid for research and development and innovation 2022/C 414/01, C/2022/7388, OJ C 414, 28.10.2022, EUR-Lex - 52022XC1028(03) - EN - EUR-Lex (europa.eu).

[21] Weber & Rohracher (2012). Legitimizing research, technology and innovation policies for transformative change. Combining insights from innovation systems and multi-level perspective in a comprehensive ‘failures’ framework. Research Policy.

[22] Communication from the Commission Framework for State aid for research and development and innovation 2022/C 414/01, C/2022/7388, OJ C 414, 28.10.2022, EUR-Lex - 52022XC1028(03) - EN - EUR-Lex (europa.eu).

externality could also occur for the outcomes of research and innovation that are relevant to societal challenges (**societal relevance and challenges**).

The availability of information, and the resulting **information asymmetry**[23], could have an impact on research and innovation ecosystem at the level of **actors**, availability of and **acquisition of (new) financial capital** and **innovation** as a key activity. At the level of **actors**, limited or incomplete information on potential partners' capabilities could lead to a smaller number of opportunities for an actor with an innovative idea to attract sufficient funds from the market. For example, it could be that researchers within universities do not know which company might have a commercial interest in the researcher's idea, resulting in disruptions in building partnerships. The other way around it means that companies do not have access to information that can lead to commercialization of new innovations. The search costs of finding each other might be so high, that cooperation in for instance research projects might never occur. This might lead to lower level of innovations and knowledge base within an ecosystem than socially desirable.

The outcomes of innovation and research are uncertain, particularly in the earlier stages. Furthermore, innovations and research are both products that can be generated over an uncertain period of time. They could also require large commitments or investments from a number of parties or it becomes clear they are needed at a later stage. The risks associated with these uncertainties cannot be fully predicted or calculated[24]. Thus it could lead to too little innovation generated within an ecosystem. Therefore, the presence of market failures related to **availability of information** reduces incentives for private investment in innovation, precluding investments or **acquisition of new capital** from reaching socially optimal levels.

Table 3 summarizes the different types of market failures linking them to the specific elements of an ecosystem outlined in Chapter 2.

Table 3 - Overview of market failures that potentially might occur in a minimum viable system

Type of market failure	Failure mechanism	Ecosystem aspect where failure mechanism can originate
Market concentration	Substantial market power leads to entry barriers and socially lower level of investment into research and innovation	• Actors • Market forces and access
Public good	Public good character of the outcomes of innovation leads to underinvestment in R&D&I (others are able to gain from the public good without paying for it, i.e. free rider behaviour)	• Financial capital • Innovating • Societal relevance and challenges

[23] It is also known as imperfect information.
[24] (Bryan & Williams, 2021).

Externalities	- Actions of one party has an anticipated effect on another party, e.g.: - The adoption or production of innovation creates new knowledge that spills over to other users and producers, thus generating extra knowledge and innovation[25] - The possibility to externalize costs leads to innovations that can damage the environment or other social agents	• Knowledge base • Innovating • Developing and disseminating knowledge • Societal relevance and challenges
Information asymmetry	- Imperfect or asymmetric information about prices, quality, costs or risks[26], e.g.: - Uncertainty about outcomes of innovation and insufficient ability to hedge the risks lead to underinvestment in R&D&I - Lack of or insufficiently available information about potential partners' capabilities, their reliability or integrity	• Actors • Financial capital • Acquiring new capital • Developing and disseminating knowledge • Innovating

Note: adapted from Arrow (1962), authors elaboration

3.2 System failures within minimum viable ecosystems

Besides market failures, the innovation literature refers to problems or imperfections that hinder the development or functioning of an innovation ecosystem as **system or systemic failures**. The system failures framework originate in a different scientific field compared to the market failures framework.

System failures are imperfections in the character of the entire research and innovation ecosystem. The nature and the functioning of the institutions and networks might hinder optimal innovation process within an ecosystem caused by a lack of sufficient elements in the innovation system or non-optimal interaction between these elements[27]. Under this category of failures, the following types are usually distinguished: infrastructure, institutional, interaction and capabilities failures[28]. These types of failures are briefly described below linking them to the specific element of a research and innovation ecosystem (in blue) as specified in Chapter 2.

[25] It is otherwise known as knowledge spill-overs.
[26] The typical examples of this failures manifests in information deficiencies, information bias, coordination failure and incomplete contracts.
[27] (Klein-Woolthuis, Lankhuizen, & Gilsing, 2015)
[28] (Klein-Woolthuis, Lankhuizen, & Gilsing, 2015)

Infrastructure failures are the shortcomings of existing or developing (essential) **supporting infrastructures** needed to enable innovation activities. Examples of such infrastructure could be physical infrastructure like high-speed IT, telecom, roads and energy supply. Other typical example is science and technology infrastructures. This type of infrastructure refers to availability of applied knowledge and skills, testing facilities, possibilities for knowledge transfer. Another example is financial infrastructure of available subsidies, financial programs and grants. Usually such infrastructures are large scale, therefore there could be little or no incentive for private companies to invest in such infrastructures[29].

