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Assessment of entrepreneurial ecosystems

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Authors

Surname	First Name	Beneficiary
Leendertse	Jip	Utrecht University
Beyer	Casparis	Utrecht University
Sanders	Mark	Utrecht University
van Rijnsoever	Frank	Utrecht University

In case you want any additional information or you want to consult with the authors of this document, please send your inquiries to: irissmartcities@gmail.com.

Reviewers

Surname	First Name	Beneficiary
Troedsson	Emma	IMCG International
Peekel	Arno	Utrecht Sustainability Institute

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Executive Summary

This deliverable provides insight into what factors in the local environment are creating conditions for developing and implementing new business models, and what factors are barriers to such business model development. To do so we make use of the entrepreneurial ecosystem (EE) approach, which outlines the factors and actors that influence entrepreneurial activities in a city/region. We present a tool that provides in depth insight in the conditions that influence entrepreneurs coming up with new business models and look at this from a generic (overall entrepreneurship) and specific (sustainable entrepreneurship) perspective. In addition, we develop and apply a qualitative method to get an in depth understanding of the local EE and apply this in two cities. This qualitative tool can be applied to LHs and FCs as well as all other European regions/cities for understanding how they can foster transformative entrepreneurial ecosystem.

This deliverable combines four studies that each contribute to a part of the overall deliverable. In the remainder of the executive summary a summary of each of these four chapters is presented, followed by an overall list of recommendations for specific audiences of our work.

The first study focuses on the *assessment of regional entrepreneurial ecosystems*. Despite the popularity of the EE approach in science and policy, there is a scarcity of credible, accurate and comparable metrics of entrepreneurial ecosystems. This is a severe shortcoming for both scientific progress and successful policy. This is the case for two reasons. First, metrics are needed to empirically test which elements of the local environment influence the creation of entrepreneurship. Second, these metrics allow for comparing entrepreneurial ecosystems, to identify strong performance and to learn from best practices in other regions. In this chapter, which is also published as a peer-reviewed paper in top journal Research Policy, we bridge the entrepreneurial ecosystem metrics gap. Entrepreneurial ecosystems consist of the actors and factors that enable entrepreneurship. We operationalize the elements and outputs of entrepreneurial ecosystems for 273 European regions. The ecosystem elements show strong and positive correlations with each other, confirming the systemic nature of entrepreneurial economies and the need for a complex systems perspective. Our analyses show that physical infrastructure, finance, formal institutions, and talent take a central position in the interdependence web, providing a first indication of these elements as fundamental conditions of entrepreneurial ecosystems. The measures of the elements are used to calculate an index that approximates the quality of entrepreneurial ecosystems. This index is robust and performs well in regressions to predict entrepreneurial output. The entrepreneurial ecosystem approach and the metrics we present, provide a lens for public policy to better diagnose, understand and improve entrepreneurial economies. Furthermore, we present a full overview of how all 273 European regions score on each of the ten entrepreneurial ecosystem elements as well as on entrepreneurial outputs. This data can be used as a tool by policy makers to assess how well their region fares regarding the factors and actors that contribute to entrepreneurship.

In the second chapter we focus on the *assessment and operationalization of sustainable entrepreneurial ecosystems*. This chapter builds on the findings from the first chapter regarding how the local environment influences entrepreneurship. We shift our focus to a specific type of entrepreneurs, sustainable entrepreneurs. Sustainable entrepreneurs introduce new sustainable technologies and business models to the market. They thereby can help with tackling grand environmental challenges and are key in building smart cities. Regional governments are increasingly implementing policies to develop a supportive ecosystem for sustainable entrepreneurship in their region. For these policies to be effective, policy makers need to understand which regional factors influence the founding of sustainable start-ups by these entrepreneurs. We build on the sustainable entrepreneurial ecosystem and innovation system literatures to develop hypotheses about which factors could determine the presence of sustainable start-ups in a region. We test these hypotheses on data from 274 European NUTS-2 regions containing 46,741 start-ups. We use text analysis to identify which start-ups are environmentally sustainable. We find that the quality of an entrepreneurial ecosystem is important for the presence of sustainable start-ups, even more so than for their regular counterparts. We further find strong evidence that the presence of sustainable start-ups is positively influenced by the presence of regular start-ups, the presence of sustainability-oriented actors and resources, and possibly on the presence of favorable institutions towards sustainability. We make two contributions to the literature. First, we explore the applicability of the entrepreneurial ecosystem literature to contexts of sustainable start-ups. Second, our research contributes to the emergence of the sustainable entrepreneurial ecosystem concept by enriching this literature with insights from the literature on innovation systems. Policy makers can use our results to establish policies that help build ecosystems for sustainable entrepreneurship in their region.

In the third chapter we take a qualitative approach. We develop and apply a method to look in depth at *how the local entrepreneurial ecosystem can play a role in the transition to a more sustainable society*. In this chapter we combine the entrepreneurial ecosystem with the multi-level perspective on transitions (MLP). We use two case studies (IRIS city Vaasa in Finland, and non-IRIS city Rotterdam in the Netherlands). These are used to develop the qualitative method. This chapter integrates findings of 44 semi-structured interviews with relevant actors. Based on the findings, we propose a *transformative entrepreneurial ecosystem* (TEE) framework that combines EE and MLP theory and depicts the generalizable configuration of the entrepreneurial ecosystem that encourages entrepreneurship across multiple niches, which subsequently support the urban transition to sustainability. Besides transformative refinements to the ten original framework and systematic conditions of Stam's (2018) framework, this adds two new transformative conditions: 'Involvement of incumbents' and 'TEE branding'. The 'Involvement of incumbents' condition is added to acknowledge the main finding of the increasing importance of start-up - incumbent collaborations. Especially in the field of transformative entrepreneurship, the impact can seldom be scaled without this collaboration. The condition' TEE branding' shows the importance of promoting the successfulness of the TEE and promoting its (successful) transformative entrepreneurs to the external environment. By developing this conceptual TEE framework, we present policy makers with a tool to analyse their cities in more depth. As such, the tool also shows how to build on quantitative findings with qualitative insights.

In the fourth chapter we zoom in from the meso-perspective of regions and cities to the *performance of the individual start-ups* that develop new sustainable business models. Sustainable start-ups introduce new sustainable technologies and business models that facilitate the transition to a carbon neutral economy. To understand how to create viable sustainable start-ups, we study what factors predict their business performance and climate performance (i.e. the ability of the start-up to reduce CO_2 emissions), and if these contradict. A critical factor we consider is technology, which is commonly at the root of climate performance, and important for business performance because it influences a start-up's competitive advantage. Using a sample of 197 sustainable start-ups, we find a paradox between business and potential climate performance. Start-ups that exploit hardware technologies have a lower business performance, but a higher potential climate performance. Through the use of mediating effects we show that the sustainable start-up paradox is context specific. Start-ups can partly escape this paradox by focusing on novel and hardware technologies.

Recommendations

Policy makers can use the measures we present as an essential input for ex-ante policy diagnosis: to discover the weaknesses and strengths of entrepreneurial ecosystems. These weaknesses and strengths are always relative to other relevant regions: the benchmark. This is why the construction of large-scale datasets is a necessity for regional policy. Benchmarking the region could trigger policy by learning from regions that have comparable, entrepreneurial ecosystems. By using data to show how the various parts of the ecosystem for entrepreneurship (or any subject for that matter) are doing, we offer policy makers the opportunity to better understand their region. In other words, the usefulness of an ecosystem index lies in the use of the underlying data and how it can help to better understand the ecosystem and how it can be improved. Tackling the weakest elements of entrepreneurial ecosystems is likely to provide the most efficient and effective way of improving the overall quality of the entrepreneurial ecosystem. However, a limitation in applying our metrics is that they provide insight into where to look for improvement, but not how this improvement should be achieved. It is thus important to combine these metrics with qualitative insights about specific entrepreneurial ecosystems. We therefore provide a process-based recommendation. Use the diagnosis behind the entrepreneurial ecosystem index as the starting point. Sit down with each other, entrepreneurs, companies, regional development agencies, provinces, municipalities, universities, colleges, etc., and discuss the diagnosis: Which weak elements are recognized (or not)? What is this due to? How could it be better? Do all stakeholders agree or do we/they have a difference of opinion? How can we improve this region together? By making use of this dialogue, it is possible to deepen the diagnosis and subsequently convert it into points for improvement. Then compile the interventions (both formal and informal policies) based on this dialogue. Please don't jump to conclusions, but use our (and other) research to start the conversation.

Regarding the study on sustainable entrepreneurial ecosystems policy makers can use our results to establish policies that help build ecosystems for sustainable entrepreneurship in their region. In line with our results, a first step is to focus on building a strong entrepreneurial ecosystem. In addition, we find that there are additional elements beyond the regular EE that matter for SSUs. Especially, supporting actors and resources active in a region is particularly important for SSUs. Actors provide SSUs with access to markets, resources, and thereby help them overcome the constraints they face. We identify two specific actor types that are important. First, the number of regular start-ups. Second, the presence of sustainability-oriented actors and the resources they control. Stimulating the presence of both types of actors are thus potential avenues to a higher presence of sustainable start-ups. As a second contribution we show the amount of SSUs currently present in each region and the top performing regions. This allows policy makers to look not only at how their regions are doing, but also to identify and learn from other regions that have a high presence of SSUs.

Based on the qualitative study we find that entrepreneurial ecosystems for transformative entrepreneurship require strategic coordination because of its purposiveness. For the two cases we find that strategic coordination consists of ecosystem-level collaboration and transformative leadership. This requires going beyond the nurturing of new technologies and taking a more holistic approach to developing the TEE that in turn enables bottom-up sustainable value creation as a whole.

Our results from the study into sustainable start-up performance show that economic and climate ambitions are not easily combined. This challenges the idea of 'green growth' (Hockerts & Wüstenhagen, 2010). If the goal is, primarily, to stimulate start-ups for economic growth, we recommend policymakers to facilitate entrepreneurship based on software technologies. However, if the goal is to pursue green growth by combining climate potential and business performance we recommend to focus on sustainable start-ups with a hardware and novel technology. The results show that deviating from existing technological trajectories is beneficial for society as it results in start-ups with more climate potential, however, doing so does not benefit the business performance of the start-up. To mitigate the business risk of these sustainable start-ups governments should provide them with additional support. One way to do so is through co-investing and taking equity. If some of the sustainable start-ups become profitable, at least part of this investment is publicly retained. In particular, results suggest that having a diverse portfolio of sustainable start-ups can pay off. The limitations of some start-ups may be complemented by the strengths of other start-ups, thereby reducing the risks of the overall investment portfolio. The profits from the low-sustainable start-ups with software technology can then be re-invested into sustainable start-ups with a hardware technology. Finally, another strategy is to reduce the business performance liabilities of start-ups with a hardware technology. This could be done by subsidizing or giving investment guarantees for manufacturing investments or by investing in shared manufacturing facilities that can be used by start-ups.

Entrepreneurial ecosystem actors such as business advisors, investors, or incubators can use the results of the meso-analysis into entrepreneurial ecosystems in a similar way to policy makers, we recommend them to look at what they can do to improve the local ecosystem as a better ecosystem is a clear driver of entrepreneurial acitivity. Regarding the performance of sustainable start-ups our study also has implications. Because the antecedents of climate performance and business performance are different, these stakeholders can have an impact on both forms of performance by focusing on particular antecedents. Specifically, investors can urge sustainable start-ups to follow a technological strategy that is focused on software to maximise business performance. Incubators that may have a predominantly societal goal may instead urge sustainable start-ups to follow a hardware-based strategy to maximise climate performance. If external stakeholders' aim is to maximise both forms of performance, we advise to invest in sustainable start-ups with a hardware technology and high climate potential.

This research also shows that there are fundamental differences in the performance of start-ups based on their type of technology and it's novelty. We argue that start-up support programmes should then also differentiate the support they offer to these start-ups. This is in line with earlier findings that different types of start-ups require different types of support (Soetanto & Jack, 2013; van Weele, van Rijnsoever, Groen, & Moors, 2019).

Finally, for entrepreneurs our meso-studies can help them understand what factors are needed in a supportive ecosystem and to, if certain resources are not present, look across the boundaries of the own entrepreneurial ecosystem from an early stage. Based on the start-up performance study we have specific recommendations based on the fact that achieving (1) climate performance and (2) business performance simultaneously is not straightforward as both require different strategies. In terms of technological characteristics, our study shows that by using novel and hardware-based technologies, sustainable start-ups may partly escape the paradox of maximising both climate and business performance. Additionally, having high climate ambitions partly alleviates the negative effect of hardware technologies on business performance. We therefore advice sustainable start-ups who exploit a hardware technology to dream and act ‘climate-big’.

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List of Abbreviations and Acronyms

Abbreviation	Definition
EU	European Union
WP	Work Package
EE	Entrepreneurial Ecosystem
SEE	Sustainable Entrepreneurial Ecosystem
SSU	Sustainable start-ups
IRIS	Integrated and Replicable Solutions for Co-Creation in Sustainable Cities
HIC	Harbor Industrial Complex
MLP	Multi-Level Perspective on Socio-Technical Transitions
R&D	Research and Development
SME	Small- Medium-sized Enterprise
SNM	Strategic Niche Management
STEEM	Strategic Transformative Entrepreneurial Ecosystem Management
TEE	Transformative Entrepreneurial Ecosystem
LH	Lighthouse City
FC	Follower City
GRP	Gross Regional Product
TIS	Technology Innovation System

1. Introduction

The purpose of the lighthouse projects in general and IRIS specifically among them is to promote smart city innovation in European Cities. In work package 3 the focus is on the development of the business models surrounding these innovations. Innovations are not developed by entrepreneurs who operate independent of their context, in a so called vacuum, but they are developed by entrepreneurs who are in turn influenced by their environment. In Task 3.1 we zoom in on the characteristics of the regional ecosystem that surrounds the new, integrated solutions that IRIS demonstrates and develops. T3.1 thus targets what factors in the local environment create conditions for developing and implementing new business models and what factors are barriers to such business development. Furthermore, T3.1 analyses the LHs innovation ecosystem to help develop a strategy for improving the ecosystems, with a focus on the sustainable business models that are developed in entrepreneurial ecosystems. While the initial proposal argued for the use of the Technology Innovation Systems (TIS) across districts we, for D3.1, adjusted the focus from the TIS to the entrepreneurial ecosystem (EE) approach. We make this adjustment because the EE has the entrepreneur implementing the new business models at the centre. As this Task in IRIS focuses on the implementation of new business models the entrepreneur should be at the centre. As such the EE, is better suited for the approach than the TIS framework. This is not a big deviation since an EE can, from a theoretical perspective, be considered a special case of an innovation system (van Rijnsoever, 2020; van Weele et al., 2018b). An innovation system consists of (1) actors that interact and exchange resources in a network under an (2) institutional regime and an (3) infrastructure (Carlsson and Stankiewicz, 1991; Van Rijnsoever et al., 2015). An entrepreneurial ecosystem comprises a set of interdependent actors and factors that are governed in such a way that they enable productive entrepreneurship, the implementation of scalable business models by entrepreneurs, within a particular territory (Stam, 2015; Stam and Spigel, 2018). So while the theoretical framework used is the EE and not the TIS we still meet the aim of this deliverable which is, quoted from the grant agreement *'To understand what factors in the local environment are creating conditions for developing and implementing new business models, and what factors are barriers to such business model development.'* The shift from TIS to EE places the entrepreneur more at the center which enables a better understanding of the conditions surrounding new business models emerge.

To provide the best insight in the conditions of EEs that influence the development of new business models it is important to have good metrics on EEs that enable the comparison across EEs. We develop a tool that we apply to LHs and that can be used in FC and other cities for understanding how the conditions for implementing business models can be improved in cities. This tool starts with the development of metrics for the quality of EEs across Europe. These metrics enable adequate diagnosis and monitoring in the policy cycle. The usefulness of these metrics for policy and improving cities lies in the use of the underlying data and how it can help to better understand (1) the regional EE, (2) how it can be improved, (3) and in the future whether the intended improvements have been achieved, and (4) why or why not? Particularly this enables the IRIS cities to assess how their region is performing, to compare how their IRIS partners are performing and on which elements they can learn from each other but also to find comparable regions (outside IRIS) that they can learn from. The European scope of these metrics allows LHs and FCs alike to go beyond IRIS and also learn from or interact with other regions.

The tool that we propose in this deliverable has several components. First, an overview of the quality of the EE in IRIS (and other) regions across Europe (Chapter 2, second a particular focus on sustainable entrepreneurship to better fit with the type of entrepreneurship that comes out of IRIS (Chapter 3). This also includes an overview of the amount of sustainable start-ups (SSUs) in the European regions, again to enable comparison. Third, a method to analyse the developments in a region, focused on transformative entrepreneurship to, which has overlap with Chapter 3, but a slightly different focus on those entrepreneurs that really transform cities (Chapter 4). In Chapter 5 we look specifically at when sustainable entrepreneurs can become successful with their business models which provides valuable insights in the process from a more micro-perspective. This chapter is not explicitly part of the tool. The final component of this tool is an outline of how this can be used by policy makers, in IRIS LH and FCs as well as other cities, to improve the conditions for entrepreneurship in our region. The section on policy advice brings together these findings and share how stakeholders can exchange ideas on how to prioritise and strengthen system functions. Our advice is deliberately not a list of actions for each region. Instead, our advice is process-based. Use the diagnosis behind a ranking, the look under the hood, as the starting point. Sit down with each other, entrepreneurs, companies, regional development agencies, provinces, municipalities, universities, colleges, etc., and discuss the diagnosis: Which weak elements are recognized (or not)? What is this due to? how could it be better? Do all stakeholders agree, or do we/they have a difference of opinion? How can we improve this region together? In particular, we organized a session on the 8th of February 2021 during the IRIS show-off and a Gothenburg specific session on 30th of September 2021 organized by the Johanneberg Science applied this discussion model in specific IRIS cities. These sessions helped share the insights obtained in T3.1 with relevant stakeholders and at the same time served as input for the completion of the deliverable.

As such, the deliverable includes not just the analysis of the various innovation system, but also how this analysis was used to scope improvement possibilities within the cities. D3.1 takes a complementary perspective to D3.2 which provided a TIS assessment of the seven IRIS cities aimed to understand how replication in the IRIS cities could take place. D3.1 is complimentary to this by zooming out a step further and enabling comparison not just between IRIS but all European regions. In our reasoning to do so we underline the limits of contributions only focused on specific cities (e.g. IRIS) and go beyond the context of IRIS to more regions. We look in depth at the institutions, and actors present in regions and what this means for the implementation of new or replicated business models.

1.1. Scope, objectives and expected impact

T3.1 will target to understand what factors in the local environment are creating conditions for developing and implementing new business models, and what factors are barriers to such business model development. T3.1 will analyse the LHs innovation ecosystems and help develop a strategy for improving that ecosystem. To do so we make use of the entrepreneurial ecosystem (EE) approach, which outlines the factors and actors that influence entrepreneurial activities in a city/region. In particular, we compare the LHs and FCs included in IRIS with a total of 274 European regions. This study provides insights in the conditions for letting new business models emerge. We present a tool that provides in depth insight in the conditions that influence entrepreneurs coming up with new business models and look at this from a generic (overall entrepreneurship) and specific (sustainable entrepreneurship) perspective. This tool can be applied to LHs and FCs as well as all other European regions/cities for understanding how they can foster entrepreneurship in sustainable solutions. We outline both the method behind the tool and how to use the tool in practice. As such D3.1 includes not just the analysis of the various entrepreneurial ecosystems, but also how this analysis can be used to scope improvement possibilities within the cities. As such the overview of the state of all European EEs allows to categorize best practices, to learn from other cities and to develop plans to enable the improvement of the ecosystem that allows for the implementation of potential replication plans. In this tool we include the specific context of the cities (LHs, FCs and others) by looking at multiple factors including the regulatory context and the innovation capabilities of present actors.

We compliment the quantitative method that is used in the design of this tool by empirically testing the framework in two quantitative studies. Furthermore, we perform fieldwork in two cities (less than anticipated due to COVID) to contribute qualitative insights to the framework. Finally, we also study when entrepreneurs are able to successfully build sustainable businesses around their sustainable business models. This last element adds a micro-perspective to the meso-perspective taken in the rest of the tool.

In sum, what we do, is an "analysis of the various innovation systems, but also how this analysis was used to scope improvement possibilities within the cities:" as well as include a subsection on the learning events to strengthen system functions. Furthermore, the EE analysis and the results takes a broader scope by analysing all European regions and, as such, also allows the LHs and FCs to place their local potential and conditions for entrepreneurial solutions in a European content. Furthermore, we provide specific analysis on which elements of EEs contribute specifically to sustainable (smart city) innovations and provide an analysis on how cities can improve their ecosystem to stimulate these innovations.

As such, the results of this study are highly useful for policy makers, both from the IRIS cities but also beyond, who aim to improve the conditions in their city and region that influence the presence of (sustainable entrepreneurship). They can obtain insight in what are the determining factors, in how their city/region is performing on these factors and in examples of other cities and regions that are performing similar/better to learn from these studies. We also provide an explanation of how to interpret and utilize these results. Second, our results are useful for other entrepreneurship support organizations who aim to improve the conditions in their EE. Third, entrepreneurs can use our tools to obtain a better understanding of the strengths and weaknesses of the ecosystems in which they are embedded or to which they are expanding. Thus, enabling to look across to other cities and regions to help obtain access to resources that are underdeveloped in a region. Of particular interest for entrepreneurs is also the fourth chapter which provides insight into the factors that influence the performance of sustainable entrepreneurs.

1.2. Contributions of partners

This report is primarily written by Utrecht University and has received support from IMCG in the research process. In addition, Merinova Technology Center contributed by hosting a master student from Utrecht University in Vaasa for the qualitative analysis included in this report. In addition, the work is connected to conversations with a number of partners inside and outside of the IRIS-team. This includes discussions with our academic IRIS partners at Chalmers University of Technology, the municaplity of Utrecht, Johanneberg Science Park, UtrechtInc, an incubator that is a third party beneficiary, but also with many actors at conferences such ase EU-SPRI, EURAM, GEOINNO, DRUID Furthermore, we thank Chris Eveleens, Mirella Schrijvers, Erik Stam who from different functions contributed to the academic work that makes up the individual chapters. In addition, we thank Martine de Vos, Maarten Schermer, Casper Kaandorp, and Robert-Jan Bood for their contributions in collecting the website data used to identify sustainable start-ups.

1.3. Relation to other activities

The work done in this work package connects to D3.4 in which a cookbook for smart city incubation was developed. Furthermore, the internship of Casparis Beyer at Merinova Technology Center was an across work packages collaboration that contributed to the understanding of the Vaasa ecosystem. This was also covered in a local newspaper article https://www.vaasainsider.fi/forskning-utbildning/vasaregionen-teneriffa-rotterdam-med-oppet-sinne-tar-casparis-beyer-reda-pa-vad-regionerna-kan-lara-varandra/.

This deliverable and the activities underlying it is naturally closely related to the work done in Tasks 3.2 and Task 3.3. The first task focusses on the development of new business models. In particular, "T3.2 focuses on **development and testing of new business models**, in order to come up with and strengthen viable IRIS solutions at district scale. To be comprehensive, T3.2 contains activities devoted to different stages of business model development. More specifically T3.2 aims to **bring user innovation and design thinking** to the stage of business incubation; to take existing emergent business models in LH-city Utrecht to the next level of business incubation; and to match business model developers to the resources they need". This relates closely to the ecosystem approach and as such Task 3.2 and Task 3.1 are closely connected. The work in Task 3.1 is also partly influenced by some of the work that was done for and presented in Task 3.3, D3.6. That is, the city innovation management performance tool developed in that task. Finally, the work is complementary to D3.2 which provided a TIS based analyses of the individual cities in IRIS. Our work is complimentary in two ways, first by taking a broader perspective and going beyond the borders of IRIS to bring learnings to the IRIS cities and two by taking an altered approach using the EE which has a more explicit focus on the entrepreneurs working on business models. Furthermore, milestone MS4 in T3.3 presents a business model adaptation tool that can be applied to specific IRIS solutions and how to implement/replicate these in different settings. This milestone is a core part of the broader WP3 Development of Bankable Business Models and Exploitation Activities. The work in D3.1 adds to the work done for this milestone by providing insight in the different contexts. D3.1 thus provides an overview of the state in a region or city that can be used when applying the business model adaptation tool. It thus serves as relevant input when applying the business model adaptation tool to specific new business models.

During the IRIS show-off sessions on the 8th of February 2021 the results of the project were presented to IRIS partners from several work packages, this included discussion about how to integrate them in the work of these partners. This lead to a follow up session with the Gothenburg participants on the 30th of September 2021 organized by the Johanneberg Science park, in this session we zoomed in specifically on the status of the Gothenburg ecosystem and on potential improvements. These inputs were also used in framing how this report can contribute to the challenges that policy makers and other stakeholders face in building a supportive entrepreneurial ecosystem.

1.4. Structure of the deliverable

The deliverable contains four additional chapters that provide separate contributions to the overall aim of the report. The second chapter contains a tool that provides insight in the quality of the EE in 274 European regions. This chapter outlines the creation of this tool, tests it empirically and provides an overview of the assessment for all 274 regions. This contributes to the goal of providing insight in the conditions that influence entrepreneurial activities in a region. Furthermore, we present the quality of the EE for the IRIS cities and provide an evaluation on what to learn. A modified version of this chapter has been published as a scientific paper: Measure Twice Cut Once: Entrepreneurial Ecosystem Metrics and is also available at https://doi.org/10.1016/j.respol.2021.104336. The third chapter builds on this tool but expands specifically towards sustainable entrepreneurship. This chapter provides insight in the distribution of sustainable entrepreneurship across the 274 regions and develops and implements an overview of the factors that influence the occurrence of sustainable entrepreneurship. This is then tested empirically and results in insights into which factors influence sustainable entrepreneurship and where this is happening. Again, all results are made available in a table that can be used as a tool for policy makers. This chapter is currently submitted to an international peer-reviewed journal. As a fourth chapter, we performed qualitative fieldwork in two cities. Comparing an IRIS to a non-IRIS city and further studying what factors influence sustainable or transformative entrepreneurship. This chapter has been submitted as a masterthesis and is also available at: https://studenttheses.uu.nl/bitstream/handle/20.500.12932/37028/MSc%20Thesis%20CB%20Beyer%20SBI%20FINAL.pdf?sequence=1. The fifth chapter takes a micro dive into sustainable entrepreneurship and studies what factors influence the success of sustainable entrepreneurs. This work complements the regional/city perspective taken into the three previous chapters and has been published as a scientific paper: The sustainable start-up paradox: Predicting the business and climate performance of start-ups. This chapter is also available at https://doi.org/10.1002/bse.2667.

In each chapter we develop and outline the methodology of that particular research approach separately. Hence, we do not first present a separate overall methodology. Furthermore, in the conclusion we start with an integration of the findings of the previous study with a focus on the seven cities that are part of IRIS, as such providing an in depth analysis of these cities.

2. Assessment of regional European entrepreneurial ecosystems

A slightly modified version of this chapter has been published as *Leendertse, J., Schrijvers, M., & Stam, E. (2022). Measure twice, cut once: Entrepreneurial ecosystem metrics. Research Policy, 51(9), 104336.* https://doi.org/10.1016/j.respol.2021.104336.

2.1. Introduction

Even though the academic literature on entrepreneurial ecosystems has been flourishing recently, it does not yet provide an actionable framework for economic policy. An important reason for this is the scarcity of credible, accurate and especially comparable metrics of entrepreneurial ecosystems. An entrepreneurial ecosystem comprises a set of interdependent actors and factors that are governed in such a way that they enable productive entrepreneurship within a particular territory (Stam, 2015; Stam and Spigel, 2018). The entrepreneurial ecosystem approach has become popular due to the gradual shift from managerial economies to entrepreneurial economies (Thurik et al., 2013). In these entrepreneurial economies, entrepreneurship is considered a key driver of economic change (Schumpeter, 1934).

The entrepreneurial ecosystem approach offers a lens to empirically trace the systemness of entrepreneurial economies and the degree to which economic systems produce entrepreneurship as an emergent property of the system (Brown and Mason, 2014; Isenberg, 2010; Stam, 2015). It is instrumental to synthesize and integrate a large variety and quantity of data to measure the (changing) nature, outputs and outcomes of (regional) economies (Stam, 2015). The entrepreneurial ecosystem approach thus has the potential to provide an actionable framework that guides policymaking.

However, the scarcity of sufficient metrics on entrepreneurial ecosystems makes it difficult to have adequate diagnosis and monitoring in the policy cycle. The lack of adequate diagnosis and monitoring is one reason why economic policy often fails to achieve its objectives and learn from previous mistakes. The objective of this paper is to quantify and qualify regional economies with an entrepreneurial ecosystem approach. We address the metrics gap by developing and applying entrepreneurial ecosystem metrics to analyze entrepreneurial economies. These metrics enable adequate diagnosis of entrepreneurial economies and allow for the monitoring of economic change generated by policy and other dynamics. This paper thus takes heed of the old carpenter's adage "measure twice, cut once", by reducing policy failures with better measurement tools.

While the entrepreneurial ecosystem approach has become very prominent over the last decade, it still lacks empirical evidence. The existing empirical studies are often qualitative case studies, such as those by Spigel (2017) in Canada and Mack and Mayer (2016) in the US. There are earlier attempts to measure entrepreneurial ecosystems with quantitative data, such as the study by Ács et al. (2014). However, these studies focus on the national level (Ács et al., 2014; Radosevic and Yoruk, 2013). In this study we instead focus on the regional level, because entrepreneurship is largely a regional event (Feldman, 2001), and there is substantial variation in entrepreneurship between regions within countries (Sternberg, 2009; Fritsch and Wyrwich, 2014). The level of the (city-)region is generally seen as the more adequate level from a policy (Katz and Bradly, 2013; Spigel, 2020) and entrepreneurship practice (Feld, 2012; Feldman, 2001) point of view. This study will be the first to create a harmonized dataset to measure entrepreneurial ecosystems at the regional level in a large number of countries.

Developing entrepreneurial ecosystem metrics encompasses quantification and qualification. Quantification involves measuring the key elements with a wide range of data sources (Credit et al., 2018). Qualification involves developing a methodology that provides insight into the extent to which these elements are interdependent, into the overall quality of entrepreneurial economies, and how this relates to entrepreneurial outputs. We have three main research questions.

First and foremost, how can we compose a harmonized dataset to measure the quality of key elements of entrepreneurial economies? We develop a universal set of constructs for each entrepreneurial ecosystem element, and we source data from a large variety of datasets to compose credible, accurate, and especially comparable metrics of entrepreneurial ecosystems. We measure entrepreneurial ecosystems with a harmonized dataset in the context of 273 regions in 28 European countries. Europe provides an excellent laboratory for analyzing entrepreneurial economies because it contains a large number of regions that exhibit striking variation in socio-economic conditions, entrepreneurial activity, and economic growth.

Second, to what extent and how are the elements of entrepreneurial economies interdependent? Interdependence is a key aspect of complex systems (Aghion et al., 2009; Simon, 1962). Studying if there are strong interdependencies between the elements thus helps answer the question whether entrepreneurial economies can be seen as complex systems. Using multiple statistical methods, we show to what extent and how the elements of entrepreneurial economies are interdependent.

Third, how can we determine the quality of entrepreneurial economies? We answer this question with a synthesis of our entrepreneurial ecosystem element metrics into an entrepreneurial ecosystem index. We then analyze the relation of the entrepreneurial ecosystem index to entrepreneurial outputs. Entrepreneurial output is an indicator of the emergent property of entrepreneurial economies. We use multiple data sources and metrics to determine entrepreneurial outputs at the regional level. Using novel methods, including web scraping and geocoding, we determine entrepreneurial outputs per region in the form of the number of (Crunchbase listed) innovative new firms and unicorns – young private firms with a valuation of more than $1 billion.

The outline of our paper is as follows. First, we discuss the key mechanisms that explain the prevalence of entrepreneurship and economic development. Second, we discuss and develop the measures needed to approximate the key elements of entrepreneurial economies. These measures allow us to quantify the elements and to qualify entrepreneurial economies. Third, we relate the developed metrics to entrepreneurial outputs. The final sections conclude, reflect on the findings and policy implications, and set out an agenda for further research.

2.2. Entrepreneurship and economic development

In this section, we discuss the state of the art of empirical research on the (inter)relation between entrepreneurship and (regional) economic development, synthesize this into an entrepreneurial ecosystem framework, and advance our understanding of entrepreneurial ecosystems with a complex systems perspective. The empirical literature on entrepreneurship and (regional) economic development can be divided into the economic growth literature[1], focusing on the aggregate economic growth effects of entrepreneurship, and the geography of entrepreneurship literature, focusing on the causes of the spatial heterogeneity of entrepreneurship. In the following two sections, we summarize the insights from these two types of literature.

2.2.1. Entrepreneurship and economic growth

The role of entrepreneurship in economic development has been studied for a long time, going back to Schumpeter (1934), Leibenstein (1968) and Baumol (1990). The economic growth literature is mainly concerned with the question of how and to what extent entrepreneurship affects economic growth. Even though the literature does not provide full consensus on the positive effects of entrepreneurship, there seems to be more evidence in favor of than against positive (causal) effects of entrepreneurship on economic growth (Audretsch et al., 2006; Bosma et al., 2018; Carree and Thurik, 2010; Fritsch, 2013). Key causal mechanisms are the creation and diffusion of innovations and the competition created by entrepreneurs (Bosma et al., 2018). The direction and strength of the effect of entrepreneurship on economic growth depend on the type of context and the type of entrepreneurship. Ambitious, opportunity and growth-oriented types of entrepreneurship are more likely to lead to economic growth than self-employed, necessity-based entrepreneurship (Bosma et al., 2018, 2011; Fritsch, 2013; Stam et al., 2011; Stam and Van Stel, 2011). In addition, entrepreneurship is most productive in contexts with inclusive and growth-enhancing institutions (Bosma et al., 2018; Sobel, 2008). Entrepreneurship does not occur in a vacuum but is very much a local event (Feldman, 2001). There are also substantial regional variations in the prevalence of entrepreneurship, with underlying causes being very much spatially bound (Alvedalen and Boschma, 2017; Guzman and Stern, 2015).