Institutional failures are the shortcomings in the **institutional setting and rule of law** (both formal mechanisms and informal ones such as norms and values) that hinder the innovation processes. Institutions themselves define and structure research and innovation ecosystems (or any other ecosystem), therefore it is important that when regulating the economic behavior or interactions, the innovation process is not hampered. The literature distinguishes between hard or formal, and soft or informal failures. The **hard institutional failures** are for example, the absence or lack of specific type of regulation or standards, IPR and other legislative actions within which various actors of ecosystems operate. The informal or **soft institutional failures** refer to political context, social norms and values, entrepreneurial spirit or trust, which implicitly can have an impact on the innovation ecosystem. This particularly could be reflected in the **organizational structure** of an ecosystem.

Interaction failures that could be either internal or external, exist if there is lack of or limited coordination between **actors** within an innovation ecosystem, in other words within **embedded networks**, and thus can hamper the innovation process**.** At the same time, too much coordination and dependence on dominant actors could hamper the innovation process as well. Each party within an ecosystem interacts with other parties, therefore the type of a network to which such party belongs determines the type of information and knowledge it can access. Usually, strong connections to other parties means synergies, complementary know-how, perhaps even capacity sharing. Such strong relations could however also lead to unwillingness to include or exclude (new) actors in the existing networks (**networking and building partnerships**), thus hampering the creation of new knowledge. There might also be a strong reliance on a certain party within an ecosystem, thus hindering the ability to change partnerships or ways of doing. Actors may be 'locked into' their relationships due to asset specificity, switching costs or due to a lack of alternative partners in e.g. high-tech or highly monopolised markets (Klein-Woolthuis, Lankhuizen, & Gilsing, 2015). On the other hand, the interactions between various actors within an ecosystem could be weak because of differing objectives or lack of trust. Therefore the innovative cycles may be prevented or underutilised. This in itself might lead to a lack of coordination of research and shortcomings in **lobbying and influencing**, and thus underinvestment in certain areas.

[29] This is an example of a failure that could be potentially caused by other types of failures, for example by information assymetry.

Capabilities failures refer to inability or lack of necessary capabilities to adapt to new and changing circumstances and opportunities. It could also stem from the lack of technological and innovative capacities within the actors. Similarly to the interaction failure, such a failure could also lead to a lock in effect and underinvestment. For example, if a shift is needed to change to a completely new technological paradigm, the actors require adaptation to new technologies, with the technological and organizational capabilities outside of what they currently have. Therefore such failure can originate within the following aspects or elements of an ecosystem: **knowledge base**, **key technologies** and **labour and talent**. Another possibility could be that there is a lack of or absence of certain **actors** with such capabilities. In case of such failure, there is a disruption in how development of human capital and development and dissemination of knowledge are performed within an ecosystem.

Similarly to the market failures, system failures also dominantly take place within the 'factors and (innovation) assets' aspects and the 'key activities' and less so in the 'governance and goal' aspects of the minimum viable research and innovation ecosystem. However, in contrast to market failures, the particular types of system failures are more scattered among the different types of sub-aspects.

Table 4 summarizes the different types of system failures linking it to the aspect of an ecosystem where such failure might originate in as presented in Chapter 2.

Table 4 – Overview of system failures that potentially might occur in a minimum viable system

Type of system failure	Failure mechanism	Ecosystem aspect where failure mechanism can originate
Infrastructural failure	Lack of, shortcomings in the (essential) knowledge (scientific) and physical infrastructures	• Supporting infrastructure
Institutional failure	Shortcomings or lack of access to formal and/or informal institutions that create unfavorable or even harmful environment for innovation	• Institutional setting and rule of law • Organizational structure
Interaction or network failure	Lock in effects due to closed or limited or lack of interaction and cooperation within existing networks and partnerships and inability to attract new actors resulting into lack of new knowledge flows	• Embeddedness in networks • Lobbying and influencing • Networking and building partnerships
Capabilities failure	- Lack of relevant actors with certain competencies and capabilities - Lack of appropriate competencies and resources at the level of actors to learn and adapt to changing circumstances (e.g. when changing research trajectory) and open up to new knowledge and opportunities; to develop visions and strategies	• Actors • Key technologies • Knowledge base • Labour and talent • Developing human capital • Developing and disseminating knowledge

Note: adapted from (Klein-Woolthuis, Lankhuizen, & Gilsing, 2015), authors elaboration.

3.3 Transformation failures within a minimum viable ecosystems

Additionally, literature distinguishes the so called transformation failures. These type of failures occur because research and innovation ecosystems might be experiencing strategic (long-term) challenges related to innovation, production and consumption. Examples of such long-term challenges are climate change or resource depletion. According to (Weber & Rohracher, 2012), there are four types of failures that fall under this category: directionality failure, demand articulation failure, policy coordination failure, reflexivity failure. These types of failures are briefly described below linking them to the specific element of a research and innovation ecosystem (in blue) as specified in Chapter 2.
Directionality failure is a shortcoming in the direction or strategy to which the innovation outputs contribute by generating such outputs effectively and efficiently. The direction is defined for instance by the identification of the **relevance of the major societal problems and challenges** for which solutions need to be development with the help of research and innovation (Weber & Rohracher, 2012). Such direction is reflected in a **common goal, mission and vision** and various **strategies and agendas** for an ecosystem.

Another type of failure is a shortcoming or inability to anticipate and learn about user needs, the **demand articulation failure** (Weber & Rohracher, 2012). This type of failure leads to inefficiencies within the functioning of an innovation ecosystem because of resulting shortcomings in enabling the uptake of innovations by users and consumers (**market forces and access**). When the users' needs are not known, the research and innovation trajectories might result in the innovative outputs that are not socially desirable or even redundant. In the context of grand societal challenges, markets for new technologies may not yet exist. Thus there is no information on what the market needs are or user preferences are. Therefore the **societal relevance and** grand societal **challenges** play a role in demand articulation. This type of failure is related to information asymmetries, but takes a broader perspective and considers the influence of the future adoption of innovations.

While coordination failure (part of system failures) refers to the coordination problems of R&D actors, the **policy coordination failure** identifies coordination problems at policy level. An example of such a failure could be the incoherence within the **institutional setting** between the activities of international, national, regional, sectoral, technological institutions, and/or subordinate agencies, between public and private parties. It is also captured in the governance set up of an ecosystem, specifically in the **common goal, mission or vision**, and various **strategies and agendas** adopted for an ecosystem. It could also be a horizontal issue between various sectors and cross-cutting policies such as tax policy and regional policy. Another example of a policy coordination failure is that there is lack of policies both from the government and private actors within the ecosystem to develop innovations to address specific **societal challenges**.

Since strategic long term policy goals are by its nature long term, there could be a **reflexivity failure**. It is the failure or insufficient ability of the ecosystem to monitor, anticipate, adjust and to involve actors in the processes of self-governance. In other words, this is a shortcoming in how the **leadership and steering is provided** within an ecosystem and how the **structure of an ecosystem is organized**, which should be reflected in the **common goal, strategies and agendas** adopted for the ecosystem. In addition, Lindner, Ralf et al. (2016)[30] distinguishes four capacities for reflexive innovation system: self-reflection capacities, bridging and integration capacities, anticipation capacities and experimentation capacities[31]. Shortcoming in any of this capacities of the ecosystem's (individual and organizational) actors, results in a reflexivity failure. Such a shortcoming also means that the ecosystem at the policy level is unable to cope with uncertainty and unable to stop innovation trajectories and associated policy initiatives if they turn out to be less promising than initially expected. Thus if there is a reflexivity failure within a research and innovation ecosystem, it might not be able to change the direction of the research. This also means that directionality failure is connected to the reflexivity failure.

Table 5 summarizes the different types of transformation failures linking it to the aspect of an ecosystem where such failure might originate in as presented in Chapter 2.

Table 5 - Overview of transformation failures that potentially might occur in a minimum viable system

Type of transformation failure	Failure mechanism	Ecosystem aspect where failure mechanism can originate
Directionality failure	Lack of or insufficient presence of shared goals and visions of the process of innovation	• Providing leadership and Steering • Common goal, missing and vision • Strategies and agendas
Demand articulation failure	Lack of or insufficient ability to anticipate and learn about the needs of the users of innovations and research therefore hindering the uptake of innovations	• Market forces and access • Societal relevance and challenges
Policy coordination failure	Lack of or insufficient policy coordination at different levels, policy incoherence	• Institutional setting and rule of law • Common goal, missing and vision • Societal relevance and challenges • Strategies and agendas
Reflexivity failure	Lack of or insufficient ability to monitor, anticipate changes, adjust or adapt the policies accordingly and deal with uncertainties at the governance level	• Providing leadership and Steering • Common goal, mission and vision • Strategies and agendas • Organizational structure

Note: adapted from (Weber & Rohracher, 2012), authors elaboration.