2.2.2. The geography of entrepreneurship

The literature on the geography of entrepreneurship has provided numerous insights into the role of different factors enhancing the prevalence of entrepreneurship in regions (Bosma et al., 2011; Stam, 2010; Stam and Spigel, 2018; Sternberg, 2009). We summarize the empirical literature on the geography of entrepreneurship with ten elements affecting the prevalence of entrepreneurship (cf. Stam, 2015; Stam and Van de Ven, 2021). The first element, formal institutions, provides the fundamental preconditions for economic action (Granovetter, 1992) and for resources to be used productively (Acemoglu et al., 2005). Formal institutions are not only a precondition for economic action to take place; they also affect the way

[1] While this literature is very extensive, we focus exclusively on the studies measuring the effects of (different types of) entrepreneurship.

entrepreneurship is pursued and the welfare consequences of entrepreneurship (Baumol, 1990). Informal institutions - in particular an entrepreneurship culture, which reflects the degree to which entrepreneurship is valued in society - also have substantial effects on the prevalence of entrepreneurship (Fritsch and Wyrwich, 2014). Networks of entrepreneurs provide an information flow, enabling an effective distribution of knowledge, labor and capital (Malecki, 1997). A highly developed physical infrastructure (including both traditional transportation infrastructure and digital infrastructure) is a key element of the context to enable economic interaction and entrepreneurship in particular (Audretsch et al., 2015). Access to finance - preferably provided by investors with entrepreneurial knowledge - is crucial for investments in uncertain entrepreneurial projects with a long-term horizon (see e.g., Kerr and Nanda, 2009). Leadership provides direction for the entrepreneurial ecosystem. This leadership is critical in building and maintaining a healthy ecosystem (Feldman, 2014) and involves a set of 'visible' entrepreneurial leaders committed to the region (Feldman and Zoller, 2012). The high levels of commitment and public spirit of regional leaders might reflect underlying norms dominant in a region (Olberding, 2002). Perhaps the most important condition for entrepreneurship is the presence of a diverse and skilled group of workers ('talent': see e.g., Acs and Armington, 2004; Glaeser et al., 2010; Lee et al., 2004; Qian et al., 2013). An important source of opportunities for entrepreneurship can be found in knowledge from both public and private organizations (see e.g., Audretsch and Lehmann, 2005). In addition, the presence of financial means in the population to purchase goods and services - preferably locally, but possibly also at a further distance - is essential for entrepreneurship to occur at all. The presence of demand thus is an important element of the entrepreneurial ecosystem. Income and purchasing power in a region is both a cause and an effect of entrepreneurship in a region (Berkowitz and DeJong, 2005), hinting at the role of feedback effects in the evolution of entrepreneurial ecosystems. Finally, the supply of support services by various intermediaries can substantially lower entry barriers for new entrepreneurial projects, and reduce the time to market of innovations (see e.g. Clayton et al., 2018; Howells, 2006; Zhang and Li, 2010).

2.2.3. An entrepreneurial ecosystem framework

It is necessary to combine the approaches of economic growth and geography of entrepreneurship to understand the long-term development of economies and the role of entrepreneurship. Entrepreneurship plays a double role: it is the output variable in the geography of entrepreneurship approach, and it is the input variable in the economic growth approach. To complicate matters even more, entrepreneurship and economic growth also affect the inputs of the geography of entrepreneurship approach, for example with serial entrepreneurs becoming venture capitalists and creating networks; and with economic growth leading to growth in demand, investments in knowledge, and congestion effects in the physical environment. One solution to these conceptual complications is to build on complex systems approaches (Arthur, 2013; Hidalgo and Hausmann, 2009; Ostrom, 2010; Simon, 1962) to develop and use a complex systems perspective on the evolution of entrepreneurial economies (Feld and Hathaway, 2020; Roundy et al., 2018; Stam and Van de Ven, 2021). A complex systems perspective is able to integrate the geography of entrepreneurship and economic growth literature. We build on the integrative model of entrepreneurial ecosystems by Stam and Van de Ven (2021), which includes institutional arrangements and resource endowment elements (see Fig. 1). The model consists of three key mechanisms:

interdependence and coevolution of elements, upward causation of the ecosystem on entrepreneurship, and downward causation of entrepreneurial outputs on the quality of the ecosystem (Stam and Van de Ven, 2021).

The empirical literature on the geography of entrepreneurship and economic growth reveals several factors to be relevant in explaining the spatial heterogeneity in entrepreneurship. This suggests that there is a limited set of factors that affects the prevalence of entrepreneurship in a region. The insights from the empirical literature on the geography of entrepreneurship and economic growth can be integrated into one figure (see Fig. 1), reflecting an entrepreneurial ecosystem framework with ten elements (cf. Stam, 2015; Stam and Spigel, 2018; Stam and Van de Ven, 2021). This framework with ten elements provides a compromise between other frameworks with five (Vedula and Kim, 2019), six (Isenberg and Onyemah, 2016), seven (Radosevic and Yoruk, 2013) and 14 elements (Ács et al., 2014). We build on these frameworks and develop them further by separating inputs and outputs of the system, providing an academically grounded set of elements, and using empirical indicators more closely reflecting productive entrepreneurship (Baumol, 1990; Schumpeter, 1934).

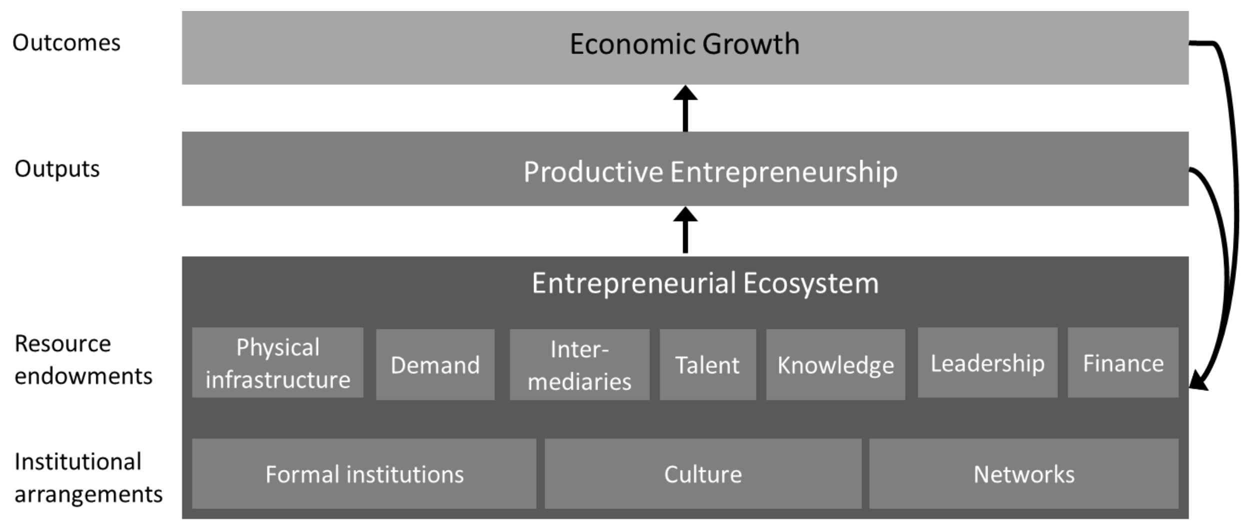

Fig. 1. Elements, outputs and outcomes of an entrepreneurial ecosystem (adapted from Stam, 2015; Stam and Van de Ven, 2021).

2.3. Measuring entrepreneurial ecosystems

The ecosystem framework discussed above identifies ten key elements of an entrepreneurial ecosystem. Based on previous literature (Stam, 2015; Stam and Van de Ven, 2021; Wurth et al., 2021), these ten ecosystem elements should be able to capture the most essential conditions for entrepreneurship to flourish. In this section, we discuss how we source data from a large variety of datasets to compose credible, accurate and especially comparable metrics of entrepreneurial ecosystems. Since there is no perfect dataset available for measuring entrepreneurial ecosystems, we have to compose one, with imperfections that we will discuss. This is also an invitation for follow-up research to improve our metrics when new data becomes available.

Several existing metrics studies on the regional level focus on themes closely related to entrepreneurship, especially in the European Union. For example, the Regional Competitiveness Index (RCI) (Annoni and Dijkstra, 2019) measures the general competitiveness of a region, including factors such as human capital and infrastructure. While the RCI and other studies such as the Regional Innovation Scoreboard (RIS) include several key indicators related to entrepreneurship, none of these explicitly focus on entrepreneurship. Therefore, a study starting from a clearly defined framework and explicitly focusing on productive entrepreneurship provides a novel and valuable contribution to understanding entrepreneurial conditions in a region.

We thus set out to operationalize the entrepreneurial ecosystem elements into measurable variables at the appropriate geographical level. We start by discussing the boundaries of an ecosystem to determine the appropriate level of analysis. Then we shortly illustrate the main data sources and describe the operational measures of each ecosystem element (for an overview, see Table 1).

2.3.1. Level of analysis

The outputs and outcomes of entrepreneurial ecosystems result from a complex set of actors and factors that occur in a temporal and varying regional setting. As Feldman and Lowe (2015, p. 1785) rightly state, there is often a disconnect "between the theoretical definition of a region as integrated contiguous space and the political and census geography for which data are readily available". In addition, since ecosystems are continuously evolving and are not limited to a specific sector, it is hard to precisely determine their boundaries (Stam and Van de Ven, 2021). The primary demarcation criterium should be the spatial reach of the causal mechanisms involved. This does not lead to one straightforward unit or spatial level of analysis.

First, given the multiplicity of causal mechanisms involved in nurturing entrepreneurship, there will be different spatial reaches: for talent, it may be the daily urban system (within a 50-mile radius), while for credit it may be the local bank, and for venture capital a two-hour drive radius (which may overlap with the regional level in large countries, but might be beyond the national level for small countries).

Second, there is a spatial nestedness of contexts: formal institutions at the municipal, regional, national, and supranational level might be important context conditions. These first two considerations make it difficult to delineate the spatial boundary of entrepreneurial ecosystems from a causal mechanism point of view.

From a practitioners' point of view, the stakeholders of entrepreneurial ecosystems, the relevant boundaries will again differ depending on their role in the ecosystem. For civil servants, it will be a particular jurisdiction, while for entrepreneurs it may be a multiplicity of layered (regional, national) or connected ecosystems (different city-regions). To determine the spatial level of analysis (although almost always imperfect), we therefore search for a common spatial denominator in combination with data availability (to allow for comparisons). It should be kept in mind that even though we choose a spatial unit to represent the entrepreneurial ecosystem, entrepreneurial ecosystems are not closed containers but open systems.

In the European context, the most relevant spatial level of analysis is between the municipal and national level, since the spatial reaches of the different elements are most likely to overlap with regional boundaries (e.g., the 50-mile radius for talent). The regional level in Europe is best defined through the NUTS 2 classification, which identifies 281 geographical regions[2] over the 27 member states and the United Kingdom. The boundaries of NUTS 2 regions are based on existing administrative boundaries and population thresholds. The population of a NUTS 2 unit is roughly between 800,000 and 3 million people (European Commission, 2018).

While for some countries and/or indicators, data is available on the more fine-grained NUTS 3 level; this was not the case for most countries or indicators we are interested in. We therefore decide to keep the unit of analysis at NUTS 2 as this would enable us to cover a larger set of regions all over Europe. It is important to include a large set of regions because it enables comparison, which is one of the main goals of this paper. This is the first step, and future studies could dive deeper into certain topics or countries and use more detailed data to do so. By defining entrepreneurial ecosystems at the NUTS 2 level, we use the same region size as the recent study by Stam and Van de Ven (2021) but instead of one country, we include all countries in the European Union and the United Kingdom.

A disadvantage of looking at regions is that data on a regional level is, for most countries, scarcer than national data. However, the European Union performs several large data collection exercises on the regional level to inform regional policy, which results in the availability of a fairly large amount of regional data. Furthermore, we use web scraping to create new metrics at the regional level. Finally, we use several national measures to account for the aforementioned spatial nestedness of, for example, institutions. This combination of data on different geographical levels is discussed in detail for each element below and summarized in Table A1 in the appendix.

2.3.2. Data sources and element construction

To measure the entrepreneurial ecosystem elements, we combine data from various sources and complement this with data obtained by web scraping. For most elements, we use very specific datasets, e.g., for finance we use the regional venture capital data of Invest Europe and for formal institutions the Quality of Government Survey. For other elements, we use specific indicators from existing datasets on related topics, e.g., the accessibility of a region from the Regional Competitiveness Index (RCI) for physical infrastructure or the percentage of innovative SMEs that collaborate from the Regional Innovation Scoreboard (RIS) for networks. The data sources used for each element are described in detail below.

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[2] We remove seven French and Spanish regions that are located in either Africa or South America as there is limited data available for these regions, and we perceive them as significantly different from the European regions.

When operationalizing the ecosystem elements, we aim to get the most robust measure possible with the lowest number of indicators. In doing so, we consider and combine the accuracy – do they accurately capture what we aim to measure? – the credibility – can the sources be confidently relied on? – and the comparability of data sources – is comparable data available for all regions? For accuracy reasons, we choose to measure some elements with multiple indicators, but we sometimes have to resort to one indicator per element for credibility and comparability reasons. In the discussion, we will elaborate on how the operationalization of the elements can be improved in the future.

We choose to measure some elements with multiple indicators for two reasons. First, some elements such as institutions are multi-faceted and hard to capture in one variable. In particular, there is a certain spatial nestedness when studying regional ecosystems. Second, some elements can be measured on a more general level and in a more specific manner for entrepreneurs, such as the workforce's education level and specific entrepreneurial skills. We thus combine variables to capture these various dimensions of one element.

Seven of the ten elements are constructed by combining multiple indicators. For those elements, we calculate the element score by first standardizing the individual measures (mean of 0 and standard deviation of 1). This ensures that the different measures each have a proportionate influence on the composite indicator. We then take the average of the standardized measures.

To measure four of our variables, high-growth firms, unicorns, leadership, and the number of incubators, we use the location of individual organizations to calculate a regional aggregate measure. The methodology of geocoding and region allocation for these measures is as follows. First, we use the nominatim package in R to geocode the given locations using OpenStreetMap (OpenStreetMap, 2019; Rudis, 2019). This is an online map that allows users to pass a list of locations into the software and obtain their coordinates. For the few regions without a match in this procedure, we manually search and add their coordinates. Subsequently, we used Eurostat shapefiles to determine in which NUTS 2 region these coordinates are located. These shapefiles contain an exact overview of the NUTS 2 boundaries (Eurostat, 2019). We then use the rgdal package in R to assign the coordinates to the corresponding NUTS 2 region (Bivand et al., 2019; Eurostat, 2019). With this procedure, we can assign 99.9% of the organizations to a region. We manually searched the remaining organizations and located the remaining geocodes through the browser tool of OpenStreetMap. After this, we were able to assign all organizations for all four variables to a region. For each of the four variables, we then count the number of organizations in each NUTS 2 region and divide this by the region's population to obtain our final measure.

For a few indicators, in some countries, data is only available at the NUTS 1 level. In those cases, we follow the approach of previous measurement studies and impute the NUTS 1 values for the NUTS 2 regions (Annoni and Dijkstra, 2019; Hollanders et al., 2019; Léon et al., 2016). While this is a second-best strategy, we only had to do this imputation for a maximum of five countries for seven (of the 33) indicators. Table A1 clearly describes these cases. Since the number of observations affected is relatively small, we do not expect this to affect our results significantly. Future research efforts to collect data for these indicators at NUTS 2 level would clearly improve our dataset. Table 1 provides an overview of each element's empirical indicators and data source, while Table A1 in the appendix provides a more detailed description for each measure.

Table 1. Operationalization of the indicators of entrepreneurial ecosystem elements and output.

Elements	Description	Empirical indicators	Data source
Formal institutions	The rules of the game in society	Two composite indicators measuring the overall quality of government (consisting of scores for corruption, accountability, and impartiality) and the ease of doing business	Quality of Government Survey (QOG) and the World Bank Doing Business Report
Entrepreneurship culture	The degree to which entrepreneurship is valued in a region	A composite measure capturing the regional entrepreneurial culture, consisting of entrepreneurial motivation, cultural and social norms, importance to be innovative, and trust in others	Global Entrepreneurship Monitor (GEM) and European Social Survey (ESS)
Networks	The connectedness of businesses for new value creation	Percentage of SMEs that engage in innovative collaborations as a percentage of all SMEs in the business population	Regional Innovation Scoreboard (RIS)
Physical Infrastructure	Transportation infrastructure and digital infrastructure	Four components in which the transportation infrastructure is measured as the accessibility by road, accessibility by railway and number of passenger flights and digital infrastructure is measured by the percentage of households with access to internet	Regional Competitiveness Index (RCI)
Finance	The availability of venture capital and access to finance	Two components: The average amount of venture capital per capita and the percentage of SMEs that is credit constrained	Invest Europe and European Investment Bank (EIB)
Leadership	The presence of actors taking a leadership role in the ecosystem	The number of coordinators on H2020 innovation projects per capita	Community Research and Development Information Service (CORDIS)
Talent	The prevalence of individuals with high levels of human capital, both in terms	Four components: The percentage of the population with tertiary education, the percentage of the working population engaged in lifelong learning, the percentage	Eurostat and the Global

	of formal education and skills	of the population with an entrepreneurship education, the percentage of the population with e-skills	Entrepreneurship Monitor (GEM)
New Knowledge	Investments in new knowledge	Intramural R&D expenditure as a percentage of Gross Regional Product	Eurostat
Demand	Potential market demand	Three components: disposable income per capital, potential market size expressed in GRP, potential market size in population. All relative to EU average.	Regional Competitiveness Index (RCI)
Intermediate services	The supply and accessibility of intermediate business services	Two components: the percentage of employment in knowledge-intensive market services and the number of incubators/accelerators per capita	Eurostat and Crunchbase
Output	Entrepreneurial output	The number of Crunchbase firms founded in the past five years per capita	Crunchbase
	Unicorn output	The absolute number of unicorns in the region founded in the last ten years	CB Insights and Dealroom

2.3.3. Formal institutions

Well-functioning institutions are essential for entrepreneurship (Granovetter, 1992). Even when fundamental conditions of the institutional framework, e.g. property rights, are in place, the quality of these institutions affects entrepreneurship (Baumol, 1990; Boudreaux and Nikolaev, 2019; Webb et al., 2019). To operationalize this element, we use a generic and an entrepreneurship specific indicator. These indicators cover two different aspects of the institutional environment, namely the overall quality of government and the regulatory framework for businesses.

To operationalize the quality of government, we use the Quality of Government study (QOG), which is the largest subnational governance study that has been performed (Charron et al., 2019). The Quality of Government study has been used in numerous other studies and is a reliable measure of institutional quality (Charron et al., 2015). The quality of government indicator consists of three components: corruption, accountability, and impartiality. These are each measured by a large regional citizen survey and complemented by the World Governance Indicators on a national level. The survey questions measure both experiences and perceptions of institutions in the particular region of the respondent (Charron et al., 2019). This measure thus accounts for the nestedness of the regional variation in the quality of government within national institutions.

To measure the entrepreneurship specific regulatory framework, we use a composite indicator: the Ease of doing business index from the World Bank, which incorporates seven elements concerning business regulations at the national level (World Bank, 2014). These elements are highly linked to national regulations, and as such, a national measure is sufficient for this indicator. By combining this entrepreneurship specific national measure with the regional measure for the quality of governance, we arrive at a measure capturing a combination of general and entrepreneurship specific institutions.

2.3.4. Entrepreneurship culture

The next element, culture, represents an informal institution. Entrepreneurship culture can be described as how much entrepreneurship is valued and stimulated in a society (Fritsch and Wyrwich, 2014). The cultural context can have a substantial effect on entrepreneurship by influencing the aspirations of entrepreneurs and whether people are likely to become an entrepreneur at all (Wyrwich et al., 2016).

To measure entrepreneurship culture, we use four indicators: entrepreneurial motivation and cultural and social norms encouraging new business activity from the Global Entrepreneurship Monitor (GEM) measured at the country level (Bosma and Kelley, 2019), and the perceived importance of being innovative and creative, and trust in others from the European Social Survey[3] measured at the NUTS 2 level (Norwegian Center for Research Data, 2014)[4]. Again, we combine entrepreneurship specific measures with a more general measure of the regional culture (trust). This general indicator is important because in societies where people trust others it is, for example, easier to have economic interaction and invest in the first place (Zak and Knack, 2001).

2.3.5. Networks

When actors in a region are well connected in networks, this allows information, labor and knowledge to flow to firms that can use it most effectively (Malecki, 1997). Networks are essential for entrants as it helps new firms to build social capital, which firms can leverage to access resources, information and knowledge (Eveleens et al., 2017; Van Rijnsoever, 2020). The connections between firms can be measured through their cooperation projects. Our focus on entrepreneurship entails that we specifically want to measure cooperation on innovative projects. Therefore, we measure networks as the number of Small and Medium Enterprises (SMEs) that collaborate on innovation projects as a percentage of all SMEs in a

[3] Data on these variables is missing for six regions; for these regions we calculated the culture score based on the two indicators for which data was available. We performed robustness checks in which we set the value for these indicators to the European average and in which we removed these regions. Both did not significantly affect our results, proving the robustness of this choice.

[4] Stam and Van de Ven (2021) use the number of new firms per 1,000 inhabitants as an alternative measure of culture. We initially aimed to combine our current indicator with this data. However, there is not (yet) a harmonized dataset on this variable for all European NUTS 2 regions, and we thus had to use a combination of OECD, Eurostat, and national statistics offices to construct this variable (see Table A1). These data sources were not consistent in their definitions and data demarcations. Hence, we deemed the validity of this alternative measure to be questionable, and we excluded this measure from our analyses. We did perform a robustness test in which we combined the birth rate of new firms with our current culture measure. The results of our analyses remained largely identical.

specific region. These SMEs will not all necessarily be entrepreneurial firms, but the focus on innovation projects means this measure captures the kind of productive collaboration that is likely to contribute to entrepreneurial output. We therefore believe that this is the best data currently available. In addition, the size of SMEs (enterprises with between 10 and 250 employees) matches our focus on entrepreneurial growth since it does not include micro firms (less than ten employees) or large firms, both of which are less relevant for our research goal. We use the data from the RIS, complemented with the European Innovation Scoreboard (EIS) for countries with only one NUTS 2 region. The RIS and EIS base their data on the Community Innovation Survey, a large survey on innovation activity including thousands of enterprises in every country in the European Union (Arundel and Smith, 2013).

2.3.6. Physical infrastructure

Physical infrastructure is essential for economic interaction between actors and thus essential for entrepreneurship as well (Audretsch et al., 2015). In this highly digital world, not only physical infrastructure enables this interaction but also digital infrastructure. Digital infrastructure provides the opportunity to meet other actors, even if they are not in close physical proximity. Therefore, it is important to include this when creating an empirical measure of infrastructure. For our indicator, we follow the approach of the RCI, which uses accessibility by road, accessibility by railway and the number of passenger flights to measure the physical (transportation) infrastructure of a region (for details, see Table A1). To this, we add a measure for the digital infrastructure of a region, which is the percentage of households with internet access and also available from the RCI (Annoni and Dijkstra, 2019).

2.3.7. Finance

An important condition for starting a new firm and growing an existing firm is access to capital (see e.g., Kerr and Nanda, 2009; Samila and Sorenson, 2010). We measure the availability of capital with two indicators: the amount of venture capital and the percentage of SMEs that is financially constrained. Again, this is a combination of an entrepreneurship specific and a general measure. It is valuable to add a measure of finance constrained firms because this is not limited to one specific form of finance and thus takes into account that firms may use different financial resources in different countries (Criscuolo and Menon, 2015).

Venture capital is measured as the average amount of venture capital in the last five years per capital. The data for this variable is from Invest Europe, an association of private capital providers which conducts research on private equity activity in Europe (Invest Europe, 2020). The percentage of finance constrained SMEs is taken from the investment survey by the European Investment Bank (Alanya et al., 2019). SMEs are enterprises with less than 250 employees. They are considered financially constrained when they were either rejected for loans or received less than applied for, or were discouraged from applying because it was too expensive or they expected to be turned down. The use of data on SMEs does, similarly to the measure for networks, not fully overlap with our focus on productive entrepreneurship but is again the best data available.

2.3.8. Leadership

Leadership in an entrepreneurial ecosystem is necessary to provide the actors in the ecosystem with a certain direction or vision to work towards and make the ecosystem function more effectively (Normann, 2013). Leadership can be provided by individual leaders but also by collaborative efforts that try to guide the system in a certain direction. Since leadership is an intangible concept, it is quite hard to measure and remains understudied (Sotarauta et al., 2017). Our study operationalizes leadership as the number of project coordinators of Horizon 2020 innovation projects in a region.[5] We thus follow the approach of Stam and Van de Ven (2021), who use the number of innovation project leaders as their operationalization for leadership. Although this measure is not limited to entrepreneurial leaders, it does capture whether organizations in a region are willing to initiate new and innovative projects. These organizations, either public or private, are likely to create collective action in entrepreneurial ecosystems. To construct this variable, we use the CORDIS database, which contains data on 23,693 innovation projects that are subsidized as part of the Horizon 2020 program of the European Union (CORDIS, 2019; European Commission, 2019). We then use the geocoding approach outlined in section 3.3 to create our leadership indicator, the number of innovation leaders per capita.

2.3.9. Talent

Human capital (or talent) encompasses individuals' skills, knowledge and experience (Stam and Van de Ven, 2021). Human capital is a critical input for entrepreneurship and has been shown to be linked to new firm formation (see e.g., Acs and Armington, 2004; Glaeser et al., 2010). It is clearly a broad concept that asks for several empirical measures to cover its different facts adequately. We break human capital down into two different components: general human capital and entrepreneurship specific human capital (Becker, 1964; Rauch and Rijsdijk, 2013). We use two measures for the general human capital component, both from Eurostat (Eurostat, 2020). The first measure is the percentage of the population having completed tertiary education and the second measure is the percentage of the population aged 25-64 that participates in education or training (lifelong learning).

Entrepreneurship specific human capital is directly related to start-up activities (Brüderl et al., 1992; Rauch & Rijsdijk, 2013). We include two measures: the quality of entrepreneurship and business education from the GEM (Bosma and Kelley, 2019), and the percentage of the population with high-level e-skills from Eurostat (Eurostat, 2020). The inclusion of digital skills is important because digital literacy is essential for working in any type of enterprise in the current digital society. In addition, a lot of productive forms of entrepreneurship currently involve some digital aspects.

[5] Horizon 2020 is the research and innovation program funded by the European Commission. It encompasses private-public partnerships working on innovation projects with the aim to stimulate economic growth in the European Union (European Commission, 2019).

2.3.10.Knowledge

The creation of new knowledge by either private or public organizations provides new business opportunities (Kim et al., 2012; Qian et al., 2013). It is therefore an important source of entrepreneurship. We measure this element as the intra-mural R&D expenditure as a share of the total Gross Regional Product (GRP). This measure includes R&D spending in both the public and private sectors. The higher the investment in R&D, the more knowledge is likely to be produced, which can then be translated into business opportunities. The data for this variable is available in both the Regional Competitiveness Index (Annoni and Dijkstra, 2019) and Regional Innovation Scoreboard (Hollanders et al., 2019). We choose to use the data from the RCI as this is available at the NUTS 2 level for a larger number of regions.

2.3.11.Demand

The purchasing power and potential demand for goods and services are important for entrepreneurs since it will only be interesting to market new products if the population has the financial means to buy them. Several studies have shown that market growth increases firm entry (Eckhardt and Shane, 2003; Sato et al., 2012). Even though most firms nowadays serve larger markets than just those in their own region, it is important for start-ups to have a potential regional market which they can easily access (Cortright, 2002; Reynolds et al., 1994; Schutjens and Stam, 2003). We measure the demand using data from the RCI, which combines three measures (Annoni and Dijkstra, 2019). The measures are disposable income per capita, potential market size expressed in GRP, and potential market size expressed in population. This measure captures both consumer demand and demand from existing businesses in the region.

2.3.12.Intermediate services

Intermediate services or producer services can help producers to start a new enterprise and market an innovation. This support can substantially lower entry barriers for new entrepreneurial projects and speed up the introduction of innovations (Howells, 2006; Zhang and Li, 2010). For this element, we again combine a general and an entrepreneurship specific measure. We operationalize the general measure as employment in knowledge-intensive market services representing the general availability of intermediate services, such as legal, marketing, accountancy, and consultancy services. The required data is available in Eurostat (Eurostat, 2020).

For the entrepreneurship specific measure, we look at incubators and accelerators as intermediate service providers. These organizations specifically aim to help people with innovative ideas to start their own companies. Incubators and accelerators typically provide various services such as access to networks of entrepreneurs and training in business skills (Cohen et al., 2019; Eveleens et al., 2017; Van Weele et al., 2017). Several studies have shown that incubators and accelerators can significantly contribute to the success of start-ups (see Ayatse et al. (2017) and Eveleens et al. (2017)). Since these organizations are put in place to support entrepreneurs and can improve the performance of new firms, it is important to include them in the analysis. For this variable we scraped a total of 950 incubators and accelerators from the Crunchbase website (Crunchbase, 2019). We then use the geocoding approach outlined in section 3.3 to determine the number of incubators per capita in a specific region. Note that we measure the prevalence of intermediate services in general and incubators and accelerators in particular, but not the quality of these services per se.

2.3.13. Entrepreneurial Ecosystem Index

To determine the quality of entrepreneurial ecosystems, we explore the option of combining the measures of the ten elements of the entrepreneurial ecosystem to calculate an index. The calculation is done using the same method applied in Stam and Van de Ven (2021). This approach relies on the crucial assumption that all ten elements are of equal importance in the ecosystem as we standardize the value for the different elements. This is clearly a very agnostic approach since one could think of reasons why certain elements should be given more weight than others. Some studies have investigated this and found that certain factors matter more than others (see e.g. Corrente et al. (2019)). However, these studies used other elements and data, and it is therefore not possible to directly transfer these weights to our data. We are aware that the index we create in this manner will not be a final solution. Instead, we present it here as a first step to determine the quality of entrepreneurial ecosystems using the metrics we have developed in the previous sections. We also perform a principal components analysis in the next section, which does not rely on the assumption that all components are equally important, as an alternative method of combining the elements. Subsequently, we also perform a series of robustness checks on the index. Finally, we present a future research agenda on ways to further improve the measurement of the quality of entrepreneurial ecosystems that includes weighting the different elements.

To calculate the index, we first standardize the composite indicators which we have created for each element. This ensures that all elements get similar weights in the creation of the index. Subsequently, to normalize the standardized values, we take the inverse natural log of the standardized values. This is necessary because normalizing requires division by the mean, which is 0 after standardization. We then normalize the element values by setting the European average of each element to 1 and by letting all other regional values deviate from this. If an element in a region performs less than average, this results in a value between 0 and 1; above-average performing regions have a value above 1. This allows us to compute an index value based on the ten elements and compare the quality of different entrepreneurial ecosystems. We calculate the Entrepreneurial Ecosystem Index in three ways. First, in an additive way (E1 + E2 +…+E10) where regions with an average value on each element will thus score an index value of 10. Second, to better account for the systemic nature of the entrepreneurial ecosystem, we also calculate the index in a multiplicative manner (E1*E2*…*E10). The disadvantage of the normalization around 1 in both these indices is that values above 1 have a stronger effect on the index than below-average values, which are between 0 and 1. We therefore take the natural logarithm to let the values oscillate symmetrically around 0; this logarithmic way (log(E1) + log(E2) +….+log(E10)) is our third index value.

2.3.14. Output

The output of the entrepreneurial ecosystem is productive entrepreneurship (see Fig. 1). This kind of entrepreneurship contributes to the economy's output and consequently leads to aggregate value creation, which is the outcome of the system (Baumol, 1990). Previous research has shown that proxies of productive entrepreneurship have strong positive effects on economic growth and job creation

(Criscuolo et al., 2014; Haltiwanger et al., 2013; Stam et al., 2011; Wong et al., 2005). Productive entrepreneurship is a subset of total entrepreneurship and thus requires another measure than, for example, the total number of new firms.

In this study, we take the number of new firms (i.e. founded less than five years ago) that are registered in Crunchbase as our measure for entrepreneurial output (Crunchbase, 2019; Dalle et al., 2017). Crunchbase predominantly captures venture capital oriented innovative entrepreneurial firms and largely ignores companies without a growth ambition and is thus a good source for data on productive entrepreneurship (Dalle et al., 2017). We choose the five-year timeframe to ensure that we select firms that experience their growth phase during the same time period (2015-2019) as most of our indicators are measured (see Table A1). This time period also helps to limit our sample towards innovative new firms as Crunchbase also includes incumbent, long-established, innovative firms. Our sample includes 31,236 innovative new firms. The data on Crunchbase mostly comes from two channels, a community of contributors and an extensive investor network. This data is then validated with other data sources using AI and machine-learning algorithms.

A limitation of the Crunchbase dataset is that it is uncertain if the coverage of start-ups is equal among the different countries. Overall, we find that around 0.2% of all new European firms are registered in Crunchbase.[6] This varies between 0.003% and 1.5% and follows a (zero-inflated) normal distribution.[7] We further acknowledge that not all start-ups are innovative (cf. Autio et al., 2014), and are also aware that our measure of entrepreneurial output does not capture all innovative activity in the economy. Nevertheless, Crunchbase is currently the most comprehensive dataset available to measure innovative new firms as entrepreneurial output (Dalle et al., 2017). Crunchbase is increasingly used for academic research (Dalle et al., 2017; Nylund and Cohen, 2017). We also explored using the ORBIS data of Bureau Van Dijk as an alternative (Bureau van Dijk, 2020; Dalle et al., 2017). However, we perceived this data to be inadequate for our purposes. First, the serial correlation between the different years in the database was very low. Second, the data also contained disproportionally large differences between countries, which were hard to render and would thus impede cross country regional comparisons. We did perform a robustness test on our measure of entrepreneurial output using data provided by Dealroom (2021). Similarly to Crunchbase, Dealroom provides data on start-ups.[8] The correlation between the Crunchbase and Dealroom output measures was 0.841, and regressions using the Dealroom data resulted in nearly identical results (Appendix B4).

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[6] The data sources for the number of new firms in each country are outlined in Table A1.

[7] However, one specific region (UKI3 – Inner London West) has an extreme value of 11,3%. This extreme value is also reflected in our Crunchbase output measure. Further research showed that this was partly the result of all central London based start-ups being assigned to UKI3 instead of to both UKI3 and UKI4 (UKI4 – Inner London East) due to these regions having the same name in Crunchbase. We therefore decided to combine these regions to form one Inner London region. Nevertheless, this region remained an extreme value and to achieve a normal distribution for the regression analyses, we performed a Tukey transformation ($\lambda = 0.2$) on this variable. In the next section, we discuss the remaining transformations in our data preparations.

[8] We obtained data from Dealroom on 31,761 start-ups founded between 2016 and 2020.

In addition to the Crunchbase output measure, we use a measure for extreme entrepreneurial output in the form of unicorns, which are young private firms valued above $1 billion. Data was collected from CB Insights which keeps a list of current unicorn companies all over the world (CB Insights, 2020). As these firms are so rare, all (49) firms founded in the last ten years that acquired unicorn status were included. This was done by scraping data from historical web pages of the internet archive and cross-checking this with Dealroom data (Dealroom, 2020).[9] We then used the geocoding procedure to allocate these 49 unicorns to a total of 20 NUTS 2 regions. As such, unicorns are a scarce and selective form of productive entrepreneurship that is only present in a small number of regions. Besides unicorns being a scarce type of organization, the value of unicorns as a measure of productive entrepreneurship has also been a topic of discussion (see for example, Aldrich and Ruef, 2018; Economist, 2019), which is why we only use this as an additional output measure.

2.3.15. Extreme values

Since the European Union covers a large and diverse set of regions, the data show a lot of variety. In particular, for the measures of knowledge, intermediate services, leadership, and entrepreneurial output there are a few regions with very high values (up to 14 times the standard deviation). Even though this variation is plausible, these outliers do disproportionally influence the correlation results and regression results. Most importantly, for the regions that score extremely high on one particular indicator, the index for the quality of the entrepreneurial ecosystem is disproportionally influenced by that indicator. This does not reflect the systemic nature of entrepreneurial ecosystems as argued in the existing academic literature (Spigel, 2017; Stam, 2015). Therefore, we performed two transformations on the data to provide better interpretable results. First, before the standardization of the composite indicators, we cap the maximum value at four standard deviations of the mean (for more information on the standardization procedure, see section 3.14 on index calculation).[10] In practice, this means that we change the values for UKI3&4 (Inner London) of the Crunchbase output, leadership, and intermediate services measures, for DE91 (Braunschweig) of knowledge (as a result of the high R&D intensity), and DK01 (Hovedstaden) of leadership. Without these transformations, the high deviations of these values skew the outcomes of the normalization process in such a way that only a few regions achieve above-average scores.

Second, we set the maximum score for any single element to five to prevent a disproportionate influence of strong performing ecosystem elements on the overall index. We perform several robustness checks on the construction of our index, which we discuss in appendix C.

[9] We used Dealroom data for the unicorn variable because Dealroom keeps a list of all European unicorns.

[10] We performed a robustness test in which we implemented a cap at three standard deviations; this required capping a total of twelve regional values but did not significantly change our findings.

2.4. Quantifying and qualifying entrepreneurial ecosystems in Europe

2.4.1. Descriptive statistics

The descriptive statistics of the empirical measures for the ten ecosystem elements, entrepreneurial outputs, and index scores are shown in Table 2. In total, our data covers 273 NUTS 2 regions divided over the 27 EU member states and the United Kingdom.

We see a large variation for several variables, from regions with less than 2 percent of the EU average to regions with over 56 times the average value. These findings are nevertheless in line with our expectations since we study regions across different countries and levels of development. Looking at the three index values that we calculated using the methods of Stam and Van de Ven (2021), we find that the difference between the smallest and largest value for the multiplicative index is a factor 10^{15}. This difference is disproportionately large compared to the actual variation in the data, as a result of the multiplicative way of calculating the index. Hence, we deem the external validity of the multiplicative index to be insufficient and instead use the additive and the logarithmic indices in our further analyses. Throughout the remainder of this study, we primarily focus on the additive index due to the intuitiveness of its interpretation.

2.4.1. Interdependence between entrepreneurial ecosystem elements

Table 3 shows the correlations between the different elements of the entrepreneurial ecosystem, the index, and the outputs. We see high, positive, and significant correlations between all of the elements of the ecosystem.[11] The strong positive correlations illustrate the interdependencies in the entrepreneurial ecosystem. This corresponds to the results shown in Stam and Van de Ven (2021) and confirms the systemic nature of entrepreneurial ecosystems. Considering the entrepreneurial output measures, we see positive and significant correlations with all elements, and with the entrepreneurial ecosystem indices we constructed.

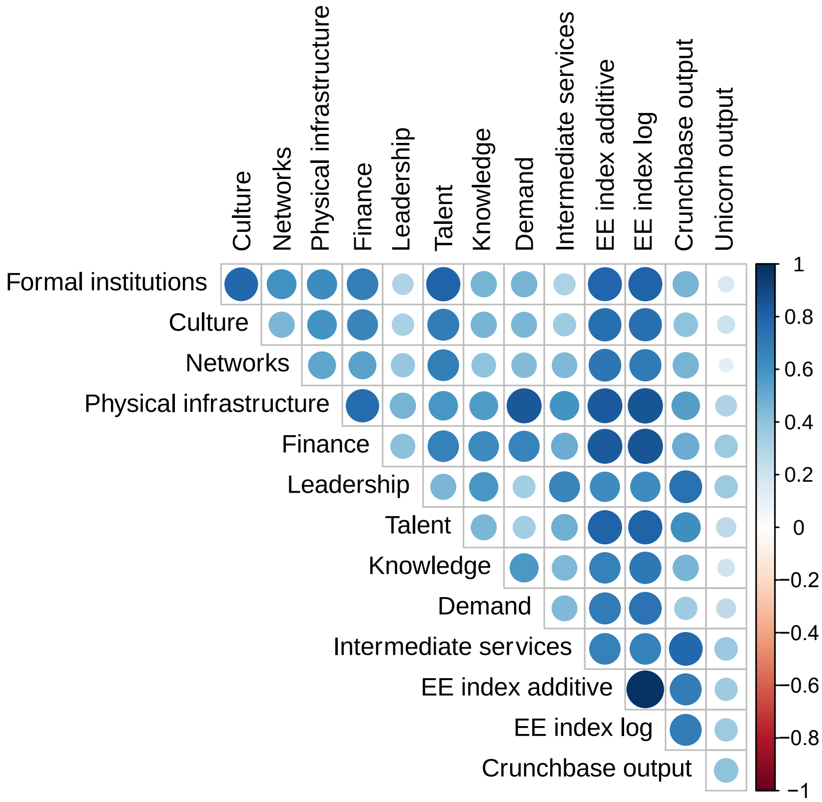
[11] For an overview of the numeric correlation coefficients with p-values see Table B1.

Table 2. Descriptive statistics of entrepreneurial ecosystems

	N	Mean	Standard Deviation	Minimum	Maximum
Crunchbase output	273	0.852	1.018	0.014	5.000 (31.958)
Unicorn output	273	0.179	1.051	0.000	15.000
Formal institutions	273	1.000	0.812	0.098	3.497
Culture	273	0.990	1.072	0.026	5.000 (6.219)
Networks	272	0.984	1.147	0.117	5.000 (6.110)
Physical infrastructure	272	0.907	1.060	0.058	5.000 (8.916)
Finance	273	0.993	0.823	0.053	5.000 (6.907)
Leadership	273	0.703	1.111	0.181	5.000 (25.751)
Talent	273	0.968	0.964	0.072	5.000 (11.913)
Knowledge	273	0.722	1.031	0.109	5.000 (33.503)
Demand	273	1.000	0.932	0.032	4.761
Intermediate services	273	0.697	1.014	0.082	5.000 (56.011)
EE index additive	272	8.934	6.462	1.262	35.081
EE index multiplicative	272	323.444	2778.293	0.000	39364.109
EE index logarithmic	272	-6.061	7.157	-21.962	10.581

Notes: The uncorrected maximum value of each element is presented between brackets. We do not have data for all elements for Aland, a small island region of Finland, so the total number of regions for which we calculate the index is 272.

Table 3. Correlation matrix of entrepreneurial ecosystems. Correlation coefficient is indicated by color and the significance level by size, only correlations that are significant at 5% level are shown.



We use a network methodology to show the interdependencies between the ten elements in Fig. 2. Physical infrastructure and finance take the most central position in the interdependence web. This central role is supported by the finding that physical infrastructure and finance have respectively eight and six interdependencies with a correlation above 0.5 (Fig. 3), followed by formal institutions and talent that each have five. When looking at the interdependencies with correlations above 0.6, formal institutions and finance are the most central in the interdependence web, with each of the five correlations above 0.6 (Fig. 3). Physical infrastructure, culture, and talent also have central positions with four correlations above 0.6. Finally, formal institutions and physical infrastructure each have two interdependencies with correlations above 0.7 (see also table B1). This provides an indication for a potential role of these elements as fundamental conditions of the entrepreneurial ecosystem.

To further explore the interdependencies, we performed principal component analysis (PCA) on the ten individual elements. This method does not assume that all elements are equally important as the elements are assigned different loadings. The results are presented in Table 4; the first component explains 44.9% of the variance and has loadings of 0.21 or higher for all components. The four elements with the highest loadings are finance (0.40), physical infrastructure (0.38), talent (0.36), and formal institutions (0.35). This result confirms our findings from the interdependence graphs, which show a strongly connected set of elements with a central role for the elements of finance, physical infrastructure, talent, and formal institutions. The second component, which explains an additional 12.8% of the variation, has loadings of

0.21 or higher for six components. Similarly, the third component explains 12.4% of the variation and here six elements have loadings above 0.24. The results of the PCA thus confirm the strong interdependencies between the entrepreneurial ecosystem elements. The high loadings of all elements also show that all elements are related to the underlying dimensions of the data and are thus likely to be relevant to the entrepreneurial ecosystem.

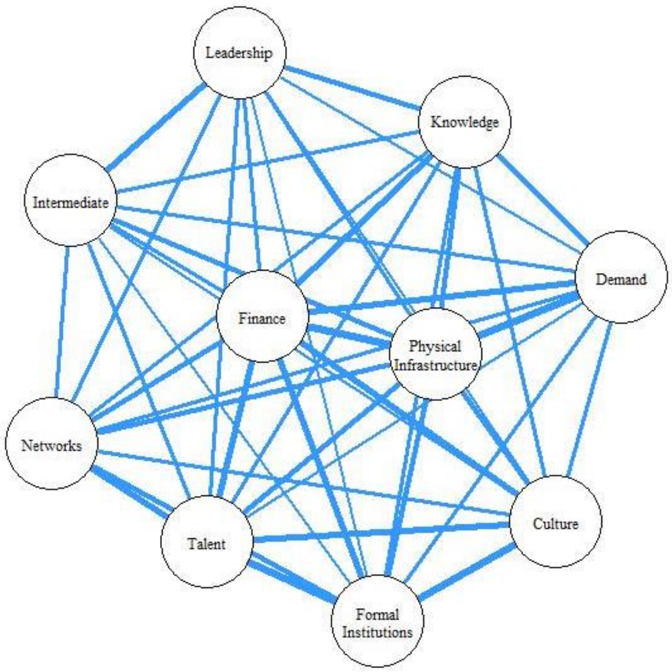


Fig. 2. Interdependence web of entrepreneurial ecosystem elements with the blue lines indicating positive correlations. The edge weight is defined based on the correlation strength.

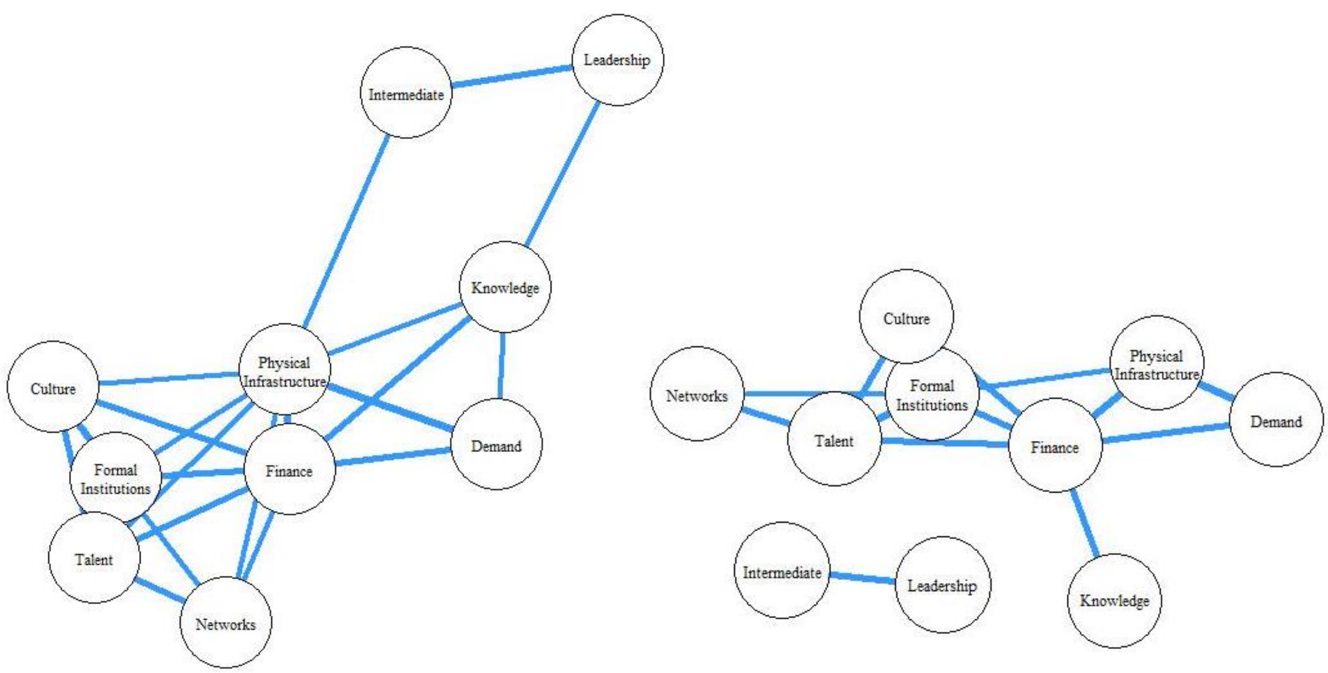


Fig. 3. Interdependence webs of entrepreneurial ecosystem elements with correlations above 0.5 (left) and 0.6 (right)

Table 4. Principal components analysis of entrepreneurial ecosystems

	PC1	PC2	PC3
Proportion of Variance	0.449	0.128	0.124
Standard Deviation	2.119	1.132	1.113
Cumulative Variance	0.449	0.577	0.701
Formal institutions	0.348	-0.476	0.161
Culture	0.308	-0.164	0.437
Networks	0.212	-0.393	-0.367
Physical infrastructure	0.379	0.041	-0.381
Finance	0.397	0.133	-0.041
Leadership	0.249	0.478	0.154
Talent	0.356	-0.256	0.357
Knowledge	0.222	0.207	0.240
Demand	0.334	0.039	-0.541
Intermediate	0.297	0.484	0.032

2.4.2. *Entrepreneurial Ecosystem Index*

We now use the Entrepreneurial Ecosystem Index to determine the strongest and weakest entrepreneurial ecosystems in Europe. The scores for the ten highest (Fig. 4) and lowest ranking (Fig. 5) regions are shown in the bar graphs below. In chapter 2.4.5 we will zoom in on the seven regions in which the IRIS cities are located. The highest scoring regions are, as expected, mainly Western European and densely populated, while the lowest scoring regions are mainly Bulgarian and Greek rural regions. To look at the different entrepreneurial ecosystems in more detail, Fig. 6 shows the map of Europe with all NUTS 2 regions colored based on the value of the Entrepreneurial Ecosystem Index. The highest index values can be found in European capital regions, including London, Helsinki, and Stockholm. Many regions in Eastern Europe show very low index values, as do some of the more rural areas in Spain. The map also shows that there is a substantial difference between urban and rural areas. Most of the high-scoring regions include large cities. In section 4.6, we will compare our index to existing variables and rankings (including GDP and the RCI) to discuss the added value of the Entrepreneurial Ecosystem Index.

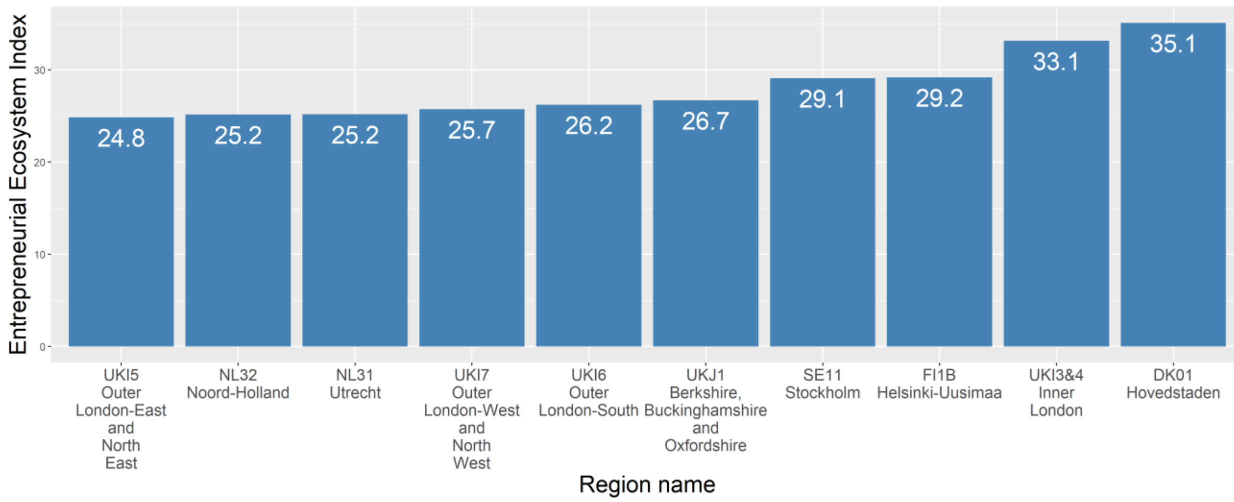


Fig. 4. NUTS 2 regions with the highest Entrepreneurial Ecosystem Index scores.

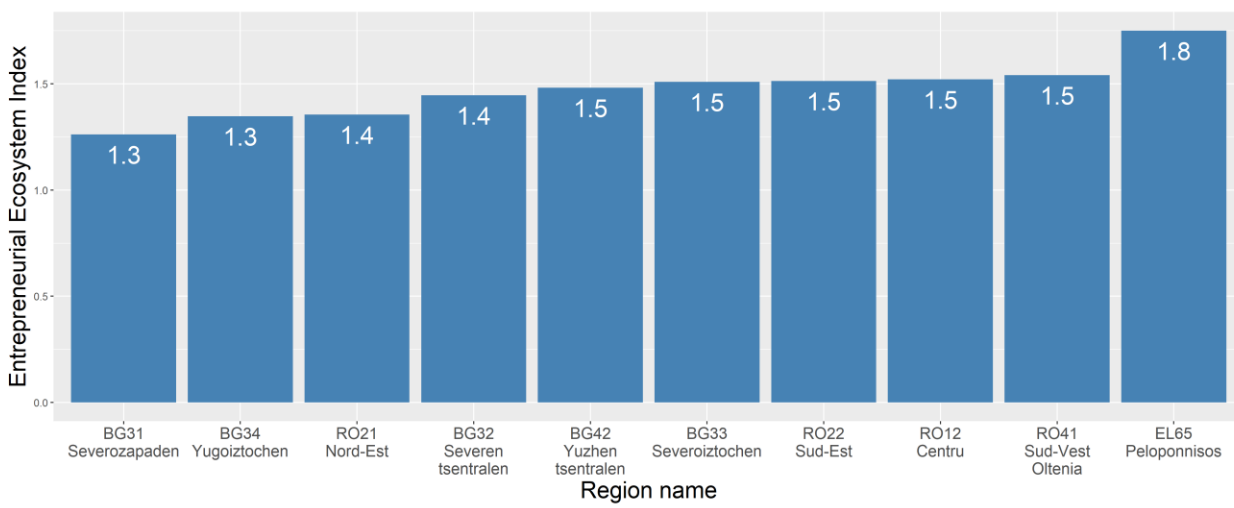


Fig. 5. NUTS 2 regions with the lowest Entrepreneurial Ecosystem Index scores.

The Entrepreneurial Ecosystem Index adds the different elements and subsequently creates a ranking based on the total value of the ten elements. A different approach to classify regions is to use cluster analysis on the ten ecosystem elements, which creates groups of regions closest to each other on the scores for each element. Particularly, we use k-means clustering, which minimizes the total intra-cluster variation (sum of squared errors) using Euclidean distance measures for an a priori fixed number of clusters (Tan et al., 2018). K-means clustering is the most popular clustering technique and was originally proposed by MacQueen (1967). The number of clusters is a parameter that has to be set by the researcher. After considering the total intra-cluster variation, the average silhouette of clusters, the gap statistic, and the interpretability of the outcomes, we selected the approach with three clusters. The results (Table 5) show a sizeable first cluster that includes low-performing regions, including for example Athens, Budapest, and Sicily. The second cluster forms a middle group and includes Manchester, Cologne, and Luxembourg. Finally, the third cluster is the smallest group with high performing regions, including Berlin, London, and Brussels. Table 5 shows a clear pattern in the average index values of the regions across the clusters. This is further confirmed through the visual representation of the clusters, which shows that the cluster distribution closely aligns with the scores of the Entrepreneurial Ecosystem Index (Fig. B1 in the appendix). Using clustering as an alternative method to classify regions, we thus find highly similar results to the index.

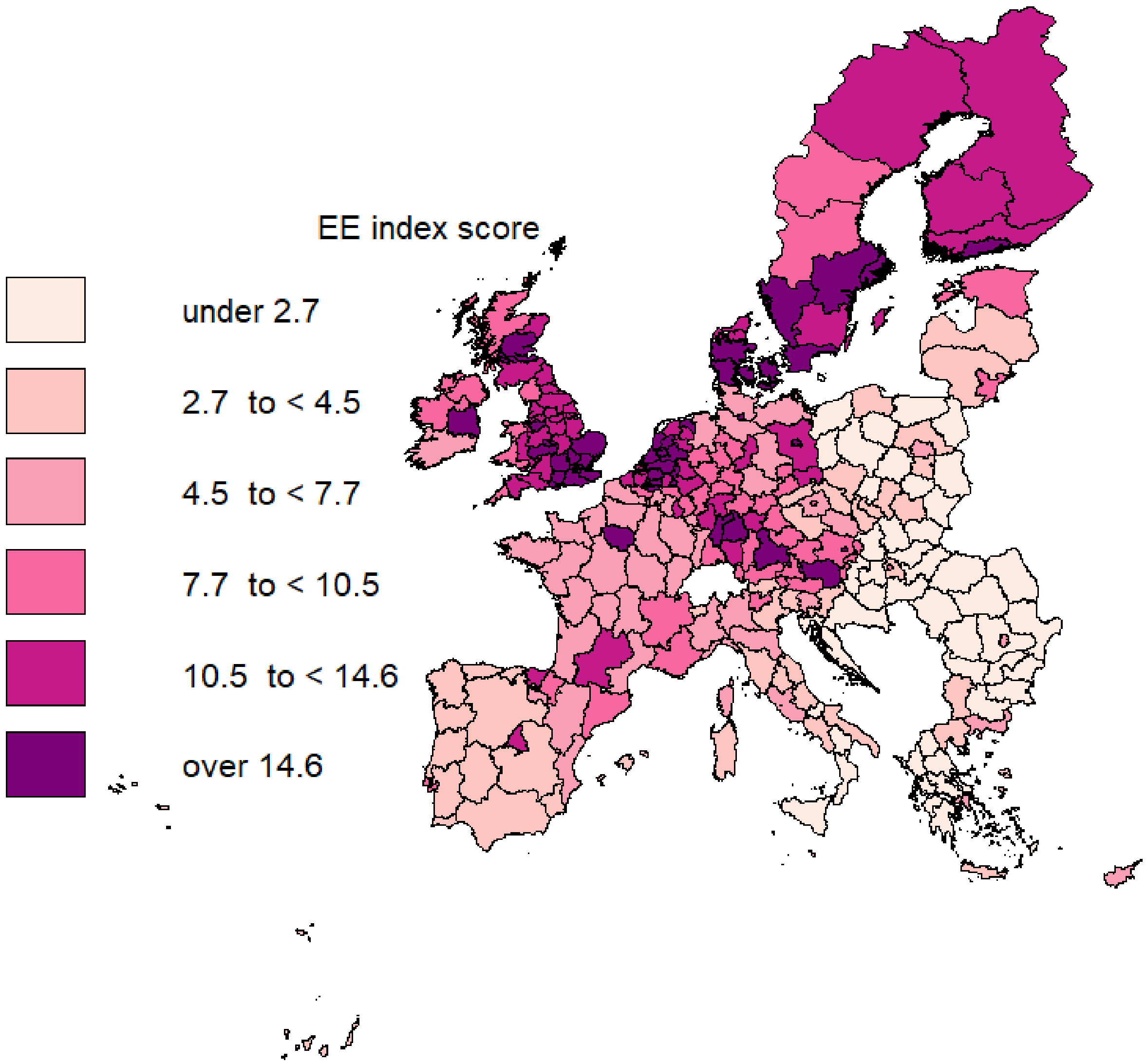


Fig 6. Map of NUTS 2 regions showing Entrepreneurial Ecosystem Index (273 regions are divided among groups of equal size). The scores of the IRIS regions are covered in chapter 2.4.15.

Table 5. Summary statistics of entrepreneurial ecosystem index and output by cluster

	Cluster 1 (N=148)	Cluster 2 (N=95)	Cluster 3 (N=29)	Overall (N=272)
Crunchbase output				
Mean (SD)	0.575 (0.767)	0.777 (0.554)	2.51 (1.64)	0.852 (1.02)
Median [Min, Max]	0.337 [0.0143, 5.00]	0.685 [0.178, 4.47]	2.18 [0.288, 5.00]	0.466 [0.0143, 5.00]
EE index additive				
Mean (SD)	4.34 (2.25)	12.0 (2.62)	22.3 (5.13)	8.93 (6.46)
Median [Min, Max]	3.58 [1.26, 11.4]	11.8 [7.58, 19.1]	21.4 [14.4, 35.1]	7.66 [1.26, 35.1]
EE index log				
Mean (SD)	-11.3 (4.75)	-1.39 (2.34)	5.32 (2.52)	-6.06 (7.16)
Median [Min, Max]	-11.5 [-22.0, -1.56]	-1.52 [-6.34, 3.51]	5.09 [0.970, 10.6]	-5.29 [-22.0, 10.6]
Unicorn output				
Mean (SD)	0.0203 (0.183)	0.0316 (0.176)	1.48 (2.91)	0.180 (1.05)
Median [Min, Max]	0 [0, 2.00]	0 [0,1.00]	0 [0, 15.0]	0 [0, 15.0]

2.4.3. Entrepreneurial Ecosystem Index and entrepreneurial output

After discussing the creation and reliability of the Entrepreneurial Ecosystem Index, we now use regression analysis to study if regions with better ecosystems indeed have higher entrepreneurial outputs. Table 5 shows that the regions in the third cluster with a high Entrepreneurial Ecosystem Index score have significantly higher outputs than the middle and laggard clusters. This indicates that the relation between the index and entrepreneurial output is not linear. A scatter plot of the Entrepreneurial Ecosystem Index and Crunchbase output confirms this suggestion (Fig. 7).

An increase in performance on the index thus goes together with a disproportionately large increase in the number of Crunchbase firms. To capture this nonlinearity in the relation between the quality of an entrepreneurial ecosystem and its entrepreneurial outputs, we performed a regression with quadratic effects; for the results, see table B2 in the appendix. The quadratic effects are significant ($p<0.001$) and show that the relation between the index and the entrepreneurial output is indeed nonlinear. However, the convex relationship between the index and output means that adding quadratic effects forces a quadratic curve on the observations that looks like a U-shape. This is an unintended side effect of using quadratic effects in linear regression.[12]

Therefore, to better capture the nonlinear relationship between the index and output, we instead perform a piecewise linear regression. This allows breakpoints in the regression line that is fitted to the data. The results are presented in Fig.7 and Table 6. The breakpoint that optimizes model fit for the additive index is located at an index score of 19.[13] At this point, the slope quite sharply increases from 0.08 to 0.39. For both the first and the second line, we find a positive and statistically significant relationship between the index and entrepreneurial output ($p<0.01$). The large increase in the slope of the regression line further shows there is a small group of regions with very high performance regarding entrepreneurial output at the high end of the index. This corresponds with our findings in the cluster analysis presented above. The results of the regression analyses with the unicorn output as a dependent variable are consistent with the findings reported in Table 6 and are presented in Table B4 in the appendix[14].

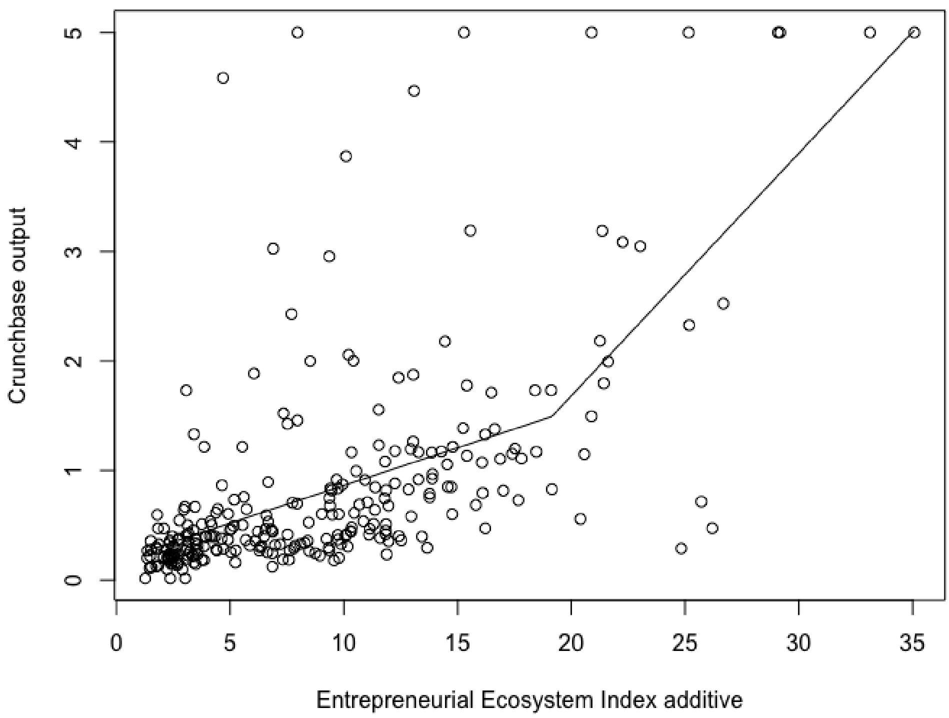


Fig. 7. Scatter plot with the line showing the fitted values of the piecewise linear regression

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[12] We use the two lines test of Simonsohn (2018) to confirm that there is indeed no U-shape relationship between the index and output.
[13] We get a very similar result when we allow for a structural break in the line. The primary method shown assumes a continuous relationship and uses the R package *'segmented'* (Muggeo, 2008).
[14] We only report these findings in the appendix because of the limited number of regions with unicorn observations (20 out of 272).

The scatter plot (Fig. 7) shows that several regions do not seem to fit the plotted line, even with the piecewise linear regression. Particularly, we see some regions with very high entrepreneurial output and low index values. The regions in the upper left corner of the plot are, for example, Malta and Luxembourg, known for very favorable tax regulations, which previous studies have demonstrated to increase high growth entrepreneurship (Guzman and Stern, 2015). On the other hand, regions with high index values but relatively low entrepreneurial output are, for example, several outer London regions.[15] These are all regions with good conditions for entrepreneurship but located very close to even more 'vibrant' entrepreneurial areas, which attract a disproportionate share of innovative new firms (e.g., Inner London).

Table 6. Piecewise linear regression

	Crunchbase output	
	(1)	(2)
EE index additive	0.081***	
	(0.014)	
Difference slope EE index additive	0.315** (0.146)	
EE index logarithmic		0.047***
		(0.009)
Difference slope EE index logarithmic		0.475*** (0.088)
Constant	0.103	1.034***
	(0.120)	(0.129)
Observations	272	272
R^2	0.422	0.431
Adjusted R^2	0.415	0.425
F Statistic	65.213***(df=3;268)	67.697***(df=3;268)

*Notes: Clustered standard errors at country level in parentheses. * p<0.05 ** p<0.01 *** p<0.001*

Since we compare regions in different countries, it is important to check whether the index not just captures differences between countries but also has explanatory power within countries. We therefore run a multilevel analysis with country-specific intercepts and our Entrepreneurial Ecosystem Index. The results of the multilevel analysis are presented in Table 7. The index variables still show a statistically significant and positive relationship with the entrepreneurial output (p<0.001). Adding country-specific

[15] For some regions, this also has to do with the fact that the data for some indicators is measured at the NUTS 1 level, as described in Table A1.

intercepts improves the model, as evidenced by an increased R^2 as well as the likelihood ratio tests. The random effects at the bottom of the table show the regional variation (σ^2) and the variation between countries (τ_{00}). Our index's strong coefficient and statistical significance when we compare regions within countries shows the index's robustness. In addition, the high regional variation supports our choice to focus on the regional level when studying entrepreneurial ecosystems.

Table 7. Multilevel analysis of entrepreneurial ecosystems

	Crunchbase output	
	(1)	(2)
EE index additive	0.149 ***	
	(0.008)	
EE index logarithmic		0.168 ***
		(0.010)
Constant	-0.285 *	2.202 ***
	(0.144)	(0.203)
Random Effects		
σ^2	0.32	0.34
τ_{00}	0.32 $_{country}$	0.76 $_{country}$
ICC	0.50	0.69
N	23 $_{country}$	23 $_{country}$
Observations	267	267
Marginal R^2	0.594	0.570
Conditional R^2	0.798	0.868

*Notes: This regression excludes countries that exist of only a single NUTS 2 region, which are Luxembourg, Malta, Estonia, Cyprus, and Latvia. Standard errors in parentheses. * p<0.05; ** p<0.01; *** p<0.001*

Finally, to test the robustness of our index, we perform seven robustness checks to study its sensitivity to different calculation methods and extreme values. These robustness tests include the use of the principal components instead of the index as independent variables, as well as different ways of calculating the index. A description of the robustness checks and their results are presented in appendix C. The findings prove that our index is robust.

2.4.4. Comparison with existing indices

In the previous sections, we showed that the Entrepreneurial Ecosystem Index proved to be a good predictor of productive entrepreneurship. However, the question remains whether the Entrepreneurial Ecosystem Index also outperforms existing rankings on similar phenomena. Therefore, we compare the Entrepreneurial Ecosystem Index with two existing indices, first the Regional Competitiveness Index (RCI), which measures the competitiveness of a region, and second the Regional Innovation Scoreboard (RIS), which measures the innovative ability of a region. Furthermore, we also include the GRP per capita as an alternative measure of economic development. The results (Table 8) show that, as expected, there are strong correlations between our index and the RCI (0.92), the RIS (0.90) and GRP (0.77). However, our index clearly has a higher correlation with both entrepreneurial output measures than any of the alternatives. This shows that there is added value in developing theory-based metrics to measure the quality of regional entrepreneurial ecosystems and that our measure captures dimensions of the ecosystem which go beyond the level of economic development of a region. An example of this is Estonia (EE00), a low GDP region with very high entrepreneurial output due to a well-performing entrepreneurial ecosystem. The Entrepreneurial Ecosystem Index captures the quality of this entrepreneurial economy better than GRP measures or other indices do.