[30] (Lindner, et al., 2016).3

[31] These are broader than reflexivity within (Weber & Rohracher, 2012) as specified in the paper itself

3.4 Various failures within a minimum viable ecosystem

The connection between **a minimum viable ecosystem** and different types of failures is presented in Table 6. The distinction between different types of failures reflect the scientific origins. Therefore they look at failures from different perspectives while not being mutually exclusive to each other. In addition, one underlying cause might lead to the various types of failures. The market failures focus on market imperfections and underlying mechanisms, therefore they are present mainly in the relations between the actors, how market forces and access are functioning, (access to) financial capital and the main activity of an ecosystem: innovating. The system and transformation failures look at an innovation ecosystem from a broader perspective. The system failures put emphasis on the systemic contexts which limits, directs or supports their innovation activities and capabilities. Thus, they are spread across factors and innovation assets, and key activities of a minimum viable ecosystem. The transformation failures framework adds a layer that in conducive to processes of transformative change, which are strategic in nature. Unlike market and system failures, the transformation failures dominantly take place in the ‘governance and goal’ aspects of the minimum viable research and innovation ecosystem.

Table 6 - Elements of R&I ecosystems and potential failures

Aspect of an ecosystem where failure mechanism might originate	Market failures				System failures				Transformation/ transition failures			
	Market concentration	Public good	Externalities	Information asymmetry	Capability failures	Interaction failures	Institution failures	Infrastucture failures	Reflexivity failure	Policy coordination failure	Demand articulation failure	Directionality failure
Key assets and factors												
Actors	x			x	x							
Market forces and access	x										x	
Institutional settings and rule of law							x			x		
Labour and talent					x							
Embeddedness in networks						x						
Key technologies					x							
Supporting infrastructure								x				
Knowledge base			x		x							
Financial capital		x		x								
Governance and goal												
Common goal, mission and vision									x	x		x
Strategies and agendas									x	x		x
Organisational structure							x		x			
Key activities												
Societal relevance and challenges		x	x							x	x	
Providing leadership and steering									x			x
Acquiring new capital				x								
Innovating		x	x	x								
Developing and disseminating knowledge			x		x							
Networking and building partnerships						x						
Developing human capital					x							
Lobbying and influencing						x						

Note: adapted from adapted from (TNO, 2020), Arrow (1962), (Klein-Woolthuis, Lankhuizen, & Gilsing, 2015), (Weber & Rohracher, 2012), authors elaboration.

Where one or multiple types of market, system and transformation failures have been determined, the government may decide to intervene to correct such failure, and thereby stimulate further research and innovation. Discovering such a failure can be seen as a necessary but not sufficient step to justify government intervention in markets on economic efficiency grounds. The government intervention is only justified if it is technically feasible to address and overcome the failure and the benefits of such intervention outweigh the costs.

4 Measures of failures within a R&I ecosystem

Based on the notions of the different types of failures, a list of potential indicators that might signal or refer to a certain bottleneck in the functioning of an ecosystem is created. The suggested indicators are an indirect measurement of a failure and shall be regarded as a suggestion to describe a certain aspect that refers to a certain failure mechanism. The value of an indicator on its own does not immediately mean that a certain type of failure is present. It has to be compared with or benchmarked against a certain level.

A proper understanding of the functioning of a research and innovation ecosystem is pivotal for deciding whether a certain indicator might explain if there are any bottlenecks within such an ecosystem. This implies that before empirically assessing the indicator for an ecosystem, the ecosystem has to be scoped and its functioning has to be assessed. The scoping and the functioning of an ecosystem are not assessed here. Instead, the focus of this chapter is on which indicators might potentially signal a certain type of failure within an ecosystem.

The list of potential indicators is a first attempt to create such a list, therefore it shall not be regarded as exhaustive. It is constructed by using indicators from the TNO LSA-database and Dialogic (2020). The LSA-database (developed in 2020) contains quantitative data on (collaboration between) actors, societal themes, funding and initiatives produced through a structured, manual analysis of policy documents, program proposals on missions and key enabling technologies (MMIP/MJP/NWA-routes) and a web scrawl on national initiatives. The LSA-database also include TNO's list of regularly used innovation indicators (often edited by TNO), including business statistics (CBS) and scientific indicators on knowledge fields (CWTS) and Key Enabling Technologies (Elsevier/Eurostat). This list also draws on Dialogic (2020), that created a set of indicators to analyse the functioning of the research and innovation ecosystems.

The list of potential indicators could be tested to understand whether they are realistic to construct, whether a certain indicator might signal a certain type of failure, whether an indicator supports an initial hypothesis and initial qualitative analysis of the research and innovation ecosystem. This is however outside of the scope of this report.

The goal of the list is to create an overview of quantitative indicators. Therefore the focus is primarily on the (available) quantitative information. More indicators could be potentially produced by doing a text mining analysis on for instance policy documents or using other new data sources (e.g. job vacancies data, social media data, web data, open data, etc).