Table 8. Correlation table indices and outcomes

	EE index add	EE index log	RCI 2019	RIS 2019	GRP per capita	Crunchbase output
EE index log	0.985****					
RCI 2019	0.919****	0.941****				
RIS 2019	0.900****	0.903****	0.885****			
GRP per capita	0.771****	0.780****	0.820****	0.724****		
Crunchbase output	0.696****	0.695****	0.573****	0.588****	0.585****	
Unicorn output	0.351****	0.362****	0.300****	0.286****	0.281****	0.400****

Note: *p<0.05; **p<0.01; ***p<0.001; ****p<0.0001

2.4.5. IRIS cities

In the previous sections we developed and present a tool that outlines the state of the EE in 274 European regions. This allows cities and regions to compare the local conditions for the development and implementation of new business models and what factors are barriers to such business model development. In this chapter we purposely use the EE instead of the TIS framework because it is better suited for this purpose because of the increased focus on entrepreneurship. We also purposely go beyond just the IRIS cities to enable the IRIS cities to learn from other cities and regions and to get a benchmark for how they are performing. This tool thus allows us to compare the LHs and FCs of the IRIS project. It is important to note that this analysis is performed at the NUTS-2 regional level and thus also encompasses the region in which the IRIS city is embedded. The quality of the EEs in the IRIS-regions is shown in Fig. 8 and shows that Utrecht (NL31 – Utrecht) is the clear top performer followed by Gothenburg (SE23 – Västverige), Vaasa (FI19 – Länsi-Suomi), Nice (FRL0 – Provence-Alpes-Côte d'Azur), Alexandroupolis (EL51 Anatoliki Makedonia, Thraki), Tenerife (ES70 – Canarias), and Focsani (RO22 – Sud-Est). Utrecht performs exceptionally well as it is also in the top 10 European regions (see Fig. 4). Focsani on the other hand scores is among the 10 regions with the lowest score for its EE (see Fig. 5). Of particular interest is also that FC Vaasa has a stronger performing EE than LH Nice.

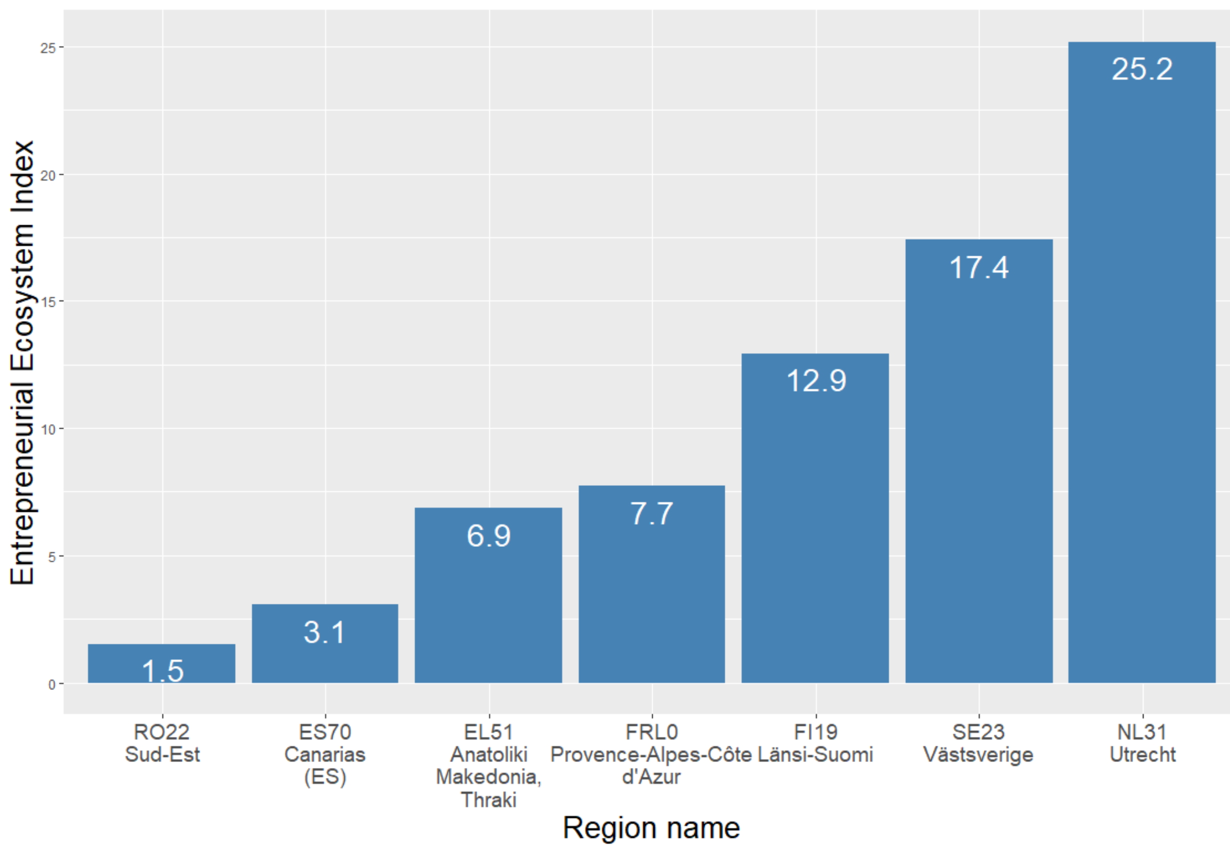

Fig. 8. Quality of the entrepreneurial ecosystems that are part of the IRIS project.

When zooming in in the actual entrepreneurial activities in the IRIS cities we get a similar overview. We find that Utrecht and Gothenburg do not only have the strongest EE, they also have the highest amount of entrepreneurial activity (Fig. 9.). Entrepreneurial activity here represents the number of start-ups/10,000 inhabitants in a given region, with a start-up being defined as a company founded in the last 5 years of the data that is listed in the Crunchbase dataset (see chapter 2.3.14 for more detail). Next, we see that Nice does outperform Vaasa regarding the amount of entrepreneurial activity. This is partly a function of the region being larger, but does correspond better with the LH, FC distinction in the initial IRIS application.

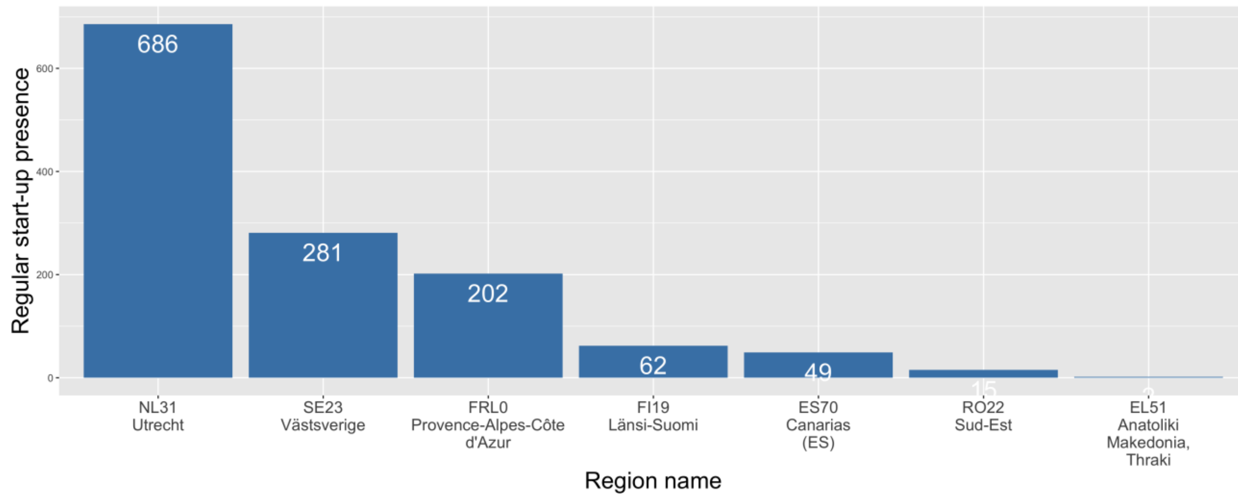

Fig. 9. Number of regular start-ups founded in IRIS regions from 2017-2021

Table 9 provides an overview of the scores for the ten elements that represent the quality of the entrepreneurial ecosystem in the IRIS cities, the cumulative EE index (additive) and the alternative logarithmic index, as well as the Crunchbase output, which represents the amount of entrepreneurial output according to Crunchbase controlled for the population of a region. Finally, we have added the absolute amount of start-ups founded between 2017-2021 (a slightly later timeframe than the original data) to provide additional insight. For the IRIS LH of Utrecht the high scores in Culture, Physical Infrastructure, and Leadership stand out most with the only below average score being Knowledge. The high score on Physical Infrastructure is a representation of the very central location of Utrecht in the Netherlands, which is also recognized in interviews in Utrecht as an important strength of the region. Leadership, which also stands out, is an indication of the high number of coordinators of H2020 Public Private Consortia. This means that many actors in Utrecht take an active role in bringing together actors from the public and private sector. The surprisingly low score on Knowledge (given that Utrecht University is a top university worldwide) is the result of low R&D investments in the region. This appears to be the most important point for improvement in the Utrecht Region. These R&D investments (Knowledge) and also Talent are the two major strengths of the Gothenburg ecosystem. As such, these are points to look to by the other IRIS cities on how they can improve their local ecosystem. We also see that while Vaasa's absolute number of start-ups (62) appeared to lag it's potential given the quality of the EE this is much less the case when looking at the Crunchbase output variable (1.20). The number of start-ups in the Vaasa region is lower due to the lower number of inhabitants in that region.

As described above the policy makers in IRIS cities can use these measures as an essential input for ex-ante policy diagnosis: to discover the weaknesses and strengths of entrepreneurial ecosystems. These weaknesses and strengths are always relative to other relevant regions: the benchmark. This is why the construction of large-scale datasets is a necessity for regional policy. Benchmarking the region could trigger policy by learning from regions that have comparable, entrepreneurial ecosystems. We help show the strength of some IRIS regions (particularly Utrecht and Gothenburg) in the EE and point to the strenghts which can be studied by the other IRIS to improve. Similtanously, these numbers point to potential weaknesses that regions can address, for the FCs but also the LHs, such as the Knowledge dimension in Utrecht. By using data to show how the various parts of the ecosystem for entrepreneurship (or any subject for that matter) are doing, we offer IRIS policy makers the opportunity to better understand their region.

Tackling the weakest elements of entrepreneurial ecosystems is likely to provide the most efficient and effective way of improving the overall quality of the entrepreneurial ecosystem. However, a limitation in applying our metrics is that they provide insight into where to look for improvement, but not how this improvement should be achieved. Furthermore, this study represents the best data available and this data is not always perfect. It is thus important to combine these metrics with qualitative insights about specific entrepreneurial ecosystems. We thus urge IRIS policy makers to use this data as a guide and not as a definitive conclusion.

Therefore, our recommendations are process based. Use the diagnosis behind the EEI as the starting point. Sit down with each other, entrepreneurs, companies, regional development agencies, provinces, municipalities, universities, colleges, etc., and discuss the diagnosis: Which weak elements are recognized (or not)? What is this due to? How could it be better? Do all stakeholders agree or do we/they have a difference of opinion? How can we improve this region together? By making use of this dialogue, it is possible to deepen the diagnosis and subsequently convert it into points for improvement. Then compile the interventions (both formal and informal policies) based on this dialogue. Please don't jump to conclusions, but use our (and other) research to start the conversation.

Table 9. Entrepreneurial ecosystem outputs and elements for the IRIS cities

NUTS2 code	Formal institutions	Culture	Networks	Physical infrastructure	Finance	Leadership	Talent	Knowledge	Demand	Intermediate	EE index additive	EE index log	Crunchbase output	2017-2021 startups
NL31 Utrecht	1.05	4.19	1.37	3.58	2.84	5.00	2.29	0.79	2.32	1.77	25.18	7.72	2.33	686
SE23 Gothenburg	2.37	2.80	0.39	0.61	1.83	0.89	3.14	3.43	0.43	1.51	17.40	2.89	1.15	281
FI19 Vaasa	1.88	2.86	0.95	0.41	1.27	0.52	3.13	1.42	0.17	0.33	12.94	-1.09	1.20	62
FRL0 Nice	0.55	0.83	0.45	0.75	1.24	0.25	1.40	1.01	0.75	0.51	7.74	-3.68	0.71	202
EL51 Alexandroupolis	0.10	0.51	0.56	0.12	0.06	4.70	0.20	0.19	0.12	0.29	6.85	-13.58	0.12	2
ES70 Tenerife	0.29	0.33	0.17	0.49	0.37	0.25	0.54	0.16	0.21	0.26	3.07	-12.55	0.41	49
RO22 Focsani	0.12	0.30	0.15	0.10	0.10	0.19	0.07	0.11	0.19	0.19	1.51	-19.69	0.12	15

2.5. Discussion and conclusions

The objective of this paper was to quantify and qualify regional economies with an entrepreneurial ecosystem approach. Quantification involved measuring the ten key elements of entrepreneurial ecosystems with a wide range of data sources. Qualification involved applying a network methodology to provide insight into the interdependencies between the elements and the construction of an Entrepreneurial Ecosystem Index to approximate the overall quality of entrepreneurial economies. Finally, we related the elements and the index to entrepreneurial outputs.

We answered three main research questions. First, how can we compose a harmonized dataset to measure the quality of key elements of entrepreneurial economies? We built on prior entrepreneurial ecosystem research and composed a harmonized dataset that measures each element of entrepreneurial ecosystems in the context of 273 regions in 28 European countries. To do so, we sourced a wide variety of data from existing datasets and online databases. However, not all elements could be measured in an entirely satisfactory way. Often, adequate data is available, but not at the same regional level or for all regions. An example is the data we used for the finance element: we prefer to have a composite indicator that includes objective data on the supply of different types of entrepreneurial finance. However, this is currently only available for venture capital in European regions. This could be improved by also including bank loans and crowdfunding. Another example is the data we used for the element networks. Even though the data provided on the engagement of SMEs in innovative collaborations is very informative, additional network data on collaborative networks and influencer networks, for example based on Twitter or LinkedIn data, could enrich the diagnosis of entrepreneurial ecosystems (Eveleens, 2019). This kind of network data would also allow for more refined measures of network diversity, density, and centrality. For other elements, there is no straightforward data available, and new variables had to be constructed. This was the case for leadership, for which others (Stam and Van de Ven, 2021) have constructed country-specific regional indicators, and we have created a pan-European indicator. However, even though this indicator provides information on the prevalence of (public-private) leadership in the context of European projects, improvements can be made to measure leadership that is more relevant for the quality of entrepreneurial economies, for example, with the prevalence of public-private regional partnerships (see Olberding, 2002). Overall, there is a significant trade-off between getting richer context-specific data (often only available in a relatively small number of regions) and getting widely available, harmonized data, enabling comparisons between regions. We invite other researchers to take up the gauntlet and improve these metrics further by collecting new and richer data.

Second, to what extent and how are the elements of entrepreneurial economies interdependent? We performed correlation, principal component, cluster, and network analyses to visualize the interdependencies between elements. These analyses revealed that entrepreneurial economies are systems with highly interdependent elements. Our analyses showed that physical infrastructure, finance, formal institutions, and talent take a central position in the interdependence web, providing a first indication of these elements as fundamental conditions for entrepreneurial ecosystems.

Third, how can we determine the quality of entrepreneurial economies? We answered this question by composing our Entrepreneurial Ecosystem Index and analyzing its relation to entrepreneurial outputs. We used multiple data sources and methods, including web scraping and geocoding, to determine entrepreneurial outputs at the regional level. We have shown that it is possible to measure the quality of entrepreneurial economies in a way that has external validity: showing a ranking of European regions and range of variation that is credible. Our analyses reveal the wide-ranging quality of entrepreneurial ecosystems in Europe, showing a large group of substantially lagging regions and a smaller group of leading regions. We also tested the internal validity using the fact that high-quality entrepreneurial ecosystems are more likely to produce emergent properties, which we measured with indicators of productive entrepreneurship. The prevalence of innovative new firms is strongly positive and statistically significantly related to the quality of entrepreneurial ecosystems, as captured with differently constructed entrepreneurial ecosystem indices. Our empirical findings are thus in line with the upward causation found by Stam and Van de Ven (2021) and Vedula and Kim (2019). The current index is formed under the assumption that each element is equally important for the quality of the ecosystem. While we find highly similar results when we challenge this assumption by employing principal component analysis, there is still a clear opportunity to improve the index in the future. We invite further research to study the respective importance of the ten elements for the quality of the entrepreneurial ecosystem and believe that the metrics developed in this study provide them with the opportunity to do so. In particular, future research should address if there are combinations of elements that are either necessary or sufficient for high outputs of productive entrepreneurship. Methods such as latent cluster analysis or qualitative comparative analysis (see Schrijvers et al., 2021) can play an important role in doing this and thus improve our understanding of the workings of entrepreneurial ecosystems.

There are several additional opportunities for improving the developed metrics that deserve substantial attention in follow-up research. First, the internal validity of the index should be tested more carefully, in particular with other (more direct) tests of causality, with longer time lags between changes in the quality of entrepreneurial ecosystems and the resulting entrepreneurial outputs, and with quasi-natural experiments in which a set of similar regions is confronted with substantially different changes in one or a few elements. In sum, we need to move from a comparative static analysis to a dynamic analysis, and therefore we need longitudinal datasets. This would make it possible to better trace processes within entrepreneurial ecosystems (Spigel and Harrison, 2018) and allow us to measure the distinct properties of complex evolving systems that arise from interdependencies, such as nonlinearity, emergence, tipping-points, spontaneous order, adaptation, and feedback loops.

Second, even though Europe provides a wide variety of regions to develop and test our entrepreneurial ecosystem metrics, these metrics also need to be developed and tested in other contexts, in large sets of regions in the US, Asia, Africa, and Latin America.

Third, our output measure of productive entrepreneurship is based on Crunchbase, and it is uncertain if the coverage of this database is equal among all regions. The same goes for the Dealroom data, which we used to test the robustness of this measure. There is a need to gain more insight into the coverage and quality of these private databases to assess their credibility. This is especially urgent given the increasing use of these databases in research on entrepreneurship and, in particular, on entrepreneurial ecosystems (Dalle et al., 2017).

Finally, statistical regions are not always overlapping with either the relevant jurisdictions or the spatial reach of the causal mechanisms involved (for example, related to culture and the provision of finance). Developing tailor-made spatial units and taking into account the nestedness of elements (cities, in regions, in countries), and neighborhood effects is also a challenge for future research. With the help of spatial econometrics, spill-over effects between regions could be analyzed. Our empirical research implicitly assumed an equal weight of all regional units. Future research can improve upon this by considering the differential (population, economic) size of regions, which might lead to more adequate regression analyses.

2.6. Policy implications

Despite the popularity of the entrepreneurial ecosystem approach in science and policy, there is a scarcity of credible, accurate and especially comparable metrics of entrepreneurial ecosystems. In this paper, we bridge this gap and measure the quality of entrepreneurial ecosystems by collecting and combining relevant data in a comprehensive set of metrics. These metrics are essential for data-and-dialogue-driven policy.

Measures of the elements of entrepreneurial ecosystems are an essential input for ex-ante policy diagnosis: to discover the weaknesses and strengths of entrepreneurial ecosystems. These weaknesses and strengths are always relative to other relevant regions: the benchmark. This is why the construction of large-scale datasets is a necessity for regional policy. Benchmarking the region could trigger policy by learning from regions that have comparable, entrepreneurial ecosystems. Tackling the weakest elements of entrepreneurial ecosystems is likely to provide the most efficient and effective way of improving the overall quality of the entrepreneurial ecosystem and stimulating productive entrepreneurship (Ács et al., 2014). However, a limitation in applying our metrics is that they provide insight into where to look for improvement, but not how this improvement should be achieved. It is thus important to combine these metrics with qualitative insights about particular entrepreneurial ecosystems.

The metrics are also an essential input for ex-post policy evaluation. They enable monitoring whether and to what degree the envisioned improvements of particular entrepreneurial ecosystem elements have been achieved and whether this has resulted in an increase in productive entrepreneurship and economic growth. For this monitoring, regular measurement of the quality of the entrepreneurial ecosystem elements is essential. For structural economic policy, annual data points would suffice, but in the context of rapidly evolving crises, including the COVID-19 crisis, more frequent monitoring with quarterly or even monthly data might be needed.

However, entrepreneurial ecosystem policy can never be entirely data-driven: comprehensive planning is computationally intractable (i.e., practically impossible) in large regional entrepreneurial ecosystems (cf. Bettencourt, 2014). Data on social phenomena are likely to remain insufficient, and interdependencies between elements and their emergent properties are unlikely to remain stable over time. Entrepreneurial ecosystem metrics facilitate a collective learning process to improve regional economies: this process combines data and dialogue. The diagnosis based on the metrics should, ex-ante, be used to facilitate dialogue between stakeholders of the entrepreneurial ecosystem about policy interventions, and facilitate, ex-post, a dialogue about the effectiveness of these interventions. Entrepreneurial ecosystem metrics are thus essential for data-and-dialogue-driven policy.

In sum, the entrepreneurial ecosystem approach, including the metrics we propose, provides the means to improve every regional economy in its own way. In particular, the approach and its metrics provide a lens for public policy to better diagnose, understand and improve entrepreneurial economies.

3. Identifying and assessing sustainable entrepreneurial ecosystem

A modified version of this chapter has been submitted to a peer reviewed journal as *Leendertse, J. & van Rijnsoever, F.J. Greening Pastures, Entrepreneurial Ecosystems for Sustainable Entrepreneurship.*

3.1. Introduction

Entrepreneurs play an important role in the transition to a more sustainable society and also to smart cities (Alkemade et al., 2011). They do so by introducing new technologies and business models that contribute to sustainability. (Bjornali and Ellingsen, 2014; Cohen and Winn, 2007; Leendertse et al., 2021; Tiba et al., 2021). Cities and regions are therefore aiming to implement policies that can help these entrepreneurs (Tiba et al., 2021). Sustainable entrepreneurship is the process of starting new companies that engage in the "discovery, creation, and exploitation of opportunities for (future) goods and services that simultaneously sustain the natural and social environment, and provide economic and non-economic gain for others" (Johnson and Schaltegger, 2020, p. 1141). These new companies are called sustainable start-ups (SSUs) (Leendertse et al., 2021; Tiba et al., 2021). We focus particularly on those SSUs that contribute to the environmental side of sustainability and smart cities.

For cities and regions who design policies to support SSUs it is important to understand what factors actually stimulate and facilitate the founding of SSUs (Giudici et al., 2019; Tiba et al., 2021). We focus on the regional factors because previous research has shown that these are an important part of the conditions (Ács et al., 2014; Acs and Audretsch, 2005; Alvedalen and Boschma, 2017; Stam, 2015) on which the presence of entrepreneurship depends (Shane and Venkataraman, 2000). We use the entrepreneurial ecosystem (EE) framework as a starting point because this literature brings together the different regional factors that influence entrepreneurship (Alvedalen and Boschma, 2017; Andersson and Koster, 2011; Stam, 2015). An EE consists of a set of interdependent actors and factors that are governed in such a way that they enable productive entrepreneurship within a geographical region (Stam, 2015; Stam and Spigel, 2017).

To move from entrepreneurship to sustainable entrepreneurship, researchers have developed the *sustainable entrepreneurial ecosystem (SEE)* concept (Cohen, 2006; Theodoraki et al., 2018; Tiba et al., 2020; Volkmann et al., 2021). So far SEEs build heavily on the factors identified in the EE literature because sustainable entrepreneurship and regular entrepreneurship are to a large extent influenced by the same factors (Giudici et al., 2019; Tiba et al., 2021).

However, sustainable entrepreneurs encounter additional market and institutional challenges and they have different motivations than regular entrepreneurs (Gibbs, 2006; Hart, 2006; Leendertse et al., 2021; Linnanen, 2002; Tiba et al., 2021). We therefore expect that there are additional factors that influence an SEE. Some studies have tried to find which other factors influence the occurrence of SSUs (DiVito and Ingen-Housz, 2021; Giudici et al., 2019; Tiba et al., 2021). These factors include a high environmental awareness by people in the region, and the presence of relevant patents that represent technical knowledge (Giudici et al., 2019), the sustainability orientation of regional actors, and the size of regional markets for sustainable products (DiVito and Ingen-Housz, 2021) and a combination of a high GRP per capita with either high shares of non-religious people or high shares of female founders (Tiba et al., 2021), However, a systematic analysis of which additional EE conditions influence the presence of SSUs is not yet there (Theodoraki et al., 2018; Volkmann et al., 2021). Such a systematic analysis is needed to provide cities and regions with advice on how policy makers can improve sustainable entrepreneurship in their region (Giudici et al., 2019; Tiba et al., 2021). This chapter therefore focuses on the following question: *What entrepreneurial ecosystem elements determine the presence of sustainable start-ups in a region?*

This will allow cities insight into what factors are important for sustainable entrepreneurship and by comparing the number of sustainable start-ups in different regions they can identify regions that have more SSUs and subsequently they can learn from these regions.

We use quantitative analyses that include 46,741 start-ups located in 274 NUTS-2 regions in 28 European countries to answer our question. We study if, and how the factors that emerge from the EE literature influence the presence of SSUs. In addition, we combine the EE literature with the innovation system literature to find and test additional factors. As such this chapter also forms a bridge between the EE approach which is needed to understand how business models can be formed and implemented in practice and the innovation system approach which looks at the development of the new innovations that can be used in those business models.

3.2. Theory

In this section we first outline the SSU dependent variable. Next, we discuss the theory on EEs. Third, we identify and talk about the added elements that make up SEEs compared to EEs.

3.2.1. Sustainable start-ups

SSUs come up with new solutions for sustainability (Dean and McMullen, 2007; van Rijnsoever, 2022). SSUs can be quite different from each other (Schaltegger and Wagner, 2011), but they face common contstraints (van Rijnsoever, 2022). These constraints are important because they allow to understand what SSUs will need.

First, SSUs act in problematic or not working markets (Hoogendoorn et al., 2019; Pinkse and Groot, 2015). The broader value for society of environmental business models is often not fully included in prices of goods or services. In addition, often users do not have the money to buy the product of SSUs (Mair and Marti, 2006; Tiba et al., 2020). Furthermore, the institutional constraints of SSUs are that the existing market's regulations, standards, norms, habits, or cognitive frames are not complied to by their products or services (Smink et al., 2015; Steinz et al., 2015).

Second, SSUs often face financial constraints. SSUs that have a sustainable technology often require large investments, more than other types of start-ups (Evans, 2018; Leendertse et al., 2020). This is the case because clean tech “Hardware” SSUs, often need to perform large-scale R&D or demonstrations or they need to set up new production lines. As a result they require more investments. This makes the services and products SSUs harder to establish and gives them more risk to fail, this can prevent investors to invest in SSUs (de Lange, 2017; Giudici et al., 2019; Martin and Moser, 2016). So not only do they need more investments, it is also harder for them to get these investments.

Third, SSUs combine their environmental and economic goals (Austin et al., 2006; Hechavarría et al., 2017; Hörisch et al., 2017). These two motivations often do not align and therefore SSUs experience tension in dealing with and bringing together both goals (Austin et al., 2006; Jolink and Niesten, 2015; Leendertse et al., 2021; Stubbs, 2017). The combination of the three constraints means that the support provided by an EE is more important for SSUs than for regular start-ups (van Rijnsoever, 2022).

3.2.2. Entrepreneurial ecosytems

An EE consists of the conditions that influence, in a particular region, city, or even country, the presence of productive entrepreneurship (Stam, 2015; Wurth et al., 2021). The focus of the EE is on the entrepreneurial actor, and how it is influenced by the environment/ecosystem around it (Wurth et al., 2021). The combination of factors and the interactions between factors make up the EE and influence the output, productive entrepreneurship. We summarize the EE literature with ten elements. In doing so we follow several other studies (Leendertse et al., 2022; Stam and van de Ven, 2021; Wurth et al., 2021). These are formal institutions, entrepreneurial culture, leadership, networks, finance, physical infrastructure, demand, talent, knowledge, and intermediaries. In European regions, the combination of these ten elements has been shown to have a strong influence on the presence of productive entrepreneurship (Leendertse et al., 2022).

We merge elements of the innovation systems literature to the EE framework. We start with the notion that the EE can, from a theoretical perspective, be considered a special case of an innovation system (van Rijnsoever, 2020; van Weele et al., 2018b). An innovation system consists of (1) actors that interact and exchange resources in a network under an (2) institutional regime and an (3) infrastructure (Carlsson and Stankiewicz, 1991; Van Rijnsoever et al., 2015). This aligns with the EE framework used in this study and that originates from Stam (2015). The ten EE elements are split up into two categories: *institutional arrangements* and *resource endowments.* The institutional arrangements cover formal and informal (culture) institutions. The *resource endowments* consists of the combination of actors (e.g. demand, leadership, intermediaries) and their resources (e.g. knowledge, finance, talent). In addition, Stam (2015) and some empirical applications of this framework (Leendertse et al., 2022; Stam and van de Ven, 2021) include infrastructure as a resource endowment through the element physical infrastructure.

3.2.3. Sustainable entrepreneurial ecosystems (SEE)

Cohen (2006), followed by several other researchers introduced the concept of SEEs (Theodoraki et al., 2018; Tiba et al., 2020; Volkmann et al., 2021). This literature studies the factors that influence the occurrence of SSUs, and subsequently how these factors can contribute to SSUs overcoming the constraints that they face. SEE literature builds very closely on already present EE frameworks. For example, Cohen (2006) adapts factors found by Neck et al. (2004) to sustainability. Tiba et al. (2021) use the EE framework by Spigel (2017). However, a systematic study of which regular EE conditions and which additional EE conditions influence the occurrence of SSUs has not yet been done (DiVito and Ingen-Housz, 2021; Volkmann et al., 2021). As a result, additional factors that are important for SSUs could be missing from the SEE literature and the knowledge of policy makers (DiVito and Ingen-Housz, 2021; Giudici et al., 2019; Tiba et al., 2021). In this paper, we do make a systemic evaluation to identify these factors. To do so, we use the shared conceptual background of the EE and innovation systems approaches.

We go beyond adapting the elements of existing framework and zoom out. We use the innovation system components to provide structure to the SEE and suggest additional EE elements that influence sustainable entrepreneurship. We then test these in empirical analysis. Innovation systems approaches are often used to understand sustainability (Carlsson and Stankiewicz, 1991; Hekkert et al., 2007). We can therefore derive factors that promote SSUs from the innovation system literature, which is outside of the EE literature. In the following sections we bring the innovation systems and the EE together based on the (1) actors and resources, and (2) institutions categories (Carlsson and Stankiewicz, 1991; Van Rijnsoever et al., 2015).[16] We hypothesize about the role of specific EE elements that can cause the occurrence of SSUs in a region.

3.2.3.1. Regular entrepreneurial ecosystems

Start-ups benefit from a good EE because it helps them develop their business models and it helps them counter the constraints they face. (Leendertse et al., 2022). SSUs face more constraints, both market and institutional (Hoogendoorn, 2016; Leendertse et al., 2021) and they are balancing economic and environmental goals (Hechavarría et al., 2017; Hörisch et al., 2017). The support offered by an EE and by organizations in that EE is extra important for them. These additional constraints mean that SSUs have a larger need for the support provided by an EE or support services therein (van Rijnsoever, 2022). A strong EE can help SSUs reduce the impact of these constraints, even more so than for regular start-ups. We make the following argument.

Hypothesis 1: EE quality has a positive effect on the regional presence of SSUs.

[16] We discuss the third element of an innovation system, infrastructure in section 3.5.

3.2.3.2. Other start-ups

We now turn to actors and resources, which is the first category from the innovation systems framework. Actors are organizations or individuals that influence the SSU success chance within EEs. The most important actors in these EEs are start-up entrepreneurs themselves (Stam, 2015). Other, colleague start-ups in the ecosystem have several ways in which they can help SSUs. Other start-ups often deal with similar problems and challenges and can therefore help other start-ups by sharing knowledge (van Weele et al., 2018a). In addition, start-ups connect each other to investors and other finance sources (van Rijnsoever, 2020). Being part of the finance network is very important for SSUs because of the financial constraints that they have to deal with (Evans, 2018; Leendertse et al., 2021; van Rijnsoever, 2022). Finally, start-ups often help each other find relevant resources, such as potential employees, and relevant incubators and other start-up support services. This leads to the following argument:

Hypothesis 2: The regional amount of start-ups has a positive effect on the regional presence of SSUs.

3.2.3.3. Actors & resources

Besides other start-ups there are also non-start-up actors in an SEE that can influence the presence of SSUs, examples of these are universities, incubators, investors, incumbent firms, consumers, and governments (DiVito and Ingen-Housz, 2021). These other actors can supply resources or connect SSUs with other actors. In doing so they can help SSUs overcome their constraints (Clarysse et al., 2014; van Rijnsoever, 2022). Actors that are actively working on or focusing on sustainability are very important for SSUs (DiVito and Ingen-Housz, 2021). The presence of actors focusing on sustainability can help SSUs get access to the market (ibid). They can do so in two ways. First, they can link them with established actors and second, they can also buy the products or services of SSUs thereby functioning as the customers. Both points mean that SSUs have the potential to get to the market and to get past their market constraints. Finally, these actors who are active in the sustainability field also have resources under control. SSUs might be able to get access to these resources. A good example are sustainability patents, which Giudici et al. (2019) find to lead to higher numbers of SSUs in that region. We come up with the following hypothesis based on these:

H3: The regional presence of sustainability-oriented actors and resources has a positive effect on the regional presence of SSUs.

3.2.3.4. Institutions

The second category that we use from the innovation systems literature are the institutions. Innovation systems assume that actors are influenced by the *institutional regime*, this is a semi-coherent set of formal and informal rules that influence actors' behaviour (Kemp, 1994). The institutionally regime is kept in place because the actors that follow these rules (Geels, 2004; Geels and Schot, 2007). The combination of formal and informal institutions forms the institutional regime (Douglass, 1990; Edquist and Johnson, 1997; Scott, 2008). Relevant formal institutions for SSUs are favourable and unfavourable policies. Examples of the favourable policies are subsidy schemes or regulations that require the use of sustainable technologies while unfavourable policies can be tax benefits for unsustainable technologies or regulations that make it impossible to use new sustainable technologies.

Informal institutions concern the values or norms that exist about sustainability. An example is how important the people find climate change and sustainability. Hoogendoorn et al. (2019) find that institutions (formal or informal) often are a barrier for SSUs, they have institutional constrains. How favourable the institutional regime is regarding sustainability influences the presence of SSUs in a region.

Giudici et al. (2019) find that an informal institution, in specific high environmental awareness, has a positive effect on SSU presence. This makes sense for two reasons. First, when people are motivated to tackle environmental problems, we expect that more of them found SSUs (Boluk and Mottiar, 2014; Hörisch et al., 2017). Second, more environmental awareness might mean that people will buy more environmental solutions (DiVito and Ingen-Housz, 2021). Thus:

H4: The presence of beneficial a) formal and b) informal institutions in a region regarding sustainability has a positive influence on the presence of SSUs in a region.

3.2.3.5. Conceptual framework

We used the (1) actors and resources, and (2) institutional regime categories (Carlsson and Stankiewicz, 1991; van Rijnsoever et al., 2015) to combine the EE with the innovation system approach, this forms a SEE. We present the resulting SEE framework in Fig. 10. The framework shows the original ten EE elements introduced by Stam (2015), these are graphically depicted as a box within the SEE and they together make up the quality of the EE. The SEE is this box with the four new elements we hypothesized for in the theory.