Table 7 - Table 9 present an overview of the suggested indicators. It is non exhaustive and further research could result in updates and changes in the list of indicators.

Table 7 - Potential indicators that could signal the presence of market failures

Indicator	Proxy[32]	Suggested data source
Market concentration. *Failure mechanism: Substantial market power leads to entry barriers and socially lower level of investment into research and innovation since there are only innovations that protect the market power*		
Distribution of market shares/profit shares	€Profit (as % total) €Revenue (as % total) #Employees (as % total) Number of companies	CBS microdata - Revenue & Profit per company
Distribution of share of innovation	€ spent on R&D (as % total)	CBS - WBSO expenditure per company & CIS spending per company
Age distribution of companies		CBS - Age of companies
Age distribution of innovative companies	(% of) patenting firms under 5 years old	OECD (2010), Measuring Innovation: A New Perspective
	(% of) patents filed by firms under 5 years old	OECD (2010), Measuring Innovation: A New Perspective
	age distribution of companies that spend on R&D	CBS - Age & WBSO
Public good. *Failure mechanism: Public good character of the outcomes of innovation leads to underinvestment in R&D&I*		
R&D intensity	€R&D as % of Revenue €R&D as % of Value Added (GVA)	CBS - WBSO & revenue
Gap between demand and desire for capital		CBS - financieringsmonitor
Limited available financial capital	Available subsidies, €	Governmental programmes, Volg innovatie
Externalities. *Failure mechanism: The adoption or production of innovation creates new knowledge that spills over to other users and producers, thus generating extra knowledge and innovation; Actors are not able to absorb new knowledge that was not anticipated to be created; The possibility to externalize costs leads to innovations that can damage the environment or other social agents*		
Spillover at companies	#Spinoffs from other companies	CBS - bedrijvenregister
R&D intensity	€R&D as % of Revenue €R&D as % of Value Added (GVA)	R&D intensity
Cooperation in science with other disciplines		LSA database
Information asymmetry. *Failure mechanism: Uncertainty about outcomes of innovation and insufficient ability to hedge the risks lead to underinvestment in R&D&I; Lack of or insufficiently available information about potential partners' capabilities, their reliability or integrity*		
Participation in PPS projects	% distribution triple helix type of actors involved in PPS projects	CBS, RVO, Volginnovatie, LSA database

[32] The proxies for market failures refer to the underlying data, on the basis of which the concentration ratio, Herfindahl-Hirschmann Index, chum rates and others are constructed.

	€ revenue # of PPS projects	
Usage of government funding	# Applications # participants (Primarily in WBSO, but also other RVO instruments)	Volginnovatie
Funding of start-ups / scaleups	€awarded grants to private equity / venture capital or #rejected	Webscraping websites of start-ups funds, kick-starters, techleap
Information sharing	#Emails from network organisations Number of network events & #participants	Desk research, Elsevier
Participation in incubators / accelerators	#Participants %Participants	Desk research / innovatiespotter
Participation in network organisations /belangenverenigingen	#Participants %Participants	Desk research
Businesses collaborating on innovation with higher education or research institutions	% of innovative SME - Businesses collaborating on innovation with higher education or research institutions	OECD, based on the 2017 OECD survey of national innovation statistics and the Eurostat, Community Innovation Survey (CIS-2014), http://oe.cd/inno-stats, June 2017. (Graph published in OECD Science, Technology and Industry Scoreboard 2017)
	% of innovative Large Businesses - Businesses collaborating on innovation with higher education or research institutions	OECD, based on the 2017 OECD survey of national innovation statistics and the Eurostat, Community Innovation Survey (CIS-2014), http://oe.cd/inno-stats, June 2017. (Graph published in OECD Science, Technology and Industry Scoreboard 2017)
Scientific collaboration	% University-industry collaboration (Bibliometric examination based on publications) #Scientific co-publications as % of total publications	Elsevier

Source: (Dialogic, 2020), authors elaboration.