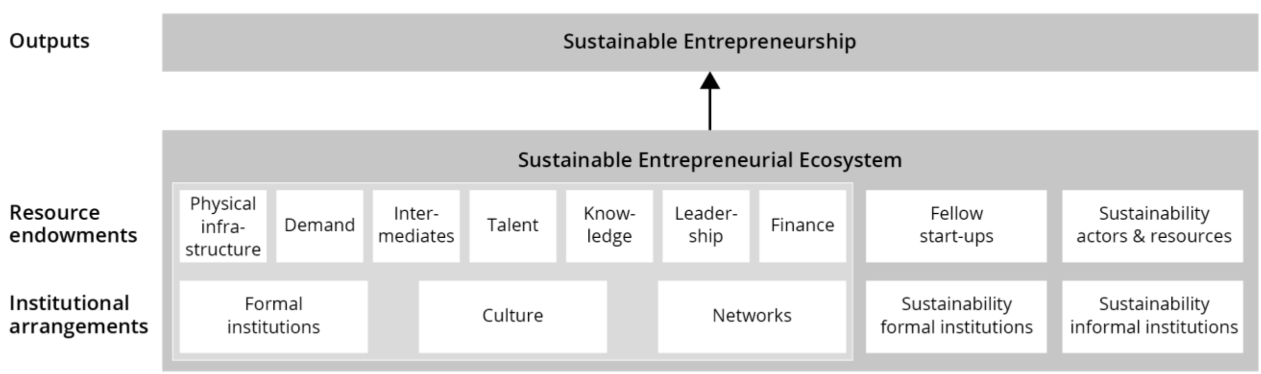

Fig. 10. Sustainable Entrepreneurial Ecosystem conceptual framework

3.3. Methodology

3.3.1. Research design

We collect data about SEEs and SSUs in 28 European countries, the 27 EU member states and the United Kingdom. We follow Leendertse et al. (2022) who argue that, in the European context, the regional level is the best level to look at EEs.

The NUTS-2 classification identifies 281 geographical regions fits best with this European regional level. We use 273 regions in our analyses as we leave out 7 overseas Spanish and French regions because they are not actually in Europe and combine two UKI3 and UKI4, the two inner London regions because we could not separate them for some of our data.

3.3.2. Sample and data collection

We collect data from a several places. First, for the number of start-ups and SSUs, we use Crunchbase. This has the best start-up database for Europe.[17] We used information for 46,741 start-up firms which are founded in the last 5 full years of the data (2017-2021) to define the SSUs[18]. For regular start-ups we used start-ups founded between 2015-2017 to ensure a lag with the dependent variable. Second, for EE quality we follow Leendertse et al. (2022) who put together comparable data to measure the European EE quality using the ten elements by Stam (2015). Their data is mainly about 2013-2019. Third, for our sustainability focused actors and resources, we use the CORDIS and PATSTAT databases. CORDIS has data on members of public-private consortia, that received financing as part of the European Unions Horizon 2020 program (CORDIS, 2022; European Commission, 2022). There is data on 15,005 public-private consortia that received funding between 2014-2017[19] (CORDIS, 2022; European Commission, 2022). From PATSTAT we include patents from 2013-2017[20]. PATSTAT has 293,005 patents filed during this time. Fifth, for formal institutions, we use OECD data on environmental tax revenues. This is the share of total taxes between 2013-2017 that comes from environmental taxes. Sixth, for the informal institutions, we use data from the, in 2016 conducted European Social Survey 8. This is available on the NUTS-2 level but contains data on 211 instead of 273 regions as several countries didn't participate. For the control variables we use Eurostat.

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[17] We downloaded the Crunchbase data on the 6th of July 2022 using academic access.

[18] We perform robustness tests in which we include the 80,414 start-ups founded between 2015-2021 or the 80,884 start-ups founded between 2015-2022. The regional number of start-ups of both these alternative times have correlations over 0.99 with our measure . Our findings are thus robust over different timeframes.

[19] There are no Horizon2020 projects started in 2013 and a lower number in 2014 as the Horizon2020 programs official start year is in 2015. We performed robustness tests looking at the 20,067 public-private consortia started 2014-2018 and the 25,245 consortia started 2015-2019. These timeframes have correlations over 0.99 with our selected timeframe and the results remain the same. Our analyses are thus robust for the selected timeframe.

[20] We performed a robustness test using 2014-2018 as an alternative timeframe. The correlation between these two variables is larger than 0.99 and our results remain the same.

3.3.3. *Dependent variable*

To find where the start-ups are located we use geocoding. This process looks as follows. First, we use the tmap package in R to geocode the locations given by Crunchbase using OpenStreetMap (OpenStreetMap, 2022; Tennekes, 2018). This online map lets us send a list of locations and returns coordinates. This process results in a clear location match for 95% of the regions. For the remaining start-ups, without a consistent match, we check their coordinates manually using Google Maps (Google Maps, 2022). Next, we use shapefiles to go from coordinates to NUTS-2 region. The Eurostat shapefiles contain the exact borders of the NUTS-2 regions (Eurostat, 2022). In particular we use an R package called rgdal which allows us to link the coordinates to the corresponding NUTS-2 regions (Bivand et al., 2019; Eurostat, 2022). We then count the number of start-ups per NUTS-2 region.

Next, we go from start-ups to identifying SSUs. For this we use text data. We use the combination of Crunchbase, that provides short descriptions of each start-up with data from the Internet Archive[21]. We use the combination because the Crunchbase descriptions, which are on average only 24 words are too short to really do this consistently. Using the Internet Archive we could get archived webpages of the start-ups. The Internet Archive regularly archives all the websites available on the internet (Ainsworth et al., 2011; AlNoamany et al., 2014). We use the Internet Archive rather than the actual websites because many start-ups are no longer in business. We get the webpages by using the Wayback CDX Server API and download the websites from the 5 years after a start-up was founded according to Crunchbase.[22] We download the ten webpages with the shortest URL. We use URL length as a proxy for the centrality of the website (Dean, 2022; Google, 2022).[23] This results in 353,036 webpages for 43,585 start-ups founded between 2017-2021. We thus find websites for 93% of the start-ups we study. We then use this text for our analyses. On average our dataset includes 8 webpages for each website and these pages contain 816 words.

We follow Tiba et al. (2021) by using the Detectlanguage and Googletranslate functions from Google Sheets to identify the language of each webpage and subsequently translate it to English for those webpages (about 40%) that are not in English text. Next, we use a thesaurus to identify if a start-up explicitly talks about environmental sustainability. Using a thesaurus means applying a set of search terms to identify whether a document matches a particular topic. Romero Goyeneche et al. (2022) successfully use this to study whether publications cover the Sustainable Development Goals (SDGs). We use SDG 6, 7, 11, 12, 13, 14, and 15 to operationalize environmental SSUs. This thesaurus is specifically built for use on publications (Romero Goyeneche et al., 2022, 2021) and has also been used on the websites of large international organizations (Bogers et al., 2022). We therefore manually coded a set of start-ups to

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[21] The Internet archive is available at https://archive.org.

[22] More information is available at https://github.com/UtrechtUniversity/ia-webscraping

[23] This is based on the hierarchical structure of websites and the assumption that http://www.start-up.com/product is closer to the home page, and thus more relevant, than www.start-up.com/product/new-release.

identify how well they matched the thesaurus. There were some issues so we made several modifications to the thesaurus, tailoring it for start-ups.

We use the number of thesaurus matches per 100 words as a cut-off. We identify a start-up as an SSU if it exceeds a 1 match per 100 words in either the Crunchbase or the website text. This cut-off value was derived based on manual evaluation of the start-ups.[24] Using this approach we now know which European start-ups are actively talking about environmental sustainability in their business. There are 2,877 SSUs in total and they make up 6.2% of all start-ups. This percentage is in line with earlier studies who identify the percentage of environmental SSUs between 1 and 14% of start-ups (Giudici et al., 2019; Tiba, 2020). We use this data to construct our dependent variables, the presence of SSUs in each region. We define this as the absolute number of SSUs founded in a region between 2017-2021.

3.3.4. Independent variables

A full overview of the independent variables is shown in Table 9. We record most of the independent variables between 2013-2017[25], creating a lag with the dependent variable, which is recorded from 2017-2021.

3.3.4.1. Regular entrepreneurial ecosystems operationalization

Leendertse et al. (2022) combined data from various sources to a dataset that measures EE quality in European regions using the ten EE elements by Stam (2015). We use this data for this variable and this third chapter of the deliverable thus explicitly builds on the second chapter. Leendertse et al. (2022). More information is provided in the Annex of Chapter 3, Appendix A.

3.3.4.2. Other start-ups

For the other start-ups, we use the absolute number of start-ups in each region (regular and SSUs), which is obtained after geocoding the Crunchbase start-ups. We use a slightly different timeframe as we expect start-ups founded at an earlier time to help the SSUs founded in our dataset. In total we identify 48,681 start-ups founded from 2015-2017. These start-ups can support SSUs founded in the future, between 2017-2021. We do a logarithmic transformation because the average path length in a network decreases logarithmically with the number of actors (Albert and Barabási, 2002; Watts and Strogatz, 1998), this means that the meeting changes with a new actor actor only increase marginally when the number of

[24] We perform robustness check using both a harsher and more lenient cut-off values. With a cut-off value of 1 match per 50 words we identify 4.4% of start-ups as SSUs and with a more lenient cut-off value of 1 match per 200 words we identify 8.2% of all start-ups as SSUs. The resulting measures for the presence (and inherently also the prevalence) of SSUs per region have correlations above 0.96. Our final results remained highly similar, showing that our analyses is robust for the specific cut-off value.

[25] Some variables included in the EE index have slightly different timeframes (Appendix A), with the latest data coming from 2019. Our results remain robust when we perform a robustness test that includes only SSUs founded between 2019-2021.

start-ups grows (van Rijnsoever, 2020). Hence, the marginal effects of peer support becomes less as the number of start-ups grows.

3.3.4.3. Actors and resources

To measure how sustainability oriented other actors are we look at the number of times actors in the region are participating in public-private consortia focused that address environmental sustainability. We use the thesaurus and geocoding method described earlier to determine the number of public-private consortia on environmental sustainability per region. We consider the number of partner-project pairs present in one region, in total there are 27,514 occurrences of actors participating in environmentally sustainable public-private consortia.[26]

For favourable resources we use the number of patents on environmental technologies for each region. Patents represent the technological impact and market value of technologies (Debackere et al., 1999; Verhoeven et al., 2016) as well as knowledge (Breschi and Lissoni, 2004) available in a region, making this good fit to operationalize sustainability resources. We use the number of environmental Y02 class taken from the Cooperative Patent Classification (CPC) table. The Y02 class identifies patents relating to inventions or technologies for mitigation or adaptation against global climate change and has been widely adopted by researchers (Hille et al., 2020; Veefkind et al., 2012). In total, there are 33,025 Y02 patents in our data.

We combine the two measures into one variable. To do so we first standardize the individual measures and then calculate the average of them. The created variable has a Cronbach's alpha of 0.796 so this is a good fit.[27]

3.3.4.4. Institutional regime

For the formal institutions we use the strength of environmental sustainability tax regulations. We look at the extent to which current regulations tax negative impacts on the environment. In particular, the share of total tax revenues that comes from environmental taxes. We use the average of the five years between 2013-2017. This is country level data, and we therefore use the national scores for the individual regions.

For informal institutions, we look at how important citizens find addressing climate change. We combine five questions from the 8th wave of the European Social Survey that focus particularly on the perceptions of citizens on the seriousness and impact of climate change or about feelings of being personally

[26] We perform two additional robustness tests. First, we look only at the number of unique sustainable projects in which a regional actor is involved, this measure has a correlation over 0.99 with our selected measure. Second, we only look at the number of unique actors that are involved in public private consortia, ignoring the number of projects these actors are involved in. This measure has a correlation higher than 0.95 with our measure. Both measures do not alter our results.

[27] We perform a robustness test in which we add the two variables separately. The results are the same, with both variables having a positive, significant influence.

responsible.[28] We calculate the average regional score based on all individual responses in a region. The Cronbach's alpha is 0.773. Again, this is based on standardized individual measures.

[28] An overview of these five questions is provided in Appendix B.

Table 10. Operationalisation of the sustainable entrepreneurial ecosystem independent variables

Elements	Description	Empirical indicators	Data source	Year
Entrepreneurial Ecosystem quality	The quality of the regional entrepreneurial ecosystem.	The EEI score based on the ten elements of the Entrepreneurial Ecosystem.	Leendertse et al. (2022)	2013-2019
Fellow start-ups	The number of start-ups in a region.	The absolute number of start-ups in a region.	Crunchbase	2015-2017
Actors & resources	The degree to which actors in the region are actively participating in public-private partnerships focused on contributing to environmental sustainability.	The absolute number of Horizon2020 projects that are about environmental sustainability.	CORDIS	2013-2017
	The degree to which actors in the region already produce knowledge on environmental technologies.	The absolute number of patents on environmental technology as evidenced by patents filed in the Y02 class.	PATSTAT	2013-2017
Formal Institutions	The degree to which taxing environmental damage is implemented as part of the tax system.	The share of tax revenues which comes in through environmental taxes.	Eurostat	2013-2017
Informal institutions	The degree to which environmental sustainability is important to citizens.	The degree to which citizens indicate that they are worried about the consequences of climate change.	European Social Survey S8	2016

3.3.5. Control variables

In our models we use two control variables. The total population, for which we use the average population between 2013-2017 and the wealth of each region through the Gross Regional Product (GRP) per capita, here we use the standardized average between 2015-2017 from the Regional Competitiveness Index.

3.3.6. Analysis

Table 10 shows the descriptive statistics of and correlations between the variables.

Table 11. Correlation matrix for sustainable entrepreneurial ecosystems

		mean	S.D.	1	2	3	4	5	6	7
1	Presence of SSUs	10.538	32.975							
2	EE index	8.934	6.462	0.468						
3	Other start-ups	4.517	1.501	0.517	0.646					
4	Actors & resources	0.000	1.823	0.530	0.449	0.549				
5	Formal Institutions	6.992	1.666	-0.011	-0.180	-0.132	-0.136			
6	Informal Institutions	-0.003	3.626	0.094	0.055	0.189	0.227	-0.512		
7	Population	1854267	1514715	0.349	0.088	0.553	0.636	-0.140	0.271	
8	GRP	96.401	35.697	0.307	0.691	0.525	0.430	-0.325	0.178	0.118

To test our hypotheses, we perform linear regression models in R (R Core Team, 2023). First, we only used the control variables. We then tested H1, by adding the EE index as predictor to the model. For H1, we also study if SSUs profit more from EE quality than regular start-ups. For this we look at the prevalence of SSUs, the share of start-ups that are SSUs in a region. SSU prevalence is also used by Tiba et al. (2021). If EE quality has a significant effect on the prevalence of SSUs we know that EE quality matters more for SSUs. We perform this extra analysis by using beta regression models, these allow modelling dependent variables that have a value between 0 and 1, which is the case as we look at a share (Ferrari and Cribari-Neto, 2004). We tested H2, H3, H4a, and H4b by including the respective variables in four separate models to the model with control variables and EE index. This because we argue that the additional components of an SEE function on top of the EE index. Finally, we fit a model with all variables included. We report on the model performance with the adjusted R^2 for each analysis we check that the variance inflation factors are below the recommended value of 5. This is the case

3.4. Results

3.4.1. Descriptive results

Fig. 11 shows a map with SSU presence per region and Fig, 12. shows the top ten regions with the highest SSU presence. We dive into more depth on the IRIS cities in the next section. We find that Inner London has the most SSUs followed by Berlin, Île-de-France (Paris), and the Dutch regions Noord-Holland and Zuid-Holland. In general, we find that regions with the highest presence of SSUs are also regions with strong entrepreneurial ecosystems (Leendertse et al., 2022). Looking at the other top regions we see that most regions are in Northwestern Europe, while there are two Southern European regions, the Spanish regions Madrid and Cataluña. In general, we find relatively few Eastern European regions with a large SSU presence. Estonia, which ranks 14th, is the exception and the only Eastern European region in the top 30.

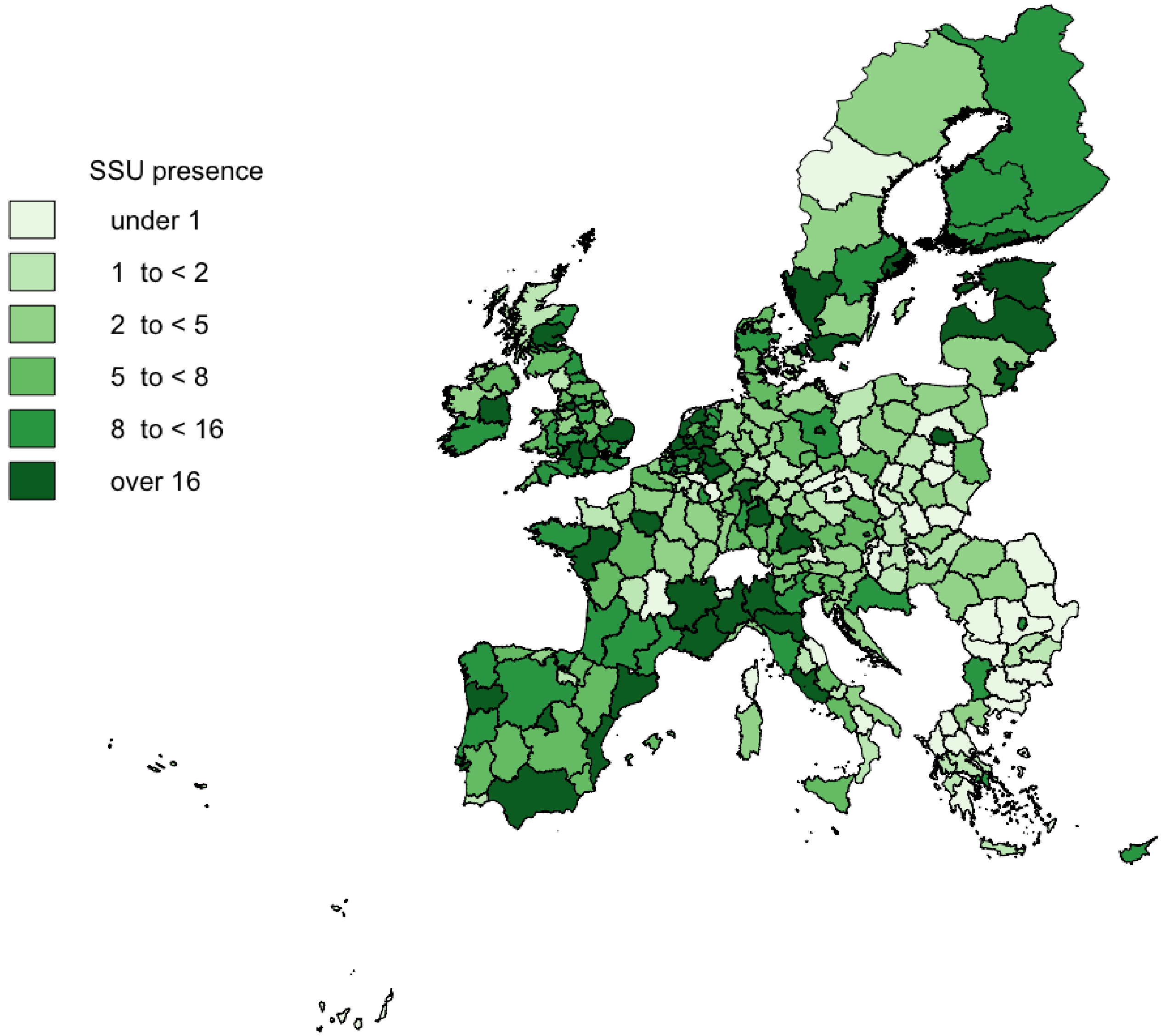

Fig. 11. The presence of environmentally sustainable start-ups per European region

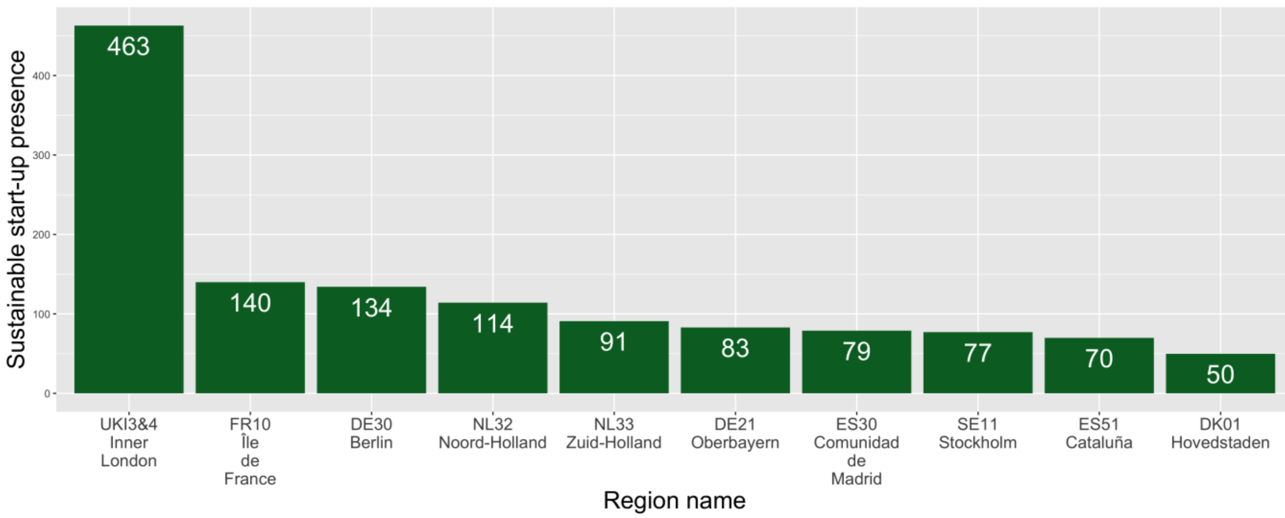

Fig. 12. The ten European regions with the highest presence of environmentally sustainable start-ups

3.4.2. IRIS Cities

Specifically for the IRIS cities we show the number of environmentally sustainable start-ups according to the outlined method in Fig. 13. We see that the order of the cities regarding the number of SSUs is the same as for regular start-ups (Fig. 9). However, it is interesting to note the higher share of SSUs in the Gothenburg region than in the Utrecht region. In addition, it stands out that 3 of the 4 FC cities did not have any start-ups in them that were identified as environmentally sustainable, according to the method outlined in chapter 3.3.3. The 3.8% of start-ups that are environmentally sustainable in the Utrecht region and the 5.4% in the Nice region are also below the 6.2% which was found for Europe overall. The Gothenburg region, with 7.8% environmentally sustainable start-ups and the Vaasa region with 8.1% both do outperform the European region. It will be interesting to see if the IRIS projects leads to a change over time as start-up foundation is generally a delayed function of the quality of the regions. Overall, we see that the IRIS cities can still learn from other regions regarding the conditions for sustainable entrepreneurship and that the LHs are ahead of the FCs regarding sustainable entrepreneurship and that the FCs can thus learn from the LHs recording how to stimulate this specific type of entrepreneurship.

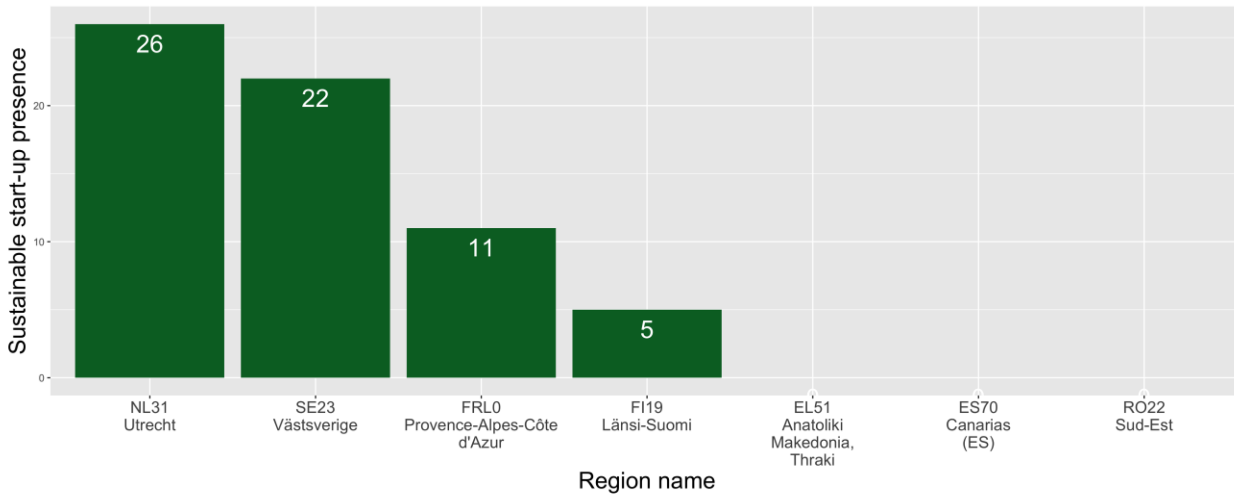

Fig. 13. Number of sustainable start-ups founded in IRIS regions from 2017-2021

3.4.3. Regression analyses

Table 12 displays the results of the linear regression models. In model 2, we find a positive significant effect between the EE index and SSU presence. This supports hypothesis 1, there is a positive relation between EE quality and SSU presence. The EE index increases the explained variance by 10% in comparison to model 1. This shows that the EE quality is important to SSUs. In the beta-regression analysis (Table 13), we find that the quality of EEs has a positive significant influence on SSU prevalence. This shows that the quality of an EE is more important for SSUs than for regular start-ups. This is an important finding.

In models 3-6 we add the other SEE variables. We find that other start-ups have a positive and significant effect on SSU presence (Model 3), which supports hypothesis 2. SSUs benefit from peer effects. In model 4 we find that in line with hypothesis 3, regions with sustainability-oriented actors and resources have a higher SSU presence. SSUs benefit from these actors and their. The effects of hypotheses 1,2, and 3 are also significant in the full model, model 7.

In line with hypothesis 4a, we find I model 5 that formal institutions have a positive significant influence on regional SSU presence. However, in model 7 this effect is no longer significant. This could be because model 7 has over 60 less observations than model 5 because of the informal institutions variable. To make sure this is not the reason we run an additional model which excludes only informal institutions (Appendix: Table C1). The results do not change. So that explanation is not the cause. Instead, this could be because the effect of formal institutions on SSU presence is taken over by the presence of sustainability focused actors and resources. For hypothesis 4b, informal institutions there is no significant effect on SSU presence model 6 and model 7. We thus do not confirm the finding of Giudici et al. (2019) that a high environmental awareness in a region has a positive influence on the presence of SSUs. This could be because environmental concerns of citizens do not lead to the actions that create market demand for the products and services of SSUs (see Boluk and Mottiar, 2014; Hörisch et al., 2017). However, it could also be due to missing values for several countries. Of the control variables, population has a positive significant effect on the presence of SSUs in models 1-6, while GRP is only strongly significant in model 1. This loss of significance has no further consequence for our hypotheses.

Overall, we find that EE quality, the presence of other start-ups and the presence of sustainability focused actors and resources have a strong influence on the presence of SSUs in a region. This aligns with hypotheses 1,2, and 3.

Table 12. Regression results for sustainable entrepreneurial ecosystems

	Dependent variable:						
	Sustainable start-up presence						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Entrepreneurial Ecosystem index		2.487^{***}	1.980^{***}	2.010^{***}	2.437^{***}	2.992^{***}	1.265^{**}
		(0.357)	(0.426)	(0.362)	(0.356)	(0.476)	(0.626)
Fellow start-ups			4.231^{**}				8.448^{***}
			(1.964)				(2.916)
Sustainability actors & resources				5.978^{***}			6.069^{***}
				(1.353)			(1.594)
Formal institutions					2.237^{**}		0.805
					(1.058)		(1.904)
Informal institutions						-0.115	-0.016
						(0.617)	(0.690)
Population	0.001^{***}	0.001^{***}	0.000^{***}	0.000^{*}	0.000^{***}	0.000^{***}	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GRP	0.249^{***}	-0.062	-0.080	-0.112^{*}	-0.023	-0.083	-0.119
	(0.051)	(0.065)	(0.065)	(0.064)	(0.067)	(0.100)	(0.100)
Constant	-26.232^{***}	-18.457^{***}	-25.729^{***}	-1.437	-37.871^{***}	-24.499^{***}	-29.213^{*}
	(5.443)	(5.150)	(6.129)	(6.296)	(10.517)	(8.153)	(15.782)
Observations	273	272	272	272	272	210	210
Adjusted R^2	0.187	0.309	0.318	0.354	0.318	0.318	0.378
Residual Std. Error	29.727	27.455	27.271	26.553	27.280	30.663	29.263

F Statistic	32.343^{***}	41.406^{***}	32.636^{***}	38.083^{***}	32.572^{***}	25.314^{***}	19.183^{***}
Note:	$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$						

Table 13. Beta regression models to predict the prevalence of SSUs

	Dependent variable:	
	Sustainable start-up prevalence	
	(1)	(2)
Entrepreneurial Ecosystem index		0.030^{***}
		(0.011)
Population	0.000^{**}	0.000^{*}
	(0.000)	(0.000)
GRP	0.007^{***}	0.004^{*}
	(0.001)	(0.002)
Constant	-3.519^{***}	-3.420^{***}
	(0.174)	(0.176)
Observations	273	272
R^2	0.072	0.090
Log Likelihood	508.797	510.260
Note:	$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$	

3.5. Discussion

3.5.1. Conclusion and theoretical implications

In this paper we answered the question: *What entrepreneurial ecosystem elements determine the presence of sustainable start-ups in a region?* We present a framework that sees an SEE as a combination of actors and institutions and that combines the existing EE framework of Stam (2015) with the innovation systems literature (Carlsson and Stankiewicz, 1991; Hekkert et al., 2007; van Rijnsoever et al., 2015).

We find that regular EE quality has a strong positive influence on SSU presence and on SSU prevalence. This confirms that the quality of an EE is more important for SSUs than for regular start-ups. Second, we find that the presence of other start-ups and favourable actors and resources has a strong positive influence on SSU presence in the future. We find limited evidence for the effect of institutions on SSU presence. We argue that this effect is supplanted by sustainability focused actors and resources as these are influenced by these institutions.

3.5.2. Limitations

Our research comes with several important limitations. First, using text data to find if organisations are working on environmental sustainability means there is a risk of greenwashing. This is a serious issue as identifying SSUs on a large scale remains a huge challenge. This even though other studies have found success in using text data (Horne et al., 2020; Leendertse et al., 2021; Tiba et al., 2021). We argue however that this is not a large problem for this study as we do not look at individual start-ups but at regions. We do not expect different levels of greenwashing between regions. Nevertheless, it is worth to keep an eye on new EU regulations requiring more environmental reporting. In the same context, the emergence of Artificial Intelligence might provide opportunities to better identify the sustainability impact of start-ups. Second, we use the NUTS-2 level, but the more fine-grained NUTS-3 level could be a better scale to consider EEs. Finally, we do not know if the SEE framework that we developed also applies for social sustainability focused SSUs, this is a topic for future research.

3.5.3. Practical implications

Policy makers can use our results to establish policies that help build ecosystems for sustainable entrepreneurship in their region. In line with our results, a first step is to focus on building a strong entrepreneurial ecosystem. Second, they can use the additional elements beyond the regular EE to identify which areas to strengthen that matter for SSUs. Especially, supporting actors and resources active in a region is particularly important for SSUs. Actors provide SSUs with access to markets, resources, and thereby help them overcome the constraints they face. We identify two specific actor types that are important. First, the number of regular start-ups. Second, the presence of sustainability-oriented actors and the resources they control. Stimulating the presence of both types of actors are thus potential avenues to a higher presence of sustainable start-ups.

We recommend policy makers to take a process perspective to our findings. Do not just follow the overall outcome, we do well/bad but use the diagnosis made in this (and Chapter 2) as the starting point. Sit down with each other, entrepreneurs, companies, ROMs, provinces, municipalities, universities, colleges, etc., and discuss the diagnosis: Which weak elements are recognized (or not)? What is this due to? how could it be better? Do all stakeholders agree or do we/they have a difference of opinion? How can we improve this region together?

As a second contribution to practitioners our study provides insight in the amount of SSUs currently present in each region (Fig. 11) and the top performing regions (Fig. 12). This allows policy makers to look not only at how their regions are doing, but also to identify and learn from other regions that have a high presence of SSUs.

4. The Entrepreneurial Ecosystem in a Multi-Level Perspective on Transitions

A slightly modified version of this chapter has been submitted as the master thesis of Casparis Beyer as part of the Sustainable Business and Innovation programme at Utrecht University (2020) and is also available at:

https://studenttheses.uu.nl/bitstream/handle/20.500.12932/37028/MSc%20Thesis%20CB%20Beyer%20SBI%20FINAL.pdf?sequence=1.

4.1. Introduction

Urbanization is predicted to result in 6 billion urban inhabitants by 2050. Cities will be exposed to climate change, not only from greenhouse gas-induced radiative forcing but also by localized effects from this urbanization[29] (McCarthy et al., 2010). The Earths' climate is changing because industrial economies have been locked into fossil fuel-based energy systems through a process of institutional and technological co-evolution driven by path-dependent increasing returns to scale (Unruh, 2000). This climate change indicates the necessity for humanity to make a transition to a sustainable and thus low-fossil society. Especially in cities, they generate the bulk of greenhouse gas emissions and have the increasing majority of humans living there. It makes them subject most critically to climate hazards (Corfee-Morlot et al., 2009; Bulkeley, 2013). On the other hand, cities also play an important role in shaping the sustainability transition, based on evidence that indicates that some of the world's most dominant cities are the target of attempts to purposively reconfigure socio-technical systems at the scale of the city (Hodson & Marvin, 2010). The city-level stakes are high, making them a significant arena of transition. I, therefore, focus on the urban transition to sustainability.

A transition is defined as a transformation process in which society changes in a fundamental way over one generation or more (Rotmans et al., 2001). Transitions are long-term and complex processes encompassing multiple actors (Geels, 2011). A fruitful framework to study such transitions is the *multi-level perspective on socio-technical transitions* (MLP). The MLP explains and combines patterns and mechanisms in transition processes (Geels, 2002). It identifies three levels: niche, socio-technical system/regime, and landscape. The different levels are heuristic and analytical concepts to understand the complex dynamics of socio-technical transitions (Geels, 2002). Thus, the MLP is a framework which strength rests in its capacity to capture the bigger picture (Smith et al., 2010). Because socio-technical

[29] An example of this is the urban heat island effect: an urban area or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities (Kim, 1992).

transitions to sustainability are such complex and dynamic processes, it is pivotal to capture this bigger picture and wider context, making the MLP very suitable for this research (Geels, 2011).

The transition from one economic system to another has created unique opportunities for entrepreneurs to forge new companies that fill voids in the structure of industry and services in multiple transition pathways (Estrin et al., 2006; Geels & Schot, 2007). Moreover, entrepreneurship has an important function in the transition process by enabling change (Hekkert et al., 2007). Entrepreneurship that plays a significant role in sustainability transitions is defined as transformative entrepreneurship (Burch et al., 2016). A framework to create, maintain, and accelerate entrepreneurship in a certain delimited space (such as region or city) is the *Entrepreneurial Ecosystem* (EE). An EE is defined as a set of interdependent actors and factors coordinated in such a way that they enable *productive* entrepreneurship[30] within a territory (Stam & Spigel, 2016). We argue that understanding the role of entrepreneurship in regional sustainability transitions requires combining the MLP and EE frameworks. However, to link the EE to the MLP, the principal prerequisite is that this entrepreneurship created by the EE is not solely productive but also transformative. Only then can it function as an essential process in the urban sustainability transition.

We identified research gaps that have prevented the combined use of the MLP and the EE frameworks. Firstly, in the MLP literature research on conditions for entrepreneurship, in general, is scarce, and research on conditions for transformative entrepreneurship is even nonexistent. Secondly, the role of agency in MLP is not satisfactorily elaborated (Smith et al., 2010; Seyfang et al., 2010; Geels, 2011). Thirdly, MLP analyses tend to overlook *where* transitions take place (Hodson & Marvin, 2010; Smith et al., 2010; Coenen et al., 2012; Coenen & Truffer, 2012; McCauley & Stephens, 2012; Fischer & Newig, 2016). Concerning the EE, the emphasis is still very much on productive research, there is little research investigating transformative start-ups, which are, again, required for a transition. Consequently, the relation and combination between the MLP and the EE are underconceptualized. Most importantly, the MLP, thus, does not account adequately for entrepreneurship, whereas the EE does. The relation between the MLP and EE can be used to understand how transformative entrepreneurial output from an EE can play a serious role as the bottom-up component of an urban transition. This understanding can be realized by linking the theories. Scrutinizing transformative entrepreneurship as the output of an EE as a driver of transition and vice versa is therefore important. Accordingly, the research question of this study is:

What configuration(s) of the EE encourages transformative entrepreneurship, which subsequently supports the urban transition to sustainability?

To answer this research question, qualitative evidence is gathered from illustrative case studies of Vaasa and Rotterdam. These cities are illustrative for this research as they require sustainable urban solutions and are actively working on these solutions. This is demonstrated by the fact that these two cities are participating in 'Smart Cities and Community Lighthouse projects' from the European Commission. They are used to explore the different possible configurations of EEs in an urban transition context.

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[30] The term productive entrepreneurship refers to "any entrepreneurial activity that contributes directly or indirectly to the net output of the economy or to the capacity to produce additional output" (Baumol, 1996 p. 30).

We propose a novel Transformative Entrepreneurial Ecosystem (TEE) framework. This framework, and the method used to outline these cases can be applied by other cities to understand how well their ecosystem is able to contribute to transformative entrepreneurship. Moreover, the ultimate goal is not only to show the different relations between the frameworks but also to provide advice on how to rig the EE to actively use its influence and structure to support the sustainability transition in cities. In addition, the EE theory is enriched with conditions for transformative entrepreneurship. Given that the EE approach is built on strong spatial underpinnings and pays significant attention to the role of agency (O'Connor et al., 2018), it can also improve the MLP on these dimensions. The EE thus enhances the MLP with a spatial dimension and the required, more thorough, elaboration of agency. As a result, this study contributes to a better understanding of how to exploit the EE in the urban transition towards a sustainable future. It can serve as a roadmap to manage their EE for cities and regions worldwide facing a similar grand challenge of transitioning to a sustainable (low fossil) system.

4.2. Theory

4.2.1. Transitions to sustainability

To place the current urban transition in perspective, it is first crucial to stress that it is a 'sustainability transition'. Such transitions have some special characteristics differing from many historical transitions (Geels, 2011). Three of these characteristics stand out. Firstly, sustainability transitions are 'purposive' or goal-oriented as they address persistent environmental problems, as opposed to many historical transitions that were more 'emergent' (Smith et al., 2005). Secondly, because sustainability is a collective good, sustainability transitions do not offer clear user benefits. They often score lower on price and performance dimensions than established technologies. Consequently, it is unlikely that environmental innovations or 'green niches' will be able to replace systems without deep-rooted changes in underlying economic frame conditions such as taxes, subsidies, and regulatory frameworks (Geels, 2011). Thirdly, the empirical domains where sustainability transitions are needed most (e.g., energy, agri-food, and transport) are characterized by large firms holding onto 'complementary assets[31]' (Rothaermel, 2001). Hence, these large firms have a strong position relative to new firms or entrepreneurs that develop environmental innovations first but have no complementary assets as opposed to these large firms. Sustainability transitions thus need incumbents' strategic reorientation as they at first defend existing systems. These three considerations suggest that sustainability transitions are certainly about interactions between politics, technology, economics, and culture. These interactions are thus multi-dimensional and imply systemic change. The MLP is a framework that analyses transitions from a multi-dimensional and

[31] Examples are specialized manufacturing capability, experience with large-scale test trials, access to distribution channels, service networks, and complementary technologies (Rothaermel, 2001).

systemic point and is therefore chosen for this research. Moreover, the MLP has already been successfully applied to studies of contemporary and future transitions to sustainability[32] (Geels, 2011). In the next sections, the MLP will, therefore, be scrutinized.

4.2.2. Multi-level perspective on socio-technical transitions

4.2.2.1. Background

The MLP is a middle-range theory[33] that conceptualizes the overall dynamic patterns in socio-technical transitions (Geels, 2011). In this way, it serves as a heuristic approach for analyzing systemic socio-technical change (Geels, 2004; Geels, 2002). Thus, the MLP is a scheme that relates various concepts and uses empirical research to identify generalizable lessons and recurring patterns (Geels, 2011). The MLP's core concept of a *socio-technical transition* originates from the *technological transition* developed by Nelson and Winter (1982) and Rip & Kemp (1998). The MLP framework combines concepts from *science and technology studies*[34], *evolutionary economics*[35], *structuration theory,* and *neo-institutional theory*[36] (Geels, 2011). The theoretical micro-assumptions for these underlying strands of literature have been expressed elsewhere in studies by Geels (2004) and Geels & Schot (2007; 2010).

The MLP suggest that transitions result from the interplay of development of three analytical levels; an exogenous socio-technical landscape at the macro-level; the socio-technical systems that are stabilized by and intertwined with socio-technical regimes at the meso-level; and the micro-level niches, which are the locus for radical innovations (Rip & Kemp, 1998; Geels, 2002). Each of these levels refers to heterogeneous combinations of elements. Higher levels are more stable than lower levels in terms of alignment between the components and the number of actors (Geels, 2011). Transitions are defined as shifts from an old system to a new system (Geels, 2011). The landscape and niche levels are determined in relation to these systems. The landscape is defined as the external environment that influences interactions between systems and niche(s). In contrast, niches are defined as protected spaces for technologies or practices that differ substantially from existing systems (Geels, 2011). We now delve

[32] Examples are electricity systems (Verbong and Geels, 2007; Verbong and Geels, 2010; Hofman and Elzen, 2010), mobility and 'green' cars (Nykvist and Whitmarsh, 2008; Van Bree et al., 2010; Geels et al., 2011), biogas and co-combustion (Raven, 2004), organic food and sustainable housing (Smith, 2007), and animal welfare in pig farming (Elzen et al., 2011).

[33] Merton & Merton (1968:39) defined *middle-range theories* as "theories that lie between the minor but necessary working hypotheses that evolve in abundance during day-to-day research and the all-inclusive systematic efforts to develop a unified theory that will explain all the observed uniformities of social behavior, social organization, and social change". It navigates between the extremes of grand theory and abstracted empiricism, which only focuses on data-collection and data-analysis.

[34] Concepts of science and technology studies are sense-making, social networks, innovation as a social process shaped by broader societal contexts (Geels, 2011).

[35] Key concepts of evolutionary economics are trajectories, regimes, niches, speciation, path dependence, routines (Geels, 2011).

[36] Neo-institutional theory argues that rules and institutions are 'deep structures' on which knowledgeable actors draw in their actions and the duality of this structure (i.e., structures are both context and outcome of actions, the 'rules of the game' that structure actions) (Geels, 2011).

deeper into the three analytical levels as they are the backbone of the MLP. A visualization of the three analytical levels is provided in Fig. 14.

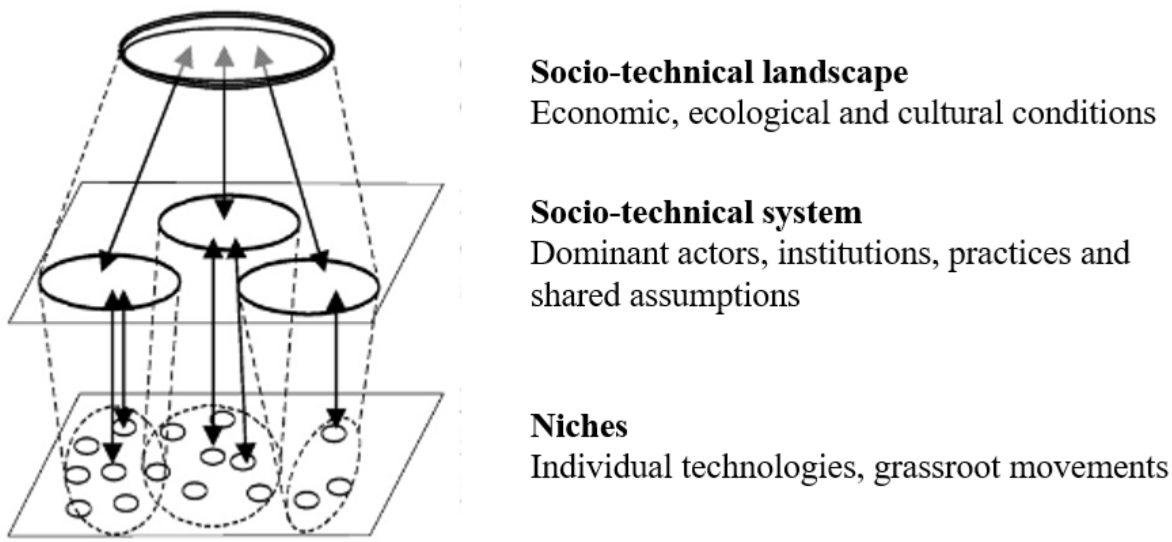

Fig. 14. The three analytical levels in MLP, based on Nykvist & Whitmarsh (2008)

4.2.2.2. Socio-technical landscape

The landscape level is the broader context affecting the system and niche dynamics (Rip & Kemp, 1998). It highlights the material and technical setting, macroeconomic patterns, demographic trends, societal values, and political ideologies that sustain society (Geels, 2011). These factors are combined within a single 'landscape' level because they form the external context that actors at both niche and system levels cannot influence in the short run. The socio-technical landscape usually changes slowly (Geels, 2011).

4.2.2.3. Socio-technical system and regime

Geels (2004) defines systems as: 'the linkages between elements necessary to fulfill societal functions (e.g., nutrition, communication or transport)'. Systems distinguish the production, distribution, and use of technologies as sub-functions, which are, in turn, fulfilled by necessary elements (i.e., resources). Systems do not function autonomously but are the outcome of human actors embedded in social groups (Geels, 2004). A schematic representation of such a system is presented in Fig. 15.

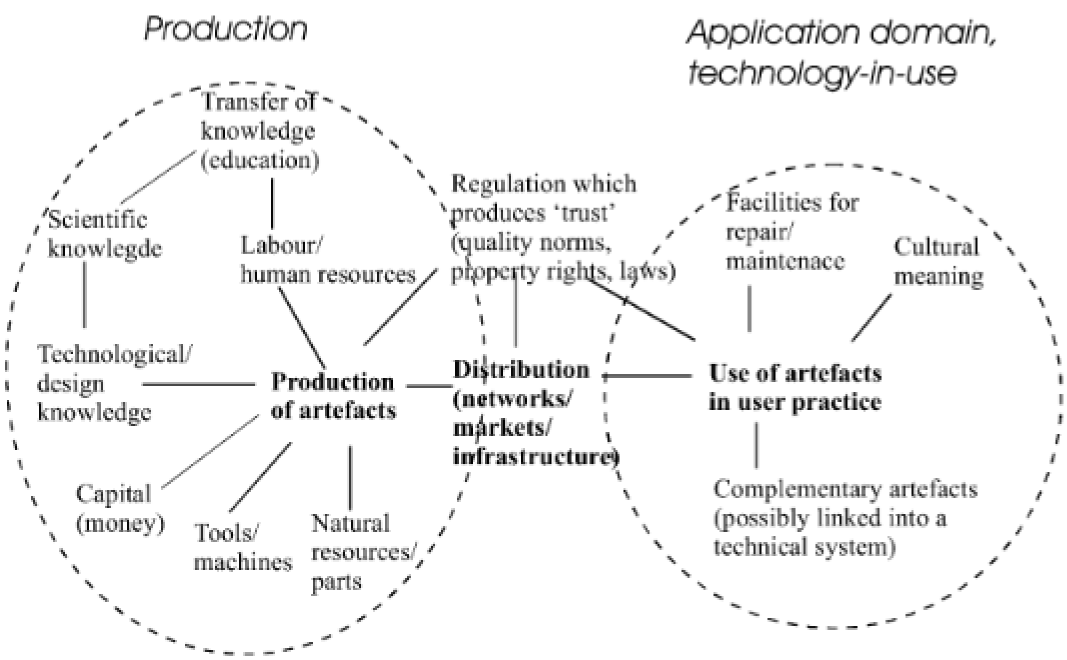

Fig. 15. The basic elements and resources of a socio-technical system, retrieved from Geels (2004)

The regime[37] forms the grammar or 'deep structure' that explains the stability of an existing socio-technical system (Geels, 2004). Thus, the regime is the semi-coherent set of rules (i.e., the institutions) that coordinate and orient the social groups' activities that reproduce the variety of elements in a system (Geels, 2011). Examples of these regime rules are favorable institutional arrangements and regulations, capabilities and competences, cognitive routines and shared beliefs, legally binding contracts, lifestyles, and user practices (Geels, 2011). Regime rules work in two ways: they are both medium and outcome of action. In other words, on the one hand, the actors represent, enact and draw upon rules in terms of concrete actions in local practices, while, on the other hand, the rules configure the actors (Geels, 2011). Existing systems are characterized by lock-in. Therefore, innovations occur incrementally, with small changes leading to stable trajectories.

4.2.2.4. Niches

The third analytical MLP level is the niche. Niches are *protected spaces* such as subsidized demonstration projects, R&D laboratories, or small market niches where users are willing to support emerging innovations (Geels, 2011). Niche actors work on radical innovations that deviate from existing systems. Examples of niche actors are *entrepreneurs, spinoffs, and start-ups.* Niche-actors have the goal of using their radical innovations to challenge the current system. If the niche actors succeed, their innovations

[37] Some clarification is required concerning the conceptual ambiguity of the terms '(socio-technical) regime' and '(socio-technical) system' in MLP literature. The terms are used interchangeably for the same phenomena; the meso-level of the MLP. However, a regime is not a system. I want to make a firm distinction here: the system is the analytical meso level in MLP, whereas the regime is the web of institutions structuring and shaping this system.

are used in the system or even replace the system (Geels, 2011). This concept of systemic replacement is another term for a transition. Systemic replacements are difficult because niche-innovations are often a mismatch with the actual system dimensions (e.g., lack of consumer practices, regulations, or appropriate infrastructure). Systems are, furthermore, as mentioned in the paragraph before, stabilized by many lock-in mechanisms. Therefore, niches are crucial for transitions; they provide the seeds for systemic change (Geels, 2011). The literature on niche innovation identifies three core processes in niche development (Kemp et al., 1998; Schot & Geels, 2008). These three processes are a prerequisite for niches to gain momentum (Geels, 2011). Firstly, the building of social *networks* and the enrolment of more actors expand the resource base of niche-innovations. Secondly, *learning and articulation processe*s in various dimensions[38]. Thirdly, the articulation (and adjustment) of *expectations or visions* guides the innovation activities and aims to attract attention and funding from external actors.

For niches to gain this momentum, scholars further stress the importance of strategic niche management (SNM). SNM is the concentrated effort of creating, developing, and controlling protected spaces for specific applications of new technology (Kemp et al., 1998). Although superficial, it is interesting to notice that at the MLP niche level, there is some reference to entrepreneurship. Nevertheless, except for this reference, MLP does not go further than vaguely stating that entrepreneurship exists at the niche level, embodied as niche actors. Conceptualization of how this entrepreneurship exists is lacking. Oppositely, entrepreneurship is the central component of EE theory. Linkages and potential synergies between the theories do exist.

4.2.2.5. The MLP framework and pathways

The three levels are combined into an ‘ideal-typical’ representation (Fig. 16), the MLP on transitions. It explains how the three levels interact dynamically in the unfolding of socio-technical transitions. Each transition is unique, but the model argues a general dynamic pattern in transitions characterized by the interaction between processes at different levels.

[38] For instance: technical design, market demand and user preferences, infrastructure requirements, organizational issues and business models, policy instruments, symbolic meanings.

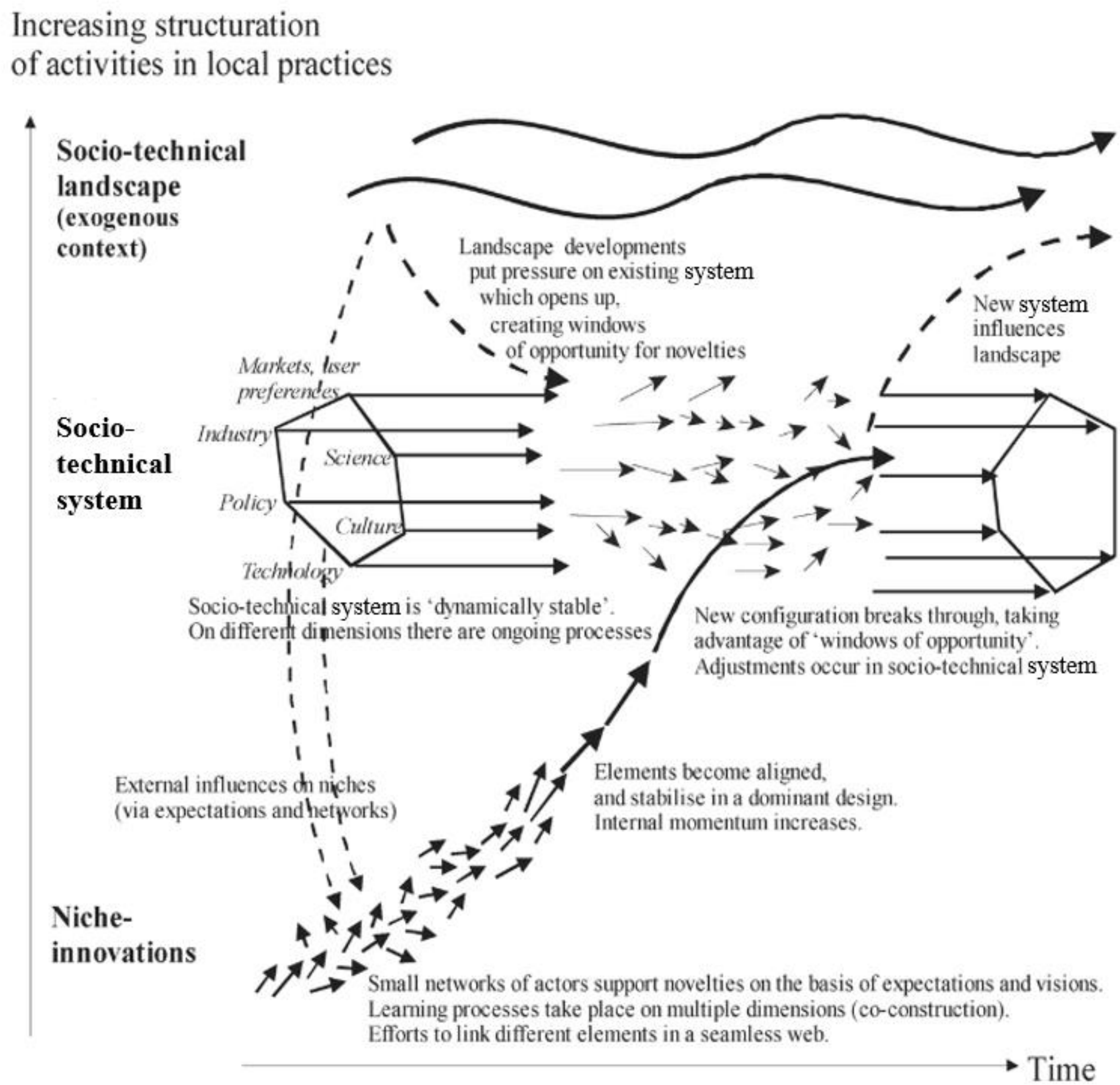

Fig. 16. The multi-level perspective on transitions, based on Geels (2011)

The MLP rules out a single cause or driver of a transition. Instead, transitions are complex phenomena with processes in multiple dimensions and at different levels influencing each other in multiple ways. The growth of certain niche-innovations can, for instance, require interactions between two (or more) systems[39]. Recognizing this complexity, Geels & Schot (2007) and Geels et al., (2016) developed a typology of four transition pathways: transformation, reconfiguration, technological substitution, and de-alignment and re-alignment. The different pathways alter in combinations of timing and the nature of

[39] Examples of these interactions are battery-electric vehicles that link transport and electricity systems, co-generation of heat and power links heat and electricity systems and biofuels link agriculture and transport systems.

multi-level interactions. Also, every transition can be unique because it can morph from one transition pathway to another and back (Geels & Schot, 2007). An overview of the four different pathways is given in Table 14.

Table 14. Transition pathways, based on Geels & Schot (2007), Geels (2011) and Geels et al., (2016)

Transition pathways	Idea in short
Transformation	In this pathway, landscape developments exert pressure on the system when niche-innovations are not well-developed. Incumbent actors modify the direction of innovation activities and development paths, which leads to gradual adjustments of systems to landscape pressures. Although niche-innovations do not break through in this path, experiences from niches can be translated and accommodated (often in a watered-down form) in the system
Technological substitution	In this pathway, competitive niche-innovations are well developed when landscape developments exert pressure on systems. Tensions in the system form a window of opportunity for the breakthrough of niche-innovations that replace the system. An alternative route is that niche-innovations gain high internal momentum (because of resource investments, consumer demand, cultural enthusiasm, political support, etc.), in which case they can replace the system without the help of landscape pressures.
Reconfiguration	In this pathway, niche-innovations are more developed when landscape developments exert pressure on systems. If niches are symbiotic to the system, incumbent actors can adopt them as 'add-ons' to solve local problems. This incorporation can trigger subsequent adjustments, which change the system's basic architecture.
De-alignment and re-alignment	In this pathway, major landscape pressures first cause disintegration of systems (de-alignment). Then, taking advantage of this 'space', multiple niche-innovations emerge, which co-exist for extended periods (creating uncertainty about which one will become the winner). Processes of re-alignment eventually occur around one innovation, leading to a new system.

As this paper is particularly looking at the MLP in combination with the EE, bottom-up components of transition pathways (i.e., niche dynamics) are the areas of interest. Appendix C will unfold which transition pathway is relevant per case based on their relative characteristics. Overall, niche innovations 'emerge' with the help of SNM, but how they emerge is unclear, actor and agency issues remain (de Haan & Rotmans, 2018). These niches are to be perceived as pivotal for bringing about system shifts, but they cannot do this independently. Linkages with ongoing external processes are also imperative (Schot & Geels, 2008).

4.2.2.6. The MLP on an urban scale

In the last section, we identified the importance of niche dynamics in all transition pathways. Next, we turn to the fact that the subject of sustainability transitions has remained at the periphery of regional and economic geography studies (Coenen & Truffer, 2012). There is, however, a need to add greater emphasis on the territorial embeddedness and multi-scalar nature of sustainability transitions (Coenen & Truffer, 2012). Transition processes are geographically uneven because of their relative uniqueness to other regions around the world (Coenen et al., 2012). Acknowledging this need provides a complete understanding of the different ways spatial contexts actively and substantially shape transition processes and, consequently, emphasizes the multiplicity and heterogeneity of transition pathways (Coenen &

Truffer, 2012). To enrich MLP theory with a spatial dimension, it should thus be combined with a geographic perspective. In the following section, we suggest such a perspective: the EE, to add required territorial encapsulation and further elaboration of niche dynamics concerning actors and entrepreneurial agency (as discussed in the previous section) to this urban transition.

4.2.3. Entrepreneurial ecosystems

4.2.3.1. Background

A bottom-up piece in the analytical puzzle of urban transitions to sustainability is the EE (Bischoff & Volkmann, 2018). Therefore, this section will first explicate the EE approach in terms of its background, assumptions, and concepts. EEs are, as stated in the introduction, defined as a set of interdependent actors and factors coordinated in such a way that they enable productive entrepreneurship within a territory (Stam & Spigel, 2016). Spigel (2017) further specified the EE as a union of active economic policies, universities, social networks, localized cultural outlooks, and investment capital that create environments of supportive innovation-based start-ups. The two dominant origins of the EE are strategy literature and regional development literature. Both lineages share common roots in ecological systems thinking, providing insights into the interdependence of actors in a community to create new value (Acs et al., 2017). Table 15 gives a representation of the EE in relation to its origins: strategic management and regional development.

Table 15. Origins of the EE approach, based on Acs et al., (2017)

	Regional development	**Strategic management**	**EE approach**
Value	Value creation by firms in related industries (productivity) driven by competition (value capture) and collaboration	Value creation and capture by firms	Value creation by individual entrepreneurs, as indicated by the prevalence of high-impact entrepreneurial efforts (such as Unicorns)
Context	Regional	Global	**City**/regional/national
Coordination	Firms' rivalry and collaboration, government policy	Governance and management by a focal orchestrator firm	Public-private governance

The EE approach is seen within academic, policy, and business literature as an important tool for creating resilient economies based on entrepreneurial innovation (Spigel, 2017). EE theory is related to multiple strands of research that include work on industrial districts, clusters, innovation (eco)systems, economic geography, triple helix, social capital, and networks (Spigel, 2017). Although these theories differ in their conceptual and methodological perspectives, they share a common idea that certain attributes exist outside a firm's boundaries but within a region, which can contribute to a new venture's competitiveness. These theories emphasize three regional resources that contribute to increased entrepreneurship and growth. Firstly, social networks within regions help spread information about entrepreneurial opportunities (Arenius & de Clercq, 2005), connect entrepreneurs with financiers (Powell et al., 2002), and create pathways for knowledge spillovers between firms and universities (Owen-Smith & Powell, 2004). The following regional resources are institutional environments and shared cultural understandings that ease interfirm cooperation and normalize practices such as firm mobility and knowledge sharing (Henry & Pinch, 2001; Gertler, 2003). Thirdly, universities and government policies can support these networks and cultures by training entrepreneurs and skilled workers by removing institutional and regulatory barriers for entrepreneurs and funding support programs tailored explicitly to incubation facilities and networking events (Feldman & Francis, 2004). Table 16 gives a thorough overview of the related theories and their input in the EE approach. Subsequently, Table 17 highlights some of the most important similarities and differences. Both tables serve to embed EE theory within its wider theoretical context. It shows that the EE approach has a focus on the external business environment in common with the other established concepts. There are forces beyond the boundaries of an organization that can contribute to an entrepreneur's overall competitiveness, and the entrepreneur contributes to a system larger than itself (O'Connor et al., 2018).

Table 16. Comparison EE with related theories, based on O'Connor et al., (2018)

	Key actors	Key concepts	Input into EE approach	Key outcome
Marshallian industrial district	- SMEs	- Labor market pooling - Specialized goods and services - Knowledge spillovers - Market competition	- Talent (labor market pooling) - Intermediate services (specialized goods and services) - Knowledge (spillovers)	Regional economic growth (productivity)
Italianate industrial district	- SMEs - Local government	- Flexible specialization - Interfirm cooperation - Trust (social embeddedness)	- Networks between entrepreneurs and enterprises	Regional economic growth (employment)
Cluster	- Innovative firms	- Factor conditions - Demand conditions - Related and supporting industries - Firm structure - Strategy and rivalry	- Talent - Finance - Knowledge - Physical infrastructure (factor conditions)	National/regional competitiveness (productivity of particular industries)
Innovation system	- Innovative firms - National government	- Networks - Inter-organizational learning - System	- Knowledge - Finance - Formal institutions - Demand	Innovation
Triple helix model	- Government - Firms - Universities	- Interactions between university-industry-government - Innovation - Knowledge-based society	- Knowledge transfer and interdependence of three sectoral actors	Innovation system
Innovation ecosystem	- Innovative firms	- Co-innovation - Adoption chain - Shared value proposition	- Interdependence or actors involved in innovation - Global networks	- Value creation and capture by firms in the ecosystem - Firm survival

Table 17. Similarities and differences between EE and related theories, based on O'Connor et al., (2018)

Approach	Industrial District, Cluster, Innovation System, Triple Helix	Innovation Ecosystem	EE
Main focus	Economic and social structures of a place that influence overall innovation and firm competitiveness. In many cases, little distinction is made between (fast-growing) start-ups and other types of organizations.	Creating customer value through a chain of independent organizations, with differential value capture by different players in the ecosystem.	Start-ups are explicitly at center of ecosystem. Are seen as distinct from established large firms and (lower growth) SMEs in terms of conceptual development and policy formation
Locus of action	Private firms and state are primary locus of action in building and maintaining industrial district/cluster/innovation system. Little room for agency in their creation.	One large firm as orchestrator of the ecosystem, with many other firms co-innovating or involved in the adoption of innovation.	Entrepreneur is the core actor in building and sustaining the ecosystem. While state and other sources might support the ecosystem through public investment, entrepreneurs retain agency to develop and lead the ecosystem

What becomes clear from Table 16 is that many theoretical constructs in the EE framework originate from these abovementioned related strands of literature. Table 17 undoubtedly shows that the EE, as opposed to related theories, places entrepreneurship at its core, rather than 'the enterprise'. In addition, entrepreneurship is not only the output of the EE. Entrepreneurs are important actors themselves in creating the EE and keeping it potent (Feldman, 2014). By doing this, the entrepreneurs retain agency to develop and lead the ecosystem. This is an important discovery in light of the lack of agency in MLP theory (Smith et al., 2010; Seyfang et al., 2010; Geels, 2011; de Haan & Rotmans, 2018). The next section will, therefore, scrutinize the EE approach.

4.2.3.2. The entrepreneurial ecosystem framework

The distinguishing feature of the EE is the focus on value creation by entrepreneurs. This entrepreneurial value creation has many manifestations, such as high-growth start-ups, innovative start-ups, 'unicorn' ventures, and entrepreneurial employees (Stam, 2013). Boundaries are defined by a city or regional geography. Also, the EE exhibits a complex mix of public-private governance (Acs et al., 2017). Researchers have created and debated a variety of lists of 'ingredients' for a successful EE[40]. Stam (2015; 2018) researched this clutter of EE literature and its shortcomings and created a causal scheme of how the framework and systemic conditions of the ecosystem lead to entrepreneurial activities as the output of the ecosystem and new value creation as the outcome of the ecosystem. This scheme is a framework for analyzing the interactions between the elements within the ecosystem. Stam's (2015; 2018) framework is an integrative model that connects the functional attributes of entrepreneurial ecosystems (including

[40] These lists range from 'nine attributes of a successful start-up community' (Feld, 2012), to 'six domains of the EE' (Audretsch & Belitski, 2017), to 'key principles to build EEs' (Isenberg, 2010), to 'EE pillars and their components' (Foster et al., 2013), to 'ten cultural, social, and material attributes of an EE' (Spigel, 2017), and to 'norms for the successful performance of a corporate EE' (Beinhocker, 2007:371).

framework conditions and systemic conditions) with entrepreneurial outputs and welfare outcomes. The framework conditions consist of formal institutions, culture, physical infrastructure, and demand. Systemic conditions are the heart of the ecosystem and include networks (of entrepreneurs), leadership, finance, talent, knowledge, and support services/intermediaries (Stam & Spigel, 2016). As shown in Table 15, these conditions greatly originate from the related strands of literature in regional development and strategic management (Table 14). we choose Stam's framework because it is the most complete framework in EE literature, bringing together previous literature, and providing more causal depth (Stam, 2015). It offers a rigorous and relevant starting point for subsequent studies into EEs (Stam, 2015). Also, the EE approach goes beyond a metaphorical attitude by composing a complex systems approach to entrepreneurship and structural economic change (Stam, 2018). This framework is presented in Fig. 17.

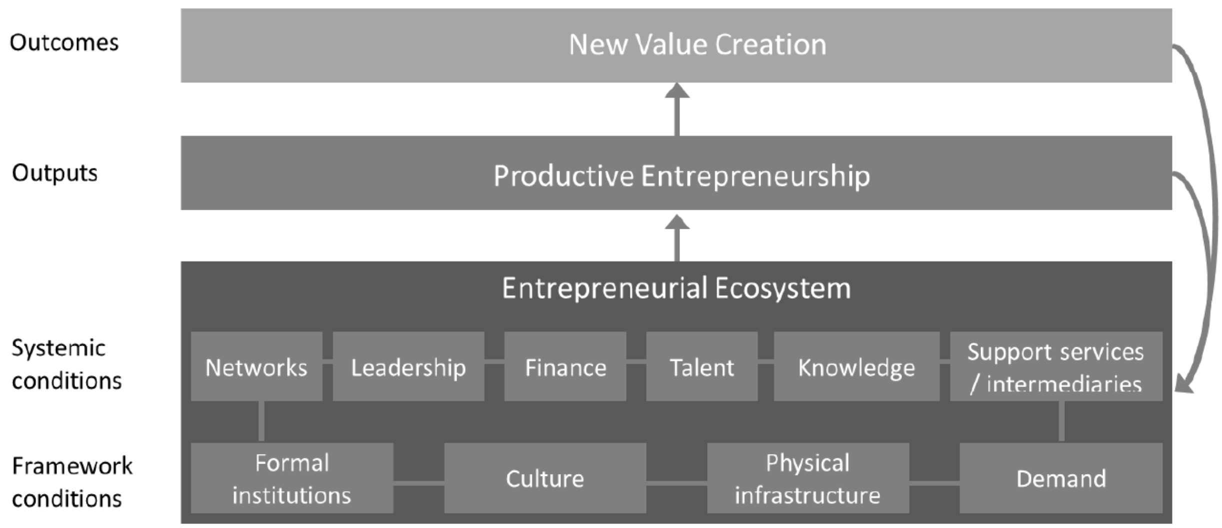

Fig. 17. The EE framework, retrieved from Stam (2018)

The EE framework visualized in Fig. 17 includes downward and upward causation. Downward causation demonstrates how outcomes and outputs of the system over time feed back into the system conditions, while upward causation reveals how the fundamental causes of entrepreneurial activity and, in turn, new value creation are mediated by the intermediate elements (Stam, 2015).

Table 18 gives a more detailed description of the systemic and framework conditions depicted in Fig 17.