Table 8 - Potential indicators that could signal the presence of system failures

Indicator	Specific data	Suggested data source
Infrastructure failure. *Failure mechanism: Lack of, shortcomings in the (essential) knowledge (scientific) and physical infrastructures*		
Available knowledge, physical infrastructure	Only qualitative indicators, probably proprietary information	Webscraping the websites
Institutional failure. *Failure mechanism: Shortcomings or lack of access to formal and/or informal institutions that create unfavorable or even harmful environment for innovation*		
Available institutes within the ecosystem	Only qualitative indicators, probably proprietary informaiton	Webscraping the websites
Interaction failure. *Failure mechanism: Lock in effects due to closed or limited or lack of interaction and cooperation within existing networks and partnerships and inability to attract new actors resulting into lack of new knowledge flows*		
See suggested indicators for information assymetry		
Capabilities failure. *Failure mechanism: Lack of relevant actors with certain competencies and capabilities**;** Lack of appropriate competencies and resources at the level of actors to learn and adapt to changing circumstances (e.g. when changing research trajectory) and open up to new knowledge and opportunities; to develop visions and strategies*		
Match between supply and demand of personnel	Speed with which job applications are filled / percentage of job applications that are filled / percentage of job applications that are filled	LinkedIn, company websites
International mobility	Net inflow / outflow of international researchers	Elsevier
Education of professionals	# trainings / relevant educational programs / mobility schemes #Of people finishing a degree for relevant 'opleidingsrichtingen'	Company websites Outflow of students per educational level per sector

Source: (Dialogic, 2020), authors elaboration.

Table 9 - Potential indicators that could signal the presence of transformation failures

Indicator	Specific data	Suggested data source
Directionality failure. *Failure mechanism: Lack of or insufficient presence of shared goals and visions of the process of innovation*		
Attention for topic in policy	#Of mentions of topic in policy	Webscraping the websites, text mining of policy documents
Innovation plans are available	#Links made with actors/ € Revenue in LSA database	LSA database
Demand Articulation failure. *Failure mechanism: Lack of or insufficient ability to anticipate and learn about the needs of the users of innovations and research therefore hindering the uptake of innovations*		
Collaboration between users and producers	#Events where users and individuals participate	Webscraping the websites, text mining of policy documents
Demand for product	€Revenue development through time	CBS – Revenue per company
Policy coordination failure. *Failure mechanism: Lack of or insufficient policy coordination at different levels, policy incoherence*		
Coherence of policy	Number of diverging priorities within the policy documents related to the ecosystem	Webscraping the websites, text mining of policy documents
Number of different initiatives	# number of policy documents / agendas	LSA-database
Number of different initiatives by region/level of scale	Indicators above split by regional/national/EU	LSA-database
Reflexivity failure. *Failure mechanism: Lack of or insufficient ability to monitor, anticipate changes, adjust or adapt the policies accordingly and deal with uncertainties at the governance level*		
The number of changes in the mission, strategy documents within an ecosystem		Webscraping the websites, text mining of policy documents

Source: (Dialogic, 2020), authors elaboration.

5 Pilot: the R&I ecosystem of photonics

Understanding bottlenecks or issues within a research and innovation ecosystem starts with understanding the ecosystem itself and its functioning. Quantitative information is not readily available for such ecosystems and has to be constructed. There is however no agreed methodology on how an ecosystem is to be scoped in practice nor how quantitatively the problems or issues within an ecosystem could be assessed. Therefore a pilot was conducted to research one specific research and innovation ecosystem. A brief summary of the pilot project is given below alongside the important lessons learned from the pilot.

The pilot explored how one specific ecosystem functions using quantitative information and microdata. This pilot's primary goal was to understand the extent in which quantitative information provides insights into the functioning of the research and innovation ecosystem. It focused on assessing the demographic, economic and network profiles of the actors or players within the research and innovation ecosystem of photonics in the Netherlands. The pilot was conducted separately from this study between May 2022 and June 2023 by TNO, Netherlands Enterprise Agency (RVO) and the Ministry of Economic Affairs of the Netherlands.

The research and innovation ecosystem of photonics was selected for this pilot based on the confirmed data availability, its policy relevance and presence of a variety of parties within the research and innovation ecosystem.

This study took the following approach. Since innovation and research ecosystems are not clearly visible in standard statistical classifications such as NACE in the EU or SBI in the Netherlands, a list of actors was created that belong to the R&I photonics ecosystem. This was done on the basis of photonics expert knowledge and the publicly available information on participation in subsidised innovative projects. Specifically these projects were funded through the Horizon 2020 programs[33], public-private partnership subsidies[34], and subsidies for SME's to stimulate innovation within regions and top sectors[35]. Secondly, the identified actors were linked to microdata from the Central Bureau of Statistics (CBS). Thirdly indicators were compiled for demographic and economic profiles. Additionally, using the population of actors that participated in subsidised innovative projects were used to perform the network analysis.

The constructed demographic profile of the R&I ecosystem of photonics suggests that expert knowledge and subsidised innovative projects are complementary sources for identifying organisations for this ecosystem. In addition, the actors were classified into different types (producers, sellers, adopters) based on the available data. Such classification of actors could help identify possible bottlenecks in the ecosystem. For example, if a limited group of adopters is observed in an

[33] Horizon 2020 (europa.eu), available at CORDIS - EU research projects under Horizon 2020 (2014-2020) - Data Europa EU.
[34] PPS-toeslag Onderzoek en Innovatie (rvo.nl), available at Volg innovatie (rvo.nl).
[35] Mkb-innovatiestimulering Regio en Topsectoren (MIT) (rvo.nl), available at Volg innovatie (rvo.nl).

ecosystem, it may mean that the technology is not yet that far advanced, and a specific action needs to be taken to speed up the adoption. While the different sources to identify the actors are complementary, the research did not reveal the origins of their differences.