Table 18. Descriptions of the framework and systemic conditions, based on Stam (2018)

	Theme	Description
Framework conditions	Formal institutions	The rules of the game in society, in particular the quality of government
	Culture	The degree to which entrepreneurship is valued in a region
	Physical infrastructure	Physical infrastructure and the position of a region
	Demand	Potential market demand
Systemic conditions	Networks	The connectedness of businesses for new value creation
	Leadership	Leadership that provides guidance for and direction of collective action
	Talent	The prevalence of individuals with high level of human capital
	Finance	The supply and accessibility of finance for startups and/or scale-ups
	Knowledge	Investments in new knowledge
	Intermediate services	The supply and accessibility of intermediate business services

4.2.4. Bridging the frameworks

The entrepreneurial ecosystem is a multi-level construct, composed of several interacting sub-(eco)systems (Theodoraki & Messeghem, 2017). The MLP also is a multi-level construct with interacting niche, system, and landscape dynamics. The critical challenge is to transform old systems into more sustainable configurations (Berkhout, 2002). Entrepreneurs define the 'place' boundary in transitions (O'Connor et al., 2018). Moreover, the bottom-up end of transitions is dependent on entrepreneurs being able to access resources that assist in new venture development (O'Connor et al., 2018). Consequently, the EE is considered a place-based change management instrument (O'Connor et al., 2018). Bridging the two frameworks towards a novel synthesis can help with future configurations of transformative EEs for the urban transition to sustainability. However, on the one hand, the EE approach lacks specification concerning transformative entrepreneurship, which is required for the urban transition. On the other hand, the MLP lacks (niche-level) specification of the conditions needed for transformative entrepreneurship. Thus, to link the MLP with the EE, the first step is to overcome these knowledge gaps. Table 19 takes this first theoretical step to combine the theories, an overview of the prevalent similarity between the MLP niche and the EE.

Table 19. Linkages between the MLP niche level and the EE

Approach	MLP niche	EE	Similarities
Definition	Niches are 'protected spaces' that allow the experimentation with the co-evolution of technology, user practices, and regulatory structures. Examples are: R&D laboratories, subsidised demonstration projects, or small market niches where users have special demands and are willing to support emerging **innovations**.	An EE is **a set of interdependent actors and factors coordinated** in such a way that they enable productive entrepreneurship within a territory.	
Main focus	To create temporary protected spaces for more sustainable technologies. Niche-innovation through SNM: niche-actors hope that their promising novelties are eventually used in the regime or even replace it. SNM is **not the purview of a single actor but a collective endeavour**.	Start-ups are explicitly at center of ecosystem. Are seen as distinct from established large firms and (lower growth) SMEs in terms of conceptual development and policy formation.	
Locus of action	The niche itself as a 'black-box' with respect to actors.	Entrepreneur is the core actor in building and sustaining the ecosystem. While state and other sources might support the ecosystem through public investment, entrepreneurs retain agency to develop and lead the ecosystem.	
Key actors	**Entrepreneurs, start-ups** and spinoffs. Niche managers' who can be state policymakers, a regulatory agency, local authorities (e.g. a development agency), non-governmental organizations (NGOs), a citizen group, a private **company**, an industry organization, a special interest group or an **independent individual.**	**Entrepreneurs, start-ups**, universities, financers, (large) **firms**, intermediaries (i.e. accelerators & incubators), **mentors & advisors, governmen**t and supporters.	**Similar actors**
Key concepts	Niche-**innovation** Niche-accumulation (i.e. growth) Strategic niche management (SNM) **Learning**	Formal institutions, culture, physical infrastructure and demand, **networks of entrepreneurs**, leadership, finance, talent, **knowledge** (in addition to market and technical knowledge, entrepreneurial knowledge is crucial) and support services/intermediaries.	**Knowledge/learning**
Key processes	"**Small networks of actors support novelties** based on expectations and visions. **Learning processes** take place on multiple dimensions (co-construction). Efforts to link different elements in a **seamless web**.	Entrepreneurial activity: the process by which individuals create opportunities for innovation. EEs focus on the cultures, institutions, and **networks** that build up within a region. **Knowledge** about the entrepreneurship process is shared between entrepreneurs and mentors through informal social networks, entrepreneurship organizations, and training courses offered.	**Building of networks of actors** **Prominent role of knowledge and learning**
Key outcome	Niche-**innovation** and growth **Building of networks of actors**	Aggregate value creation Productive entrepreneurship **Innovative** entrepreneurship	**Innovation**
Key references	Schot & Geels (2008) Geels (2011) Kemp et al., (1998)	Stam & Spigel (2016) Stam (2015) Acs et al., (2014)	

The linkages are evident, firstly illustrated by the fact that niche and EE actors are similar. Secondly, the building of (social) networks is argued as a condition for niches to gain momentum and emphasized as well in the EE approach. Thirdly, the vital role of knowledge and learning in both niche and EE. Finally, the emphasis from both theories on innovation. we propose that the EE can function as a comprehensive elaboration of an MLP niche. The EE can thus improve the MLP. This implicates the added value of combining the frameworks. On the one hand, the MLP niche level is enriched with place, actor, and entrepreneurial agency considerations. On the other hand, the EE is applied to contribute to sustainability and transition thinking in an urban context. It is important to notice that for this combination to be rigid; the EE should be configured so that its entrepreneurial output is transformative (i.e., transition oriented). Therefore, the dependent 'productive entrepreneurship' and subsequent 'new value creation' outcome of the traditional EE should be replaced by: 'transformative entrepreneurship' and subsequent 'sustainable value creation'. The data collection serves the need to scrutinize how this change in the dependent variables changes (the configuration of) the independent systemic and framework conditions of the EE. Furthermore, the data in the results section will show unique, region-specific patterns and more generalizable lessons of the shape of such a transformative entrepreneurial ecosystem (TEE). The next section provides methodological functionality on how to resolve these conceptual lacunae to answer the research question.

4.3. Method

4.3.1. Case description and selection

I take two cities as a spatial lens, because, as mentioned in the introduction, cities play an important role in shaping the sustainability transition. Qualitative evidence is gathered from illustrative case studies of Rotterdam and Vaasa. These cities are illustrative for this research as they are both requiring sustainable urban solutions and are working on these solutions, displayed by the fact that they are participating in 'Smart Cities and Community Lighthouse projects' from the European Commission. A smart city is defined by the European Commission 2019 as: "A place where the traditional networks and services are made more efficient with the use of digital and telecommunication technologies, for the benefit of its inhabitants and businesses". Rotterdam is a participant of the RUGGEDISED lighthouse project, while Vaasa participates in the lighthouse project 'Integrated and Replicable Solutions for Co-Creation in Sustainable Cities' (IRIS). RUGGEDISED is a smart city project. It tests and implements smart solutions, from energy, transport to digital technology, in three large-scale 'Lighthouse' city testbeds to pave the way towards a smarter, more sustainable Europe (ICLEI, 2019). Working in partnership with businesses and research centers, these cities will demonstrate how to combine ICT, e-mobility, and energy solutions to design smart, resilient cities. This means improving citizens' quality of life, reducing the environmental impact of activities, and creating a stimulating environment for sustainable economic development (ICLEI, 2019). IRIS is also a smart city project that started in October 2017 for five years. It draws upon a mix of local authorities, universities and research organizations, private expertise, and innovation agencies to accelerate entire communities to adopt ambitious energy, ICT, and mobility initiatives (Iris Smart Cities, 2019). The purpose is not to privilege one EE over the other; the different cities are rather used to explore the different possible configurations of EEs in their respective unique urban transition contexts.

4.3.2. Research design

This research will combine insights from literature and qualitative research. we take an overarching abductive[41] approach where the continuous interplay between theory and empirical observation is central (Dubois & Gadde, 2002). Hence, this research's primary concern is related to the development of the existing theory (EE and MLP) and the generation of new concepts from interviews. Through *systematic combining*, which is key in abductive research, theory on MLP and EE is thus refined and enriched by synergistic cross-fertilization between the established theories and new concepts derived from interviews with actors (Dubois & Gadde, 2002). Systematic combining is a nonlinear, path-dependent process of combining efforts with the ultimate objective of matching theory and reality (Dubois & Gadde, 2002). A schematic representation of systematic combining is provided in Fig. 18. One major difference between abductive research and both inductive and deductive research, is the role of the framework(s). In studies relying on abduction, the original framework is successively modified, partly due to unanticipated empirical findings but also of theoretical insights gained during the process (Dubois & Gadde, 2002).

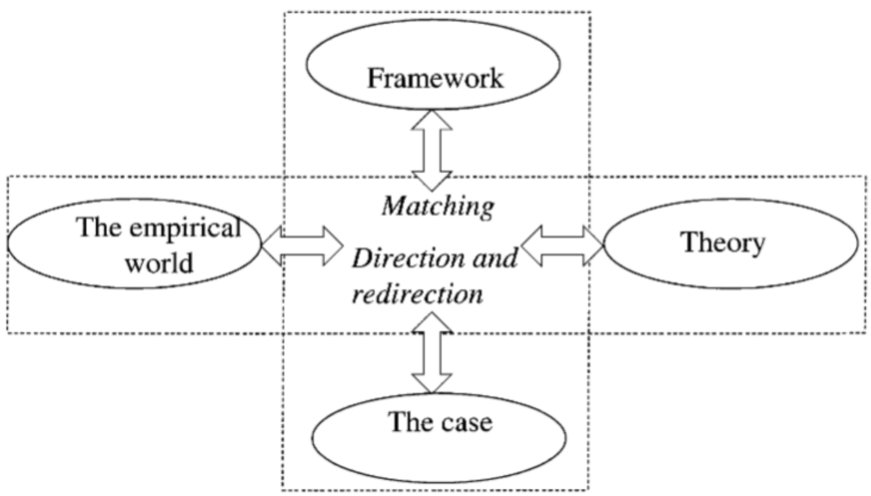

Fig. 18. Systematic combining in abductive research, retrieved from Dubois & Gadde (2002)

4.3.3. Data collection

The literature research contained desk research into MLP theory, EE theory, and related relevant topics, incorporating scientific articles, books, and, if necessary, grey literature. The empirical research was qualitative by nature and ranged from actor-observation to actor-interviews. Actor-observation was executed by attending relevant local (online) events, summits, and task force meetings in the two cities. Actor-interviews were also conducted with the different appropriate actors in the EEs of Rotterdam and

[41] Abductive reasoning starts with the observation of phenomena and then seeks to develop explanations for them, by working iteratively between theory and data (Bell et al., 2018), it refers to the place of explanatory reasoning in justifying hypotheses (Douven, 2011).

Vaasa. The interview sample encompasses all the relevant actors in the respective EE: entrepreneurs, incubators, related government officials, (early-stage) investors, affiliated businesspeople, advisors, and research institutes, both private and public. Snowball sampling (or 'chain referral sampling') was used to enrich the sample (Biernacki & Waldorf, 1981).

The interviews were semi-structured and followed an interview guide (Appendix C). Furthermore, the interview guide was personalized per interviewee based on their background and position in the EE. Semi-structured interviews are used to collect detailed information and to delve deep into a topic and understand the answers thoroughly, without the loss of information (Harrell & Bradley, 2009), which suits well with the objective of this research. The interviews were recorded (after consensus) and transcribed using Otter.ai and Sonix.ai[42]. An example transcript is provided in Appendix D. The interviewee samples of Rotterdam (20 interviewees) and Vaasa (24 interviewees) are provided in Table 20 and Table 21.

Table 20. Interviewee sample Rotterdam

#	Organization	Position	Type of Actor	Code in text
1	Erasmus Centre of Entrepreneurship	Business Developer	Intermediate service - University	R1
2	Ciphix	Founder	Start-up / Scale-up	R2
3	SpeakSee	Operations Manager	Start-up / Scale-up	R3
4	PortXL	Senior Acceleration Manager	Intermediate service	R4
5	Thrive Institute	Innovation Manager	Intermediate service	R5
6	VentureCafe	Executive Director	Intermediate service	R6
7	Contra Music / Awesome Foundation	Event Production / Co-founder	Start-up / Scale-up - Intermediate service	R7
8	iTanks	Director	Intermediate service	R8
9	Yes!Delft / start-up Corner	Community Manager / General Manager	Intermediate service	R9
10	Skoon	Founder	Start-up / Scale-up	R10
11	Uniiq	Investment Manager	Investor	R11
12	Up!Rotterdam	MatchMaker	Local government - Intermediate service (public private)	R12
13	Voor Goed Agency	Communication	Intermediate service / Investor	R13
14	Innovation Quarter	Advisor Business Intelligence	Regional development agency – Intermediate service – Investor – Regional government (public private)	R14
15	Erasmus MC Incubator	Manager	Intermediate service - University	R15
16	Up!Rotterdam	Partner Success	Local government - Intermediate service (public private)	R16
17	Rotterdam Partners	Sector Manager Agro-Food	Local government - Intermediate service (public private)	R17
18	Rotterdam Partners	Business Manager Innovation	Local government - Intermediate service (public private)	R18
19	Woodwatch	Founder	Start-up / Scale-up	R19
20	Juuve	Founder	Start-up / Scale-up	R20

[42] Both are programs that use artificial intelligence to convert audio in text.

Table 21. Interviewee sample Vaasa

#	Organization	Position	Type of Actor	Code in text
1	EnergySpin	Operations & Partners Key Account Manager	Intermediate service	V1
2	West Coast start-up	Incubator Manager	Intermediate service	V2
3	City of Vaasa	ICT director	Local government	V3
4	Wasa Innovation Centre	Director	Intermediate service	V4
5	Fusetwin	Co-founder	Start-up / Scale-up	V5
6	Wasa Innovation Centre	Sales manager	Intermediate service	V6
7	Novia University of Applied Science	Professor	University	V7
8	Platonic Partnership	Founder	Start-up / Scale-up	V8
9	MultitronicPro	Account Manager	Start-up / Scale-up	V9
10	Kvarken Council	Director	Government - Cross-border cooperation association	V10
11	University of Vaasa	PhD Student	University	V11
12	Muova	Development manager	Intermediate service	V12
13	Incoach	Founder	Start-up / Scale-up	V13
14	Hanken School of Economics	Director business lab	University	V14
15	Ecolabnet	Project manager	Intermediate service	V15
16	Innolab	Postdoc researcher	University	V16
17	VNT Management	Managing partner	Investor	V17
18	Nordic Institute of Digital Innovation	Founder	Start-up / Scale-up	V18
19	Vaasa Yrittajat	Head	Intermediate service	V19
20	Wärstsilä	Project Manager Smart Technology Hub	Corporate	V20
21	Vaasa Entrepreneurial Society	Chairman	Intermediate service	V21
22	Business Finland	Funding Advisor	Investor	V22
23	Finnish Parliament	Member of Parliament	National and local government	V23
24	Vasek	Project manager & business advisor	Region Development Company - Intermediate service (public private)	V24

4.3.4. *Data analysis*

The interviews were analyzed[43] and coded[44] in a grounded-theory[45] inspired way, using the Gioia methodology to create qualitative rigor (Gioia & Chittipedi, 1991; Gioia et al., 2013; Gehman et al., 2018). The theory evolves during the actual research, which happens through a continuous interplay between data collection, theory building, and analysis. In abductive research, theory development is stressed rather than theory generation (Dubois & Gadde, 2002). By utilizing these methods, the interview data is

[43] Data analysis is performed using NVivo which is a qualitative data analysis software program

[44] Coding means that labels (concepts) are attached to segments of data that depict what each segment is about (Charmaz, 2006, p. 3)

[45] The grounded theory, created by Strauss & Corbin (1994), consists of four methods: theoretical sampling, theoretical saturation, coding and, lastly, constant comparison.

converted into *first-order concepts*, *second-order themes,* and *aggregate dimensions* (Gioia et al., 2013). Firstly, we identified first-order concepts by using open coding (Corbin & Strauss, 1990). The second step, progressing to axial coding, is to combine similar concepts into second-order themes (Gioia et al., 2013). Thirdly, moving to selective coding (Corbin & Strauss, 1990), second-order themes are combined into broader, more abstract, and theoretically relevant aggregate dimensions (Gioia et al., 2013) to explore relationships between our interpretations. An example of this coding method is provided in Table 22. For the sake of readability, not all the first-order concepts and second-order themes that constitute the aggregate dimension in Table 22 have been included in the example.

Table 22. Example coding method, based on Gioia et al., (2013)

Example quotes	**1st order concepts**	**2nd order theme**	**Aggregate dimension**
But the funny thing is that, if it is the ecosystem in Rotterdam, everything happens, but quite fragmented, and that is therefore increasingly brought together. And the government plays a very important role in this [R11] Also think you have the right city for that. These are all things that are very high on the agenda in Rotterdam [R12] Rotterdam then pulled so hard and tried so hard for it and then received a loan, also from the municipality. And that is really unheard off actually. That is actually not done, of course, because it is a profitable organization [R16]	Stimulating and building EE	Pro-active municipality	**Formal institutions**
So that we regularly have calls with the existing hubs in Rotterdam to ask how they have been helped in their completion of their mission and the positioning of Rotterdam. And I am really talking about putting Rotterdam internationally on the map as a city where you have to go. [R16] One is attracting new international companies to start a business in Rotterdam [R17] If you want to compete internationally you must accelerate … and that is of course what we, especially for the Cambridge Innovation Centre (CIC, start-up hub), have looked at. That they had that vision at the time, that we should use such a player as CIC, not because we cannot do it ourselves, but because you sometimes also must invest in an acceleration. [R18]	International branding of the city		
And that is very special to see how it grows. And you have the luxury of just seeing a party that has done well elsewhere in the past? We are not going to do it all again ourselves, we are just going to take it in [R11] My biggest project in this, also to accelerate, was bringing the CIC to Rotterdam. But everyone has no chance of getting that here they said. We did it anyway. [R18]	Acquiring expertise		
And we also have these good councilors sitting here this term. So that is very nice [R8] Alderman visits us regularly [R20] There are a number of councilors who are very active in this, who also support us [R10]	Capable counsellors this term		
Anyway, let us go back to the Smart Mobility campus or the climate adaptation center which will come to Rotterdam, which will open their doors in October. All those initiatives are a result of years of efforts initiated by the city of Rotterdam and the port of Rotterdam, with whom we have evolved as well. [R17]	Supercharging sustainability		

That works really well. That just works tremendously here. The municipality is also a real driver [R8]

Following the data analysis, the MLP and EE theories are refined and combined through constant comparison. The *outcomes* of this research will be new insights into transformative entrepreneurship in an EE context, enrichment of the MLP by specifying conditions for transformative entrepreneurship, and, finally, a novel synthesis of the MLP and EE combined in an enriched framework.

4.4. Results

Using the frameworks introduced in the theory section as a theoretical foundation, this section consists of four subsections. Firstly, we discuss and compare the incumbent energy systems in Rotterdam and Vaasa (4.1.). Secondly, we consider the EEs of Rotterdam and Vaasa[46] to determine current transformative elements (i.e., elements that trigger transformative entrepreneurship in the current EE) and possible improvements (4.2.). Thirdly, these transformative elements and possible improvements are combined to create the TEE (as explained at the end of the theory chapter). It serves as an enabling framework to elaborate on the niche dynamics of the MLP and enrich it with actor, agency and spatial understandings (4.3.). The data of both cases concerning transformative elements are predominantly coinciding, which supports its generalizability. The findings are summarized in Table 23.

[46] A case by case deepening of the current EE of Rotterdam and Vaasa is given in respectively Appendix A and B.

Table 23. Overview of qualitative study findings

Factor		Rotterdam	Vaasa
City	Population	651,376	67,552
	GDP per capita	$53,022.2	$50,175.3
Incumbent system	Dominant cluster	Harbor industrial cluster (petrochemical)	Clean energy cluster
Current EE	Outputs	High volume and quality of start-ups and scale-ups	Shortage of start-up supply
	Formal institutions	A municipality that is active and aware and stimulates and builds the EE; positive influence UP!Rotterdam	City of Vaasa is supportive; on the national level, ineffective entrepreneurial policies and taxation
	Culture	The hands-on Rotterdam mentality is celebrated; in a wider context a general lack of ambition in NL is stressed	International city (especially considering its size); widely supported entrepreneurial spirit; bilingualism of Swedish and Finnish speaking Fins; lack of marketing of the region is barrier for growth
	Infrastructure	Benefits in proximity to (TU) Delft; good accessibility, both in terms of personal and public transit	Strong surrounding region (Ostrobothnia & Kvarken); geographic location compared to other cities in Finland is weak and train connections are poor
	Demand	Large and diverse market that is beneficial for start-ups	Due to small size a small customer base
	Intermediate services	Good incubators and facilitators; many involved actors	Relatively high volume of incubators; accessibility suboptimal
	Leadership	Public-private organizations provide EE leadership; strategic coordination among actors	Sture Udd provides EE leadership (i.e. by building the Wasa Innovation Centre); overall strategic coordination lacking
	Knowledge	High quality and volume of research institutes in the region; Knowledge from Erasmus University and TU Delft complementary	Positive influence of clean energy related knowledge from energy cluster; many universities but their level of collaboration is poor
	Finance	High level of regional public funding instruments; ambitious municipality funding into EE	High level of public financing
	Talent	Especially before the corona-crisis hard to find; improvements in progress to boost current situation	Difficulties in finding and attracting talent
	Networks	Highly collaborative on an individual level; on ecosystem level lack of collaboration	Highly collaborative on the individual level; on ecosystem level a lack of collaboration

Factor		Rotterdam	Vaasa
Transformative elements (TEE)	Outputs	The need for transformative entrepreneurs to have economically viable business models	The need for transformative entrepreneurs to have economically viable business models; transformative entrepreneurs access new business opportunities
	Incumbents	Include incumbents in the TEE because (especially in traditional industries) transformative entrepreneurs cannot 'scale-up' impact without collaboration with these incumbents	Need changing company culture for large incumbents to work with start-ups
	TEE branding	Promote successful transformative entrepreneurs (lighthouses, Tiba et al., 2020) and TEE; important to make the ecosystem transparent and map all its actors to improve accessibility	Active promotion of the TEE to increase awareness
	Formal institutions	Government needs to apply carrot and stick model for sustainability, stimulate frontrunners and correct laggards	Broad and patient governmental support for transformative entrepreneurs
	Culture	Cultural change needed on multiple dimensions: entrepreneurs themselves, the encompassing actors in the EE and society (e.g. customers)	Cultural change needed on multiple dimensions: entrepreneurs themselves, the encompassing actors in the EE and society (e.g. customers)
	Infrastructure	Create collaborative sustainable (pilot) hub; bring all (intermediate) actors literally together on one big campus	Create collaborative sustainable (pilot) hub
	Demand	Sustainable market pull of customers (related to culture but more suitable with demand)	Sustainable market pull of customers (related to culture but more suitable with demand)
	Intermediate services	Create sustainability first incubator	Create sustainability first incubator
	Leadership	Transformative leadership that serves the public interest and guides the ecosystem purposefully	Transformative leadership that creates strategic coordination to improve efficiency
	Knowledge	Transformative knowledge (i.e. existence of knowledge embedded in the TEE to challenge and transform the incumbent system) through education	Transformative knowledge
	Finance	Purposive funding instruments to enable entrepreneurs to be transformative Sustainably purposed start-up competitions	Effective funding instruments to increase impact of transformative entrepreneurs
	Talent	Ecosystem-level collaboration to increase efficiency and effectiveness of TEE	Sustainably purposed start-up competitions
	Networks		Collaboration amongst all actors (ecosystem-level collaboration)

4.4.1. The incumbent systems of Rotterdam and Vaasa

The subsequent paragraphs describe the incumbent energy systems of Rotterdam and Vaasa for two reasons. Firstly, because energy is a prerequisite for any sort of change, the energy transition is the foundation for the other transitions within the urban sustainability transition and to mitigate climate change (McCauley & Stephens, 2012). Secondly, both cities are led by a dominant energy cluster, so, it makes sense to study this energy transition aspect when looking at their incumbent systems.

4.4.1.1. Dominant clusters

Rotterdam's harbor-industrial-complex (HIC) is a key feature of its incumbent system. Rotterdam has the biggest harbor of Europe and is often referred to as 'the gateway to Europe'. This HIC has a prominent role in the Rotterdam TEE. It is a great source of economic activity but also a tremendous challenge in the urban sustainability transition: "*We were not a representative of the clean industry. So, if a city like Rotterdam is changing to, for instance, renewable energy or more sustainable companies, the impact is tremendous"* [R17]. In terms of incumbent parties, the HIC is dominated by largely traditional multinationals in the fossil industry like Shell and Vopak. Also, the incumbent actors are characterized by their large size; no middle-sized incumbents exist in Rotterdam. One interviewee acknowledges: "*We have no intermediate size companies in Rotterdam. Some very large companies, those in an industry are among the largest in the world. And we have SMEs, but in between, it is very limited"* [R11]. Next, the Rotterdam institutions are very much intertwined with the HIC as they have a long mutual history. Therefore, inhabitants of Rotterdam are also historically proud of their harbor, which works through in their institutions.

Whereas Rotterdam is shaped by its large fossil HIC, Vaasa is dominated by its clean energy cluster. It is highlighted almost unanimously by the interviewees as a major strong point of the Vaasa region. One interviewee highlight: *"I would say because this region, they embark on being the clean energy cluster hub"* [V16]. Additionally, the presence of this clean energy cluster and its adjective knowledge and capabilities is interesting in light of the urban sustainability transition: *"So, Vaasa has this kind of critical mass, even though it is a small city, in this (clean) energy field it has a critical mass"* [V17], which means that the presence of this critical mass in clean energy knowledge paves the way for a fast energy transition. This is also displayed by the fact that Vaasa has set an ambitious target to be carbon neutral before 2030 in the project 'CARBON NEUTRAL VAASA 202X' (EnergyVaasa, 2020), while in Rotterdam, the ambition to become carbon neutral is set around 2050. Similar to the HIC of Rotterdam, the clean energy cluster of Vaasa is defined by a pair of very large multinationals, Wärtsilä and ABB. Although similar in terms of size and influence, these companies have set their sustainability targets much more ambitious. They envision Vaasa to be the clean energy hub of the Nordics. The Vaasa institutions are, similar to Rotterdam, through a process of coevolution, locked in with the clean energy cluster: "*I have not seen that the government or the Vaasa city are doing anything for other businesses than energy"* [V15].

Although parallels can be drawn between Rotterdam and Vaasa in a sense that they are both dominated by an influential cluster, the contents of these clusters give rise to very different implications in a transition context. Vaasa has the potential and the will to change their current energy system to a sustainable energy system much faster than Rotterdam because they have the knowledge and skills to transform their current energy system embedded in their clean energy cluster (McCauley & Stephens, 2012). In terms of impact, however, Rotterdam can provide a significantly larger reduction of greenhouse gasses because its carbon footprint is larger than Vaasa's. The trajectory is more complex and longer, as the necessary change is larger.

4.4.2. Transformative elements of the EEs of Rotterdam and Vaasa and envisioned improvements

This chapter elaborates on Table 24 and describes the transformative elements of the EEs of Rotterdam and Vaasa[47]. It functions to make the EE's 'uniqueness' insightful by making their differences and similarities explicit. In addition, interviewees provided understandings about envisioned transformative elements to improve their current EE. Their insights are subsequently used to enrich the current EE framework with transformative elements and construct the conceptual TEE framework in chapter 4.3. which subsequently aligns with the MLP. After describing their current EE and its transformative elements, interviewees were asked to go beyond this current situation and describe what conditions are for entrepreneurship to play an important role in the sustainability transition in their respective cities.

4.4.2.1. Transformative entrepreneurship as the output of the TEE

The output of the two current EEs is very different. Whereas Rotterdam's EE creates a potent volume and quality of start- and scale-ups, Vaasa's EE is troubled by a shortage of start-up supply. As [V14] underscores: "*One really big challenge here in Vaasa is the volume of prospects".*

In addition, findings from both cases show some remarks about prerequisites for the successful outputs of transformative entrepreneurship in a TEE (the output variable). Interviewees from both cases underline that transformative entrepreneurship in the first place needs to be economically viable: *"You need to have results of at least some sort because otherwise, you cannot grow the business either. If you are not making money, you cannot grow it"* [V1]. Within this argument also the concepts of scalability and feasibility are marked, as well as the comment that the solution needs to be better than the unsustainable alternative. In terms of scalability, the importance of successful scale-ups (lighthouses) is also named in both EEs to attract new investors and create momentum. This will further be discussed in 4.2.13 (TEE branding). To make their transformative business model economically viable, entrepreneurs are strongly encouraged to collect the right (industry-specific) information and find synergies. In terms of opportunities, interviewees are confident that transformative entrepreneurs will find new business opportunities because of their higher agility compared to incumbents who are often impeded by their rigid organization.

4.4.2.2. Formal institutions

The Rotterdam municipality names itself as the 'entrepreneurial government', the most tangible present activity being the establishment of UP!Rotterdam, which is a four-year program that serves as a public-private entity and through a process of co-creation, connects the different actors in the EE. The Vaasa municipality is also perceived as supportive but, to a lesser extent, as they take a less active role than the Rotterdam municipality.

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[47] A comprehensive overview of strengths, weaknesses, similarities and differences of the current EEs of Rotterdam and Vaasa is given in Appendices A and B.

Interviewees from both cases stress that governmental support in terms of having a sound strategy and roadmap is vital for a TEE to flourish. So, not only the presence of a qualitatively high (local) government is important but also a government that is benevolent and knows what is needed in the urban transition to sustainability. It is furthermore stressed that the best way to determine this strategy and roadmap is to do it in a co-creative way (i.e., construct the vision in co-creation with the other (private) actors in the TEE). As interviewee [R14] formulates: "*Ideally, this vision has also been drawn up in consultation with the business community".* Additionally, the municipality should not be the organization that implements solitary; the implementation should be placed with knowledgeable actors in the TEE. Furthermore, interviewees suggest that a pivotal part of this strategy is to 'practice what you preach' as a municipality.

Multiple measures to enact this roadmap and strategy are suggested and they generally fall under the umbrella of the carrot and stick model to incentivize both frontrunners and laggards (Dix, 2014). These measures are enabling taxes, political encouragement, and (restrictive and supportive) regulations, *"The regulations and laws can be a driver for sustainability"* [V12]. Restrictive regulations create the 'soft force' or 'stick' to incentivize entrepreneurs (and incumbents) lagging in terms of sustainability. Also, the possibility for the municipality to stimulate transformative entrepreneurs using the instrument of sustainable public procurement is posed (related to the demand variable). Municipalities should act more often as a launching customer of a start-up: *"I think that the municipality of Rotterdam itself and its partners, should act more often as a so-called launching customer… to make more use of the innovative offers of many start-ups"* [R12].

4.4.2.3. Culture

While in general, our findings show a recurring lack of ambition in the Dutch culture of both entrepreneurs and their encompassing actors in the EE, the Rotterdam mentality is celebrated for being bold and forward, creating the right mindset to do business. For Vaasa, other elements are in play; interviewees highlight the generations-long entrepreneurial spirit in the region as opposed to other Finnish regions. Next, interviewees stress that Vaasa's region is impeding its EE growth due to a lack of branding of the region. Something which Rotterdam is very well-versed in. Rotterdam Partners is actively branding the city of Rotterdam throughout the world. So, in terms of culture, Rotterdam and Vaasa are very different but do have some interesting parallels, most notably the entrepreneurial spirit/mentality in both cities.

Cultural change is one of the key components for a TEE. The interviewees argued multiple facets of this cultural change. Firstly, the notion that entrepreneurs themselves should change their mindset towards a more sustainable oriented course. As one interviewee [V6] mentions: *"The thing that can be at odds with entrepreneurship, it is all about making money. Maybe we need to be looking at what are driving forces rather than making money; it should be more about accepting"*. Secondly, interviewees highlighted the cultural change or landscape shift in demand of society in a broader sense. *"I think, in 10 years, sustainability and business are equal because it will be a license to operate"* [R17]. Thirdly, interviewees reiterated that for an EE to become transformative, the mindset of the entire set of actors in the EE should change: *"In the end, you have to tackle the entire ecosystem and the whole range of ideas of everyone who is in it"* [R9].

4.4.2.4. Infrastructure

In Rotterdam, plans are constructed for the Mobility City Campus to settle, which is envisaged to become the place where international companies and other important players work together with start-ups on mobility concepts of the future (Verkeersnet, 2020). In Vaasa, Wärtsilä is building their Smart Technology Hub, which will serve as a new integrated center of research, product development, and production (Wärtsilä, 2020). Thus, in terms of infrastructure, both Rotterdam and Vaasa are planning to build a collaborative sustainable hub.

So, interviewees in both cities agreed that in terms of infrastructure, the most added value to a TEE is the creation of a collaborative sustainable hub. A place where actors in the TEE are literally brought together on the same campus as there are benefits in proximity. It increases the likeness of serendipitous encounters and crossovers. Simply put by interviewee [R8]: *"Take a building and put us all together and see what happens next".* This infrastructure argument is, therefore, closely related to the network and intermediate service variables.

4.4.2.5. Demand

Rotterdam has a large and diverse market, a key ingredient for (transformative) entrepreneurial success. As the interviewee [R12] discusses: "*There are large-scale corporates, there is also large-scale industry, and there is the consumer level".* On the opposite, Vaasa is dealing with a small customer base, especially outside the clean energy cluster. The reason for this is a size issue: "*It would be beneficial to be a bigger region, especially if it comes to the consumer market"* [V20]. Furthermore the paramount focus and subsequent dependence of Vaasa on its clean energy cluster. This is also one of the main impediments of a more heterogeneous and thriving (T)EE as 'access to markets' is a key condition for entrepreneurs. The demand conditions are thus very different in Vaasa compared to Rotterdam.

The common denominator for the demand variable in a TEE is the sustainable market pull of consumers, other businesses, and governments. This is closely related to and caused by the culture (change) variable but more fitting to discuss here as it concerns demand. These changing demand patterns are a consequence of this abovementioned cultural change. Interviewees anticipate that doing business in a sustainable way will be "a *license to operate*" [R17]. They suggest that demand for unsustainable alternatives will continue to drop: "*The market takes care of that. When the customers learn to ask for sustainable solutions, it means that you have to transform your business so you can meet that new demand"* [V14]. Additionally, the importance of finding early adopters as a transformative start-up is stressed. This access to markets or early adopters can be: "*Launching customers, pilots, and internationalization"* [R12].

4.4.2.6. Intermediate services

Rotterdam is home to multiple praised incubators, facilitators, and accelerators (see Appendix A for a list of actors). Furthermore, Rotterdam inhabits an accelerator tailored to their dominant HIC cluster: the accelerator PortXL. For Vaasa's clean energy cluster, the accelerator EnergySpin is established in a likewise manner. So, a similarity and transformative element is that both cities' EEs inhabit an accelerator tailored to their dominant cluster. Both accelerators are actively brokering between the incumbents' needs and the innovative solutions provided by entrepreneurs, attracting start-ups from all over the world.

Findings concerning intermediate services in a TEE are clear. Namely, the establishment of a sustainability first incubator that incubates start-ups that are selected and assessed on social, environmental and economic criteria. An example of this in the field of circularity is BlueCity in Rotterdam. However, this sustainability first incubator should be more holistic than just circularity. Interviewee [R19] contemplates: "*Create a kind of community with all kinds of sustainable start-ups and sustainable ideas".* For instance, this can be in the form of a serious playground: "*Really a place in the city where companies with new ideas can really test, so a serious playground which can also put the city in the picture"* [R6].