The economic profile of the photonics ecosystem was estimated as well. The estimation however is largely dependent on understanding the share of photonics related activities. This presented to be one of the main bottlenecks in this pilot. Without correcting for this share, determining the economic share of the photonics ecosystem through turnover, value added and other economic indicators, leads to an overestimation. It was attempted to determine this share based on the number of photonics projects for which a subsidy was given divided by the total number of subsidy projects awarded to the organisation. For other organisations that did not receive a subsidy it was imputed based on the size class and sector. This method however is most likely unreliable. More research is needed to provide a realistic estimate of the share of photonics related activities within an organisation, relative to total turnover. Increasing availability of data, especially through new data sources (e.g. job vacancies data, social media data, web data, open data) could offer possibilities to explore this.

The network analysis was conducted to outline how collaboration took place within the research and innovation ecosystem of photonics. It was based on the subsidised innovative projects and the established collaboration between actors in these projects. While this information could also be potentially retrieved from the interviews with or surveys of experts, this analysis provided quantitative evidence for it complementing the picture drawn as part of preparation of the National Photonics Agenda 2018[36]. While this analysis provides insights into the thematic sub-clusters within the ecosystem, it does not give a full picture of the collaborations that take place within the ecosystem because it relies only on the data of collaborative subsidised projects.

The results of this pilot serve as a first step to gain insights into the functioning of a R&I ecosystem. They shed light on how a research and innovation ecosystem could be mapped out and could be used as an input for the discussions with the stakeholders within the ecosystem. In addition, other methods could be used to further expand the list of actors actively participating in the research and innovation ecosystem, for example such as individual organisations requesting subsidies, job postings or the database of Innovatiespotter.

The chosen approach also makes it possible to compare ecosystems in a consistent manner, which is more difficult with qualitative information. The results from this pilot alone are not sufficient to make definitive statements about the functioning of the R&I ecosystem. The main reason for it being that within this pilot it was not possible to get a good estimate of what part of the R&I ecosystem has been captured. Therefore further research is needed to investigate it before possible bottlenecks within an ecosystem could be mapped out.

[36] Nationale Agenda Fotonica (bijlage bij 33009,nr.64) - Parlementaire monitor.

Combining this insights with the expert knowledge could enrich understanding of the research and innovation ecosystems in general and support the development of policies and strategies. At the same time, increasing availability of data, especially new data sources (e.g. job vacancies data, social media data, web data, open data) offers possibilities to further enrich the understanding of the research and innovation ecosystems.

The conducted pilot offers insights into the quantitative assessment of the research and innovation ecosystems. The results however offer limited insights into potential bottlenecks within such ecosystem. Further research is needed before the proposed measures of the failures proposed in Chapter 4 could be tested.

6 Concluding remarks

This research contributes to understanding the research and innovation ecosystem. How it functions and how it could optimally function are questions that require further investigations. A R&I ecosystem allows for many economic benefits such as job creation, productivity increase and knowledge spillovers. While there is no definition of an 'ideal' research and innovation ecosystem, R&I ecosystems exist and prosper. To ensure that an ecosystem is vital and resilient, a minimum configuration of various elements in an ecosystem is needed. Such a minimum configuration forms a minimum viable research and innovation ecosystem.

This paper focused on bridging the term of a (minimum viable) research and innovation ecosystem and the frameworks of market-, system- and transformation failures. To that end, a list of quantitative indicators and potential sources was proposed that could signal whether a certain type of failure is present. These indicators most likely provide only a limited picture individually. In addition, they have to be treated with caution as a value of the indicator on its own might not mean that there is an issue within an ecosystem. Nevertheless, together these indicators could be helpful in further understanding the functioning of an ecosystem.

To understand whether there are specific types of bottlenecks or failures within such an ecosystem starts with understanding how the system functions. The main challenges to understanding the bottlenecks within the ecosystem lie in the scoping and mapping out the actors active within such an ecosystem. The available quantitative data and information is limited for the ecosystems as they are spread across various sectors of economic activity. A separately conducted pilot focusing on the research and innovation ecosystem of photonics in the Netherlands has also shown that further research is needed into scoping and mapping out the research and innovation ecosystems. The conducted pilot also revealed that it is challenging to determine what share of activities of an organisation are associated with performing photonics activities, for example, as a share of a turnover. Without having these estimates, the indicators associated with turnover or budget spent on the core activity could be completely unreliable. Therefore further research is needed into understanding the functioning of an ecosystem before the proposed set of indicators could be tested for its relevance and reliability.

Increasing availability of data through existing sources and emergence of new data sources offers possibilities to further enrich the understanding of the research and innovation ecosystems. The examples of such sources could include job vacancy data, social media data, web data, open data. Integrating it with AI techniques (e.g. text mining, learning algorithms) could further help gathering information on the functioning of the ecosystems, how they work and how the relationships or cooperation takes place. Combining the different sources could help overcoming the limitations of each individual data source. In addition, incorporating these insights with the expert knowledge could enrich understanding of the research and innovation ecosystems in general and support the development of policies and strategies.

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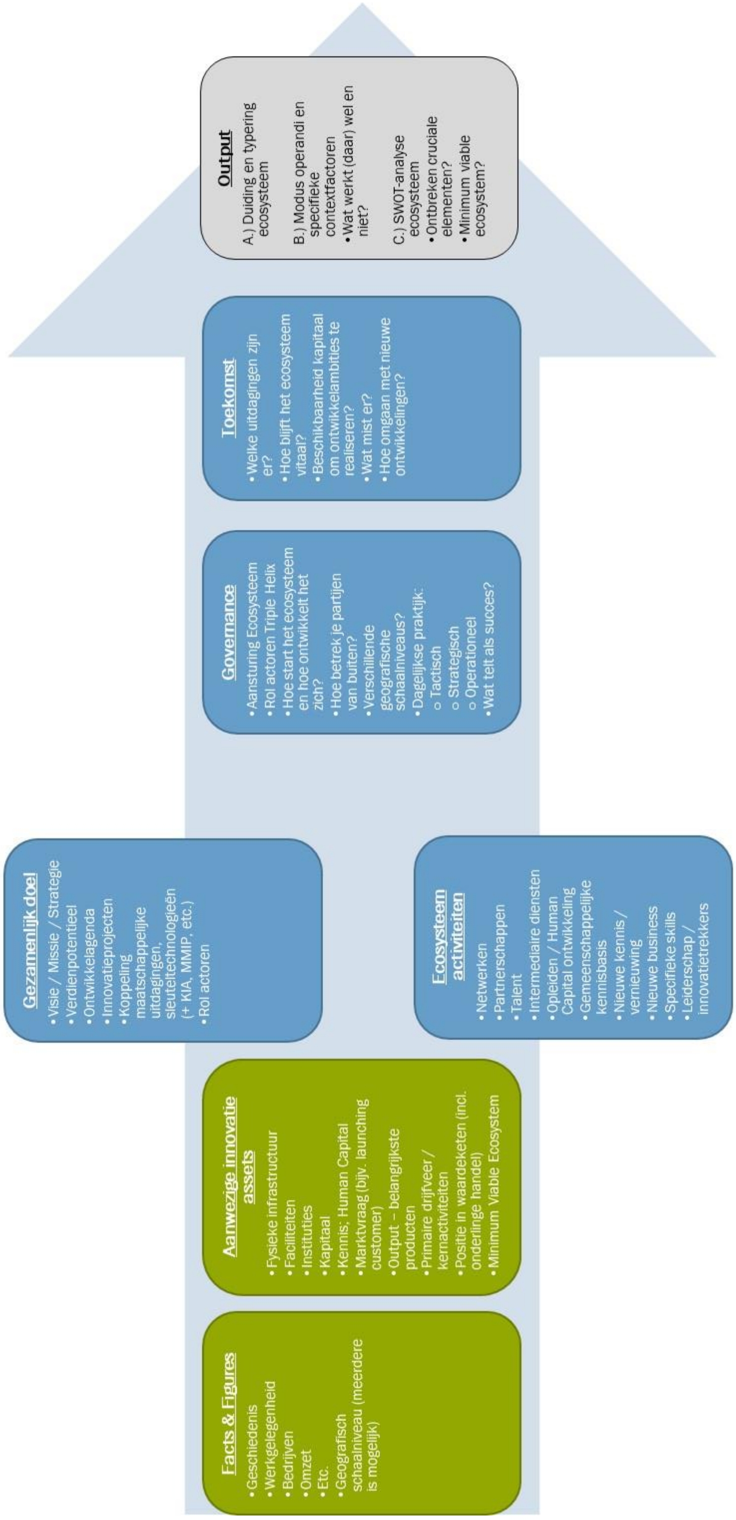
Annex 1 – Analytical framework for R&I ecosystems



Source: TNO (2021). Regionale innovatie-ecosystemen: onderzoek naar optimale vormgeving van en dynamiek in regionale innovatie-ecosystemen