4.4.2.7. Leadership

In Rotterdam, EE leadership mostly comes from central public-private organizations like UP!Rotterdam and Rotterdam Partners to *"Pull the organization out of the bureaucracy, but with some sort of accountability"* [R6]. Differently, in Vaasa, leadership stems substantially from private actors like Sture Udd, who is the owner and driving factor behind the Wasa Innovation Center and Wärtsilä, who is guiding collective action with the establishment of its Smart Technology Hub.

It became apparent in both cases that the role of (transformative) leadership becomes increasingly decisive when configuring the EE in a transformative way. The following metaphor of one interviewee gives a clear impression of the importance of such transformative leadership: "W*hat you see at the Tour de France, people stand in the form of letters. You have no use at all to someone who can stand very well. Only someone who says: you should be there, you should be there, trust me, if you all stand there where I pointed you, then that word will appear. You cannot tell everyone: guys, you have to do your best, we want this word, figure it out. That just does not work, you have to compare it with that. It is a complex problem with many actors"* [R11]. The tenor of this metaphor is twofold. Firstly, to perform as an adequate TEE, it needs to be led by one or multiple actors to guide collective action and steer the EE to a transformative path, as individual actors (almost literally) do not see the bigger picture or overarching transition challenge. Secondly, the fact that for this transformative leadership to occur and be effective ecosystem-level collaboration[48] and trust is paramount. Without this collaboration, the implementation of transformative leadership is impossible. Taking it one step further: when ecosystem-level collaboration and transformative leadership are both in place and combined, strategic coordination of the ecosystem takes place. As one interviewee pleads: *"And it is really hard to understand how to implement what you are selling, and how does it fit into the bigger picture. You get all these, like, small pieces of the puzzle"* [V24]. In other words: to configure an EE as a TEE, strategic coordination is crucial, and this strategic coordination consists of two elements: ecosystem-level collaboration and transformative (public-private) leadership.

It is also emphasized that this strategic coordination, in turn, increases the (T)EE's effectiveness and efficiency: "*I think it also raises the question like how do we coordinate resources effectively in such a way that the same thing is not done twice in two places"* [V11]. Interviewee [R11] summarizes the need for strategic coordination: "*Clearly. A number of actors that you just need for that (a successful TEE)*

[48] The concept of ecosystem-level collaboration is further elaborated on in chapter 4.2.11.

and depending on what you always used to think about, what is unique about a region today does not have to be unique in twenty years. But it always has an important impact on what is happening now. But you want to do something different. How do you ensure that that does not bite each other" [R11]?

4.4.2.8. Knowledge

Interviewees from Rotterdam stress that the Erasmus University and the Technical University Delft are complementary. Interviewee [R18]: "*That combination and that is also a good thing that you do not find everywhere in the Netherlands or in Europe. It is precisely the combination between the Delft University of Technology and the Erasmus University and even the Erasmus Medical Center"*. In Vaasa, transformative knowledge is furthermore emphasized to enable the urban sustainability transition: *"It is the value of the knowledge that exists inside these companies and the knowledge that exists in the people as a whole when it comes to the energy business (in Vaasa). And I think that is a very important and very positive thing"* [V8]. An interesting connection here is also the coevolution of knowledge institutes like universities and their collaboration with the incumbent system (again linked to the network condition). Vaasa has the advantage of their clean energy cluster meaning that transformative (energy) knowledge is embedded to a great extent in their education system: "*What the industry needs are, also shapes how we work, how we try to train the students to answer the needs that the companies have"* [V11]. The Rotterdam and Vaasa regions are both home to several universities. So, for both EEs, the inflow and investments in (new) knowledge are high.

The knowledge variable encompasses multiple prerequisites and suggestions. The education of transformative entrepreneurs can be a larger extent be a focus area of universities with more emphasis on new (transformational) domains[49]. Next, the importance for start-ups to have industry-specific knowledge of the particular dynamics in that industry is stressed. Because "*People basically only innovate and renew when it hurts so you have to quickly validate it just by gut feeling, which is only possible with people who know the industry"* [R8].

4.4.2.9. Finance

Rotterdam is characterized by a high level of public funding instruments. Most regional funds[50] are administered by InnovationQuarter and focused on the energy transition. The municipality of Rotterdam distinguishes itself by funding start-ups directly through grants and competitions and indirectly by funding the encompassing EE actors: "*Sometimes you just have to do something to speed things up, it also took the city money and time to get it all done"* [R18]. The funding landscape of Rotterdam also consists of a diverse variety of private investors. In Vaasa, the high level of public financing is accentuated as well, with multiple public funding instruments like an entrepreneurial early-stage subsidy, and municipality funding. Supplementary, the transformative funding instruments at the organizations Ely-Keskus[51] and Business Finland are highlighted: "*Sustainability is the umbrella theme, and then there are different kinds of areas under that umbrella. For example, digitalization for*

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[49] Interviewee [R12] provides an example of this: '*So you also see a development at the Rotterdam University of Applied Sciences that they are engaged in training people specifically for the maintenance plans of the large-scale wind farms that are build off the coast'.*

[50] IQcapital, EnergIIQ, Uniiq.

[51] Ely-Keskus is the 'Centre for Economic Development, Transport and the Environment' in Finland.

sustainability, cleantech for sustainability, and then the circular economy and to support sustainable development" [V22]. Like in Rotterdam, interviewees underscore the diverse array of private investors like business angels and venture capitalists in Vaasa. So, the level of public and private funding is praised in both cities. But, indirect EE funding, like in Rotterdam, is something which is less developed in Vaasa.

Interviewees highlighted the importance of purposive and effective funding instruments to enable transformative entrepreneurs. This concerns both public and private funding for entrepreneurs with clear criteria on impact: *"If we talk about funding mechanisms, then it is quite easy to have the criteria that assess from a sustainability point of view"* [V14]. In addition, the decisive stimulus of (local) subsidies for transformative entrepreneurs is underlined: *"Subsidies that only go to companies that actually pursue a social or sustainable goal. I think such initiatives really help to stimulate start-ups to do something in that direction"* [R3]. Also, cooperative funding in the TEE is assumed to be pivotal, as one interviewee affirms: "*We always invest in ecosystems in cooperation because we all know that you create more added value if you work together, and the funding and the money is often the key, and the resource, you can use to encourage that kind of cooperation"* [V22].

4.4.2.10. Talent

The Rotterdam EE witnesses difficulties attracting talent, especially in the field of transformative start-ups[52]: "*There is enough talent in the Netherlands, only finding talent is very difficult … the top of the university and the top of the university of applied sciences are very difficult to bind to socially responsible projects"* [R5]. Furthermore, the Erasmus University historically has a (too) corporate focus, making it even harder for start-ups to attract talent as they are outcompeted by these corporates. This focus also makes it less likely for students to become an entrepreneur when they graduate, which negatively affects the talent variable in the EE of Rotterdam: "*I will never forget that when I graduated it was when the Rector Magnificus said: your employers may be happy with you..."* [R2]. Also for the case of Vaasa attracting talent for (transformative) start-ups is difficult, [V10] contemplates: *"I think we will have a big problem with the labor force, because people do not want to live and to move to our regions, for some reason"*. A reason for this (and similar to Rotterdam) is that the (big) companies in the dominant cluster take a large chunk from the talent pool.

The talent variable is very much intertwined with the knowledge variable (same as demand and culture). Therefore, an improvement in the educational system often leads to an increase in highly skilled workers. Findings anticipate that the amount of talent available is sufficient (both cities have multiple universities), but attracting this talent to transformative start-ups is perceived as one of the biggest challenges associated with the TEE: "*There are plenty of people who enjoy working for start-ups who contain a lot of talent. But the crucial word is access*" [R12]. A proposed solution to increase start-ups' access to talent is a talent competition that connects the brightest students to the most pressing sustainability challenges in the region. An example of this in Rotterdam is the Rotterdam100 organized by the Thrive Institute: *"A talent competition that is very focused on: how are you going to improve the municipality? And the ideas that are created, how are they implemented as well as possible*" [R5]. Another initiative is the endeavor to attract highly skilled migrants. Next, the suggestion

[52] This lack of talent, however, is currently remedied by the corona-crisis

is made to establish an overarching job board for transformative start-ups and scale-ups to improve access to talent.

4.4.2.11. Networks

Interviewees from both Rotterdam and Vaasa stress that collaboration is also a major strong point of their EE. However, for both cities (after giving further scrutiny to this topic), interviewees highlighted a lack of ecosystem level collaboration in Rotterdam and similarly a lack of strategic coordination in Vaasa: *"I think it also raises the question like how do we coordinate resources effectively in a way that the same thing is not done twice in two places*" [V11]. So, for both cities' network dimensions, the same paradox was found that they were highly collaborative on certain levels but at the same time missed ecosystem/level collaboration/strategic coordination. In Rotterdam, improvements are triggered: "*A lot of things are happening, but quite fragmented, but that is getting better and better. And the government plays a very important role in this"* [R11]. This important role of the local government in ecosystem level collaboration is (again) observed by the establishment of UP!Rotterdam: "*The objective of UP!Rotterdam is to support and strengthen the ecosystem, not only with the municipality, also with other (private) partners"* [R12].

For a TEE to play a serious role as the bottom-up component of the urban transition to sustainability, ecosystem-level collaboration between all different actors is vital. Also in a sense that the TEE can encompass and connect the multiple niches in the urban sustainability transition. Collaboration between entrepreneurs: *"It is important that start-ups and scale-ups also have to commit themselves to be concentrated to want to work together because you just never make it on your own, certainly not on those (transformative) kinds of themes"* [R11]. Collaboration between intermediate service actors: *"I think those collaborations are the most important because it ensures the transfer of knowledge and other types of transfers that are necessary to make it a success"* [R1]. But most importantly: interdisciplinary ecosystem-level collaboration between all the different kinds of actors. As [R12] fittingly concludes: "*Indeed, all those players who are important for innovation, all those things that can work together to realize large-scale projects. Because we are all aware that the problems are simply too great to solve independently".* As this interviewee points out, transformative impact can only be reached and enlarged in collaboration. As a positive consequence, synergetic crossovers between multiple different niches within the TEE and between the TEE and the incumbent system can be realized. Finally, connecting (contemporary) transformative entrepreneurs to seasoned entrepreneurs and enabling them to share their knowledge is conveyed.

4.4.2.12. Involvement of incumbents

Interviewees from both cases argue the importance of start-up - incumbent interaction. For traditional clusters like the HIC in Rotterdam, interviewees dispute that it is even the only way: "*Some products require acceptance from larger parties. Especially when it comes to innovation in the harbor"* [R11]. A practical example to make this work is to establish an accelerator (like PortXL in Rotterdam and EnergySpin in Vaasa) as a middleman to bring incumbents and start-ups together in an effective way and respond to unique regional challenges.

Therefore, the ‘Involvement of incumbents’ condition is added to the EE framework to acknowledge this increasing importance of start-up - incumbent collaborations. Moreover, because, in a transition (and congruent to the MLP), the incumbents must be addressed. This incumbent structure subsequently has implications for the cities’ specific transition pathways[53]. Especially in the field of transformative entrepreneurship, impact can rarely be scaled without this collaboration: *“They (corporates/incumbents) have a much greater clout, so they can actually take big steps with the ideas of start-ups”* [R1]. In other words, by integrating the entrepreneur’s solution in the incumbent practice, impact can tremendously be increased. So, it is necessary to include the incumbent condition in the TEE framework because the transition challenges are too grand to tackle in solitude by transformative start-ups.

A precondition for this (and related to the culture variable in 4.2.3.) is a change in company culture for an incumbent to work together with start-ups and scale-ups effectively: “*As an incumbent*, *you must be able to use the advantages, but without the disadvantages of your rigid organization and the limitations that can even be imposed by your own system”* [R18]. So, incumbents need to improve implementation when acquiring start-ups because otherwise, the probability is high that the start-up is ‘killed’ as it loses its agility [V20]. In other words: *“One of the most important things is that people within large companies or organizations who deal with start-ups, know how to deal with it”* [R10]. Furthermore, the need to better facilitate spinouts also increases the success rate of intrapreneurship: *“Internal entrepreneurship is very important, because then you get the boat running as well”* [V1]. This can only be achieved by high level and intrinsic incumbent commitment, so both top-down and bottom-up within the incumbent’s organization: “*It is the benevolence of the companies (incumbents)to just jump into the deep end*” [R12].

4.4.2.13. TEE branding

In Rotterdam, start-up competitions like the Philips Innovation Award, Get in the Ring, and Thrive Institute are actively giving entrepreneurs a podium. In Vaasa, this podium for (transformative) entrepreneurs is lacking, which is perceived as a weakness of the EE by the Vaasa interviewees.

Interviewees from both cases[54] stress the importance of promoting the successfulness of the TEE and promoting its (successful) transformative entrepreneurs to the external environment. The transformative orientation of these role models is instrumental in creating environments in which transformative start-ups can thrive. Therefore, the condition ‘TEE branding’ is an essential addition to the original EE framework. Especially transformative entrepreneurs should be given a podium to convince a larger public of their transformative solutions, prove their concept, challenge incumbents, inspire others and get rewarded for their endeavors. This podium can, for example, be a sustainable start-up competition: “*Give them a stage, and give them handles to reach that stage, I think that is the most important thing”* [R7]. Additionally, success stories should be bolstered to increase exposure and create role models: “*A great figurehead, you really need it for this direction”* [R11]. It is believed that by doing this, the attractiveness of the (T)EE increases and that more companies and more highly-skilled individuals are engaged to settle. Therefore, it is subsequently beneficial for the talent variable. Also, the branding of the TEE as a whole is emphasized through collaboration and to create awareness.

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[53] See Appendix C.

[54] In Rotterdam based on experience with these competitions, while in Vaasa based on the absence of such competitions

Interviewee [V20] explains: "*We need to, in a sense, market ourselves and especially in those areas where we already are globally known".*

To make it easier for the TEE to be branded, interviewees furthermore highlight the need for transparency and thus mapping of the TEE to make its actors visible. This transparency is stressed to understand the TEE's heterogeneity, understand its needs, increase cooperation, and increase its actors' accessibility. Interviewee [R1] argues the connection between the concepts of transparency and increasing cooperation as follows: "*There can be many parties, but if they are not clear to the other parties, no collaborations will arise".* The appendices A and B contain these 'maps' of the current EEs of Rotterdam and Vaasa.

4.4.3. The transformative entrepreneurial ecosystem (TEE)

The findings listed in Table 23 and elaborated in paragraphs 4.2.1. up to and including 4.2.13. are bundled in Fig. 20, which envisages the TEE. Even though the EEs (and thus urban transition processes) of Rotterdam and Vaasa are different due to their relative regional uniqueness, generalizable lessons can be drawn when constructing the TEE framework. we will provide alterations to the original EE conditions and add two supplementary conditions (4.2.12.: Involvement of incumbents and 4.2.13.: TEE branding) to incorporate transformative elements in the initial framework of Stam (2018). Thus, this TEE brings the case level empirical data together in a combined framework and depicts the preferable configuration of the EE that encourages transformative entrepreneurship and consequently shapes conditions for transformative entrepreneurship on the niche level of the MLP framework.

In the theory chapter, we pointed out that the dependent outputs of the traditional EE, namely productive entrepreneurship, should be substituted for transformative entrepreneurship. Furthermore, we argued that the TEE is an extensive elaboration of an MLP niche that gives a more thorough insight into internal niche actor, agency and place dynamics rather than the 'black box' MLP literature emphasizes. In addition to this argumentation, we analyze, based on the empirical insights of this results chapter, that the TEE can encompass and connect multiple different niches within the multiple transition arenas of which the urban transition to sustainability consists. Thus, the transformational aspects of a TEE are not limited to only one transition (for instance the energy transition). The TEE framework should rather be seen as the overarching bottom-up framework at the MLP base, embracing multiple niches with sustainable value creation as its output. Additionally, as envisioned in the theory section, the TEE framework enriches the MLP niche level with place, actor, and entrepreneurial agency considerations. Findings summarized in Fig. 20 answer the research question as being the configuration of the EE that encourages transformative entrepreneurship, which subsequently supports the urban transition to sustainability in Rotterdam and Vaasa. TEE research in different cities can yield different configurations. Also, Fig. 20 does not imply that by configuring an EE in a transformative way (as depicted in this Figure), the TEE will always play the same role in the transition pathway of a certain city or region. The transition pathway is still very much dependent on the incumbent system and landscape dynamics. Instead, Fig. 20 proposes the configuration in which the likelihood of transformative entrepreneurial success and impact is the highest, thereby contributing to the urban sustainability transition the most. Hinged on their respective (T)EE and incumbent system, Appendix C depicts the likely transition pathways of Rotterdam and Vaasa. Based on empirical findings, the transformation transition path for Rotterdam and the reconfiguration transition path for Vaasa is proposed.

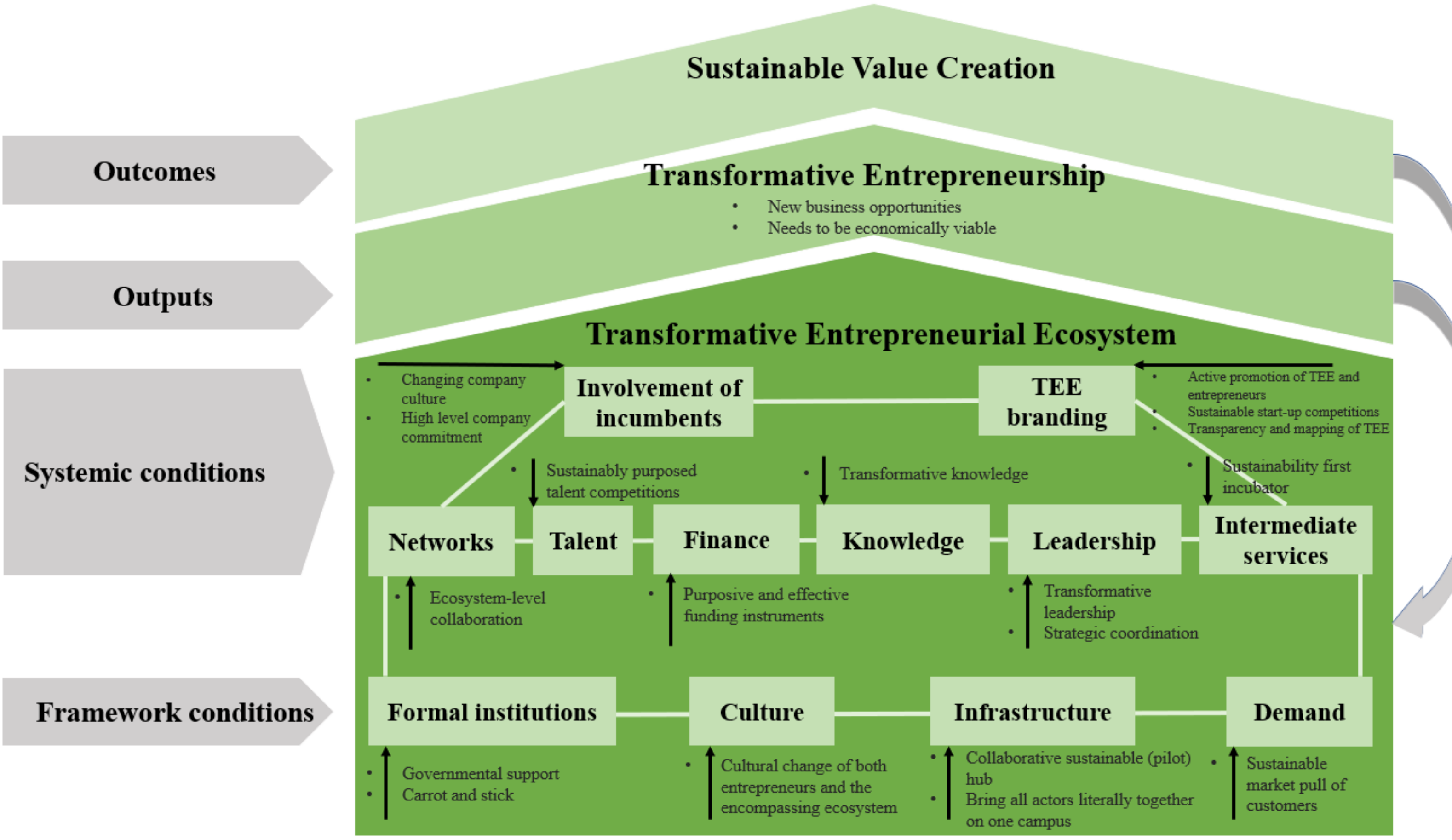

Fig. 20. The transformative entrepreneurial ecosystem (TEE), based on Stam (2018) and own findings

4.5. Conclusion

My research set out to investigate the entrepreneurial ecosystem in a multi-level perspective on transitions. The research question we posed was: *What configuration(s) of the EE encourages transformative entrepreneurship, which subsequently supports the urban transition to sustainability?* To answer this research question, we conducted 44 semi-structured interviews: 20 in Rotterdam and 24 in Vaasa. The empirical insights of these interviews were in an abductive way systematically combined with case information and EE and MLP theory. This method led to the construction of an enriched conceptual TEE framework (Fig. 20) that nests itself on the interface of EE and MLP literature. This TEE framework answers our research question by depicting the generalizable configuration of the EE that encourages transformative entrepreneurship, which subsequently supports the urban transitions to sustainability in Rotterdam and Vaasa. Firstly, it presents the necessary transformative (MLP) refinements in the form of enabling factors and requirements to the ten original EE conditions. Secondly, it adds two new transformative conditions: 'Involvement of incumbents' and 'TEE branding', to increase the conceptual embeddedness of the EE and the MLP in both ways. Thirdly, it refines the dependent outputs and outcomes of the original framework in a transformative way by substituting 'Productive entrepreneurship' and 'New value creation' for 'Transformative entrepreneurship' and 'Sustainable value creation'. we furthermore argue that the TEE can embody and connect multiple different niches within the multiple transition areas of which the urban transition to sustainability consists.

4.6. Discussion

The TEE framework envisages the configuration of the EE that encourages transformative entrepreneurship as a driver of the urban transition to sustainability. The ten systemic and framework conditions of Stam's (2018) framework are finetuned and tailored towards the urban transition to sustainability. In other words, transformative elements are added to the original conditions. Empirics furthermore showed that two conditions needed to be added to use the EE as a framework that aligns with the MLP context, namely, incumbents and TEE branding. The dependent variables, productive entrepreneurship as output and new value creation as outcome were changed for transformative entrepreneurship and sustainable value creation. The next part of this chapter will interpret the most salient findings generated from the analysis and reflect upon them in the context of the MLP and EE theory and frameworks (6.1.). Secondly, practical implications are discussed (6.2.). Thirdly the theoretical and methodological limitations of this study are listed (6.3.). The final part of this discussion will give avenues for future research (6.4.).

4.6.1. Theoretical implications

My research's central theoretical implication is the enrichment of the original EE framework of Stam (2018) with transformative elements to make the framework align with and embed in the MLP framework. The EE is thus configured transformative as a TEE. Consequently, both frameworks serve together as vehicles to achieve the end goal of a transformed and thus sustainable 'future proof' society.

The added 'Involvement of incumbents' variable of the conceptual TEE framework was abducted from empirical data as one key missing link to connect the EE and MLP framework. This variable corresponds with the notion of Rothaermel's (2000) work, which argues that sustainability transitions need incumbents' strategic reorientation as they at first defend existing systems. Also, by including incumbents as condition in the TEE framework, we make MLP dynamics regarding the incumbent system(s) more explicit. Furthermore, similarly to the work of Tiba et al., (2020), the additionally included 'TEE branding' variable is the other missing link between EE and MLP theory. It shows the importance of promoting the success of the TEE and promoting its (successful) entrepreneurs (what Tiba et al., (2020) call 'lighthouses') to the external environment to increase and accelerate the TEE's transformative impact.

Based on the empirics, for the variable of formal institutions, the importance of broad governmental support in mobilizing different elements to encourage transformative entrepreneurship was formulated. This is congruent with literature (O'Connor et al., 2018). It reflects the idea that governments around the world admit that entrepreneurship can transform their systems (Isenberg, 2010) and that they can play a role in amplifying this transformative entrepreneurship in a stepwise manner (Rotmans et al., 2001). (Local) governments should acknowledge the conflict between short-term concerns and long-term ambitions and keep the public interest in mind (Rotmans et al., 2001). In this way, municipalities can purposively mediate, engage in brokering services, stimulate, create the right conditions, engage in steering, and enforce its laws (Loorbach & Rotmans, 2010; Smith et al., 2005). Our contribution is to make the role of city-regions explicit in the governance/management of transition pathways (Coenen & Truffer, 2012).

The notion of cultural change to enable and accelerate transformative entrepreneurship that emerged from the data also finds strong theoretical underpinnings. As Konrad et al., (2008) argue, socio-cultural dynamics are part of transformation on various levels and dimensions. Seyfang et al., (2010) furthermore accentuate that behavior change will likely occur in this context. If the local culture that facilitates trust and safety is likely to improve the EE (Audretsch & Belitski, 2017), then cultural change to a sustainable trajectory is likely to improve the TEE. Also, the emphasized sustainable market pull for the closely related demand variable finds its roots in literature, as Coenen & Truffer (2012) argue that sustainability transition research analyses changes in markets. Stam (2014) phrases it as the opening of (sustainable) public demand. Next, for the infrastructure argument, we argued that there are benefits in proximity. Scholars in MLP and economic geography support this. To enable effective learning (Gertler, 2003; Owen-Smith & Powell, 2004) through relatively transparent channels (Hildén et al., 2017) and to increase the ability to learn and manage face-to-face across multiple projects (Powell et al., 2002).

Also, in terms of (transformative) leadership, our thesis is consistent with existing literature. This notion of public-private leadership and governance is confirmed by EE scholars (Acs et al., 2017). However, especially public transformative leadership should remedy possible 'disempowerment' (i.e., creating a sense of powerlessness and decreasing the ability of actors to take up roles in sustainability transitions) (Hölscher et al., 2019). Additionally, transformative knowledge, as presented in Fig. 20, is discussed by scholars to stimulate technological change, novelties, and institutional adaptation (Loorbach & Rotmans, 2010; Geels, 2002; Kemp et al., 1998). For the variable of networks and the necessary ecosystem level collaboration, scholars acknowledge these spatial configurations and dynamics of the networks within which transitions evolve (Coenen et al., 2012).

In addition, we contribute to the TEE/niche dynamics in the realm of the MLP. The factors of finance, talent, and intermediate services emerged as important elements from the empirics but are generally overlooked by MLP scholars. This is interesting and relevant as EE theory shows that these are important for (transformative) entrepreneurs and the encompassing TEE to flourish (Stam, 2018). By linking the EE to the MLP using the conceptual TEE framework, these conditions can enrich MLP bottom-up understandings to provide a more holistic view of these TEE/niche dynamics. Thereby, we argue that the TEE can incorporate multiple niches, as start-ups and scale-ups from different niches (for instance, food or energy) are not excluded in this TEE context as long as they fall under the umbrella of the urban sustainability transition. Furthermore, by recognizing this heterogeneity of niches within the TEE, crossovers between multiple niches are established by the increased probability of serendipitous encounters (i.e., different entrepreneurs from various fields coming across each other).

4.6.2. Practical implications

A practical contribution is the detailed overview of the current EEs of both Rotterdam and Vaasa to further improve and steer their respective EE in a sustainable trajectory. Although both cities visualized their EEs by mapping the current actors (see Appendices A and B), the underlying dynamics and structure were not scrutinized so far. Therefore, this can be of value to policy makers and EE actors in both cities. Also, the presence of multiple parallels and similarities between Rotterdam and Vaasa creates an opportunity to collaborate and learn from each other. Especially the embedded transformative knowledge in the clean energy cluster of Vaasa can be of great benefit to the current situation of Rotterdam. Reversely, the way Rotterdam tackles the branding of its city by the installment of Rotterdam Partners can be very beneficial for Vaasa. we therefore strongly urge representatives from both cities to open a dialogue with each other.

In addition, as posed in the research question, to create and configure a TEE that encourages transformative entrepreneurship which also supports the urban transition (which is purposive), strategic coordination (4.2.7.) is vital and logical because of its purposiveness. Therefore, this subchapter discusses and reflects on the practical implications of this concept. We argued that strategic coordination consists of ecosystem-level collaboration and transformative leadership. To capture both elements, we introduce *Strategic Transformative Entrepreneurial Ecosystem Management* (STEEM). we define STEEM as: 'the concentrated effort to develop and maintain a TEE to accelerate transformative entrepreneurship and sustainable value creation'. Thereby going beyond the nurturing of new technologies and taking a more holistic approach to developing the TEE that in turn enables bottom-up sustainable value creation as a whole (so not only from new technologies) with transformative entrepreneurs as an engine.

STEEM is the process of actively and purposively managing the TEE, recognizing the wider context of the urban sustainability transition. In that sense, applying STEEM can purposefully push the TEE component of the urban sustainability transition in the desired direction. So, the core practical implication is that cities should implement STEEM to develop and accelerate their (T)EE. Also, when looking at EE efficiency in Rotterdam and Vaasa, there is much to gain, which can be tackled using this STEEM as resources can be coordinated more effectively. In addition, STEEM can be used to consider the coevolution of the TEE structure with changing transition parameters over time. Current actors are purposefully and actively 'managed' with the knowledge that what is unique about a certain region in the present does not have to be unique in the future and to ensure that these possibly conflicting temporary and future interests do not impede each other.

Also, interesting parallels can be drawn between STEEM and SNM literature (introduced in 2.2.4.). This gives some guidance into the elaboration of STEEM. These linkages with SNM also further embed the TEE framework in the MLP literature. STEEM is in line with what Kemp et al., (1998) debated for SNM. They argued that SNM is more than a useful addition to a spectrum of policy instruments. It is a necessary and reflexive component of purposive transformation processes of systems. Indeed, STEEM as well as SNM is more than a technology push approach, as sustainable value creation requires interrelated social and technical change (Schot & Geels, 2008). Additionally, parallels can be drawn with literature on transition management, which has been emphasized as a governance approach for sustainable development (Loorbach, 2010). Finally, STEEM finds its roots in EE literature, evidenced by the notion that EEs are a vehicle focused on the strategic management of a place (O'Connor et al., 2018; Audretsch, 2015). So, to conclude, STEEM finds theoretical underpinnings in both MLP and EE literature.

4.6.3. Research design and limitations

My qualitative method allowed for a nuanced understanding of how entrepreneurs interact with their local EE and is particularly useful in situations where there are yet few standardized metrics to analyze the structure or success of EEs (Spigel, 2017). Despite this nuanced understanding, there are limitations. Firstly, the largest barrier for the reliability of the interview data is 'social desirability' of the answers given by the interviewees. In other words, respondents may answer in what they believe is the preferred social response whether it is true or not (Brink, 1989). Especially Finnish interviewees were very polite, which is embedded in Finnish culture. It is even considered inappropriate and impolite to force one's opinions on others in Finland (Nishimura et al., 2008). We tackled this by repeatedly stressing the importance of an unbiased opinion for the results of this thesis.

In terms of validity, during the interviews, the possibility of participant bias or error was witnessed (Chenail, 2011). An example of such a bias was the differing viewpoints of the interviewer and interviewee on sustainability, EE, and other specific terms (Lozano et al., 2013). We resolved this as much as possible by extensively introducing any new concept during the interviews to enable mutual understanding. In addition, all interviews in Rotterdam were conducted in March, April and May 2020, at the height of the COVID-19 pandemic, which led to the cancellation of some interviews in Rotterdam, decreasing the sample size. It also possibly influenced interviewees' answers in a negative way due to the imposed lockdown and grim future perspectives at that time, during the data-gathering of the thesis in Rotterdam. To resolve this bias, we urged the interviewees to describe the pre-COVID-19 situation.

Additionally, there are some limitations with regard to generalizability. All general conclusions should be treated with care because conclusions drawn from this two (European) city comparison do not fully incorporate the regional uniqueness of cities worldwide. TEEs on other continents, such as Asia and America, which also represent a large share of entrepreneurial activity, can provide new insights into the dynamics that foster the creation and development of TEEs. Also, we focused on the urban context, meaning that findings are not generalizable regarding transformative entrepreneurship in rural areas. In these areas, perhaps different elements and dynamics are in play.

Next, for the results section, we sometimes witnessed an overlap in findings between some conditions. This is caused by the 'interconnectedness' of the different variables in the EE (Stam, 2018). For instance, the culture condition is closely associated with the demand condition, and the talent condition is to a large extent intertwined with the knowledge condition. The consequence of this interconnectedness was that the analysis sometimes became entangled because we had to make choices where to discuss an argument. To iron this out, we made clear and explicit choices where we discussed what argument that could be discussed in multiple subchapters. Finally, a more theoretical limitation is the inherent tension between the open-ended and uncertain process of sustainability transitions (towards the future) and the ambition of governing such a process (Frantzeskaki et al., 2012). In other words, our research tries to understand and govern a process that is inherently difficult to govern because of its open-endedness.

4.6.4. Future research

Firstly, we used data and arguments based on Western/Northern Europe. Future research can further validate our findings and explore how the results can be extrapolated to (T)EEs on other continents in the world. Similarly, elaborating on the limitation regarding urban versus rural settings, further research regarding transformative entrepreneurs in a TEE context in rural areas can display other intriguing perspectives. In addition, it would be interesting to find out if combinations of certain elements can lead the transition, next to each other. So, one type of city has element 'x, y and z' and another 'a, b and c', and both can accelerate the urban sustainability transition. Therefore, future research into more opposite cases, for instance, from different continents, can yield compelling new insights in different transformative configurations of the EE.

Secondly, there is a need for a dynamic perspective that seeks to understand how the structure and influence of EEs change over time in response to both external economic and social shocks as well to internal changes, such as entrepreneurial successes or the purposive philanthropic or organizational efforts of a few ecosystem entrepreneurs or lighthouses (Spigel, 2017; Tiba et al., 2020). In other words: the EE framework (as well as the research methodology) functions as a snapshot of a current situation; therefore, it lacks a temporal aspect. Longitudinal research can for that reason be an interesting avenue for further research (Ployhart & Vandenberg, 2010). Repetition of similar research in five years makes it possible to see (1) EE and MLP coevolution and (2) the evolution of the cities using these frameworks. Next, because we studied a future urban transition to sustainability, shifts between transition pathways can occur. It is not possible to determine whether the transitions will shift between pathways (Geels et al., 2016). Also here, longitudinal research can be an outcome.

Fourthly, researchers need to develop metrics that can be used to identify the presence of the (T)EE conditions and compare them between regions (Spigel, 2017). Metrics such as the size of entrepreneurial exits, venture capital investments and start-up rates of transformative start-ups are already difficult to find, gathering *comparable* data on the effectiveness of (social) networks or cultural elements is even harder, especially because the availability of adequate data varies significantly for different regions (Leendertse et al., 2020). These research advancements will yield both a more rigorous and nuanced understanding of how TEEs affect the transformative entrepreneurial process and will also enable more reliable and precise policy recommendations to advance existing TEEs and subsequently develop successful TEEs in regions without histories of successful bottom-up sustainable growth. Finally, an interesting avenue of further research is how theme-specific incubators act as protected spaces or micro-level niches embedded within the overarching TEE.

5. Sustainable start-up performance

A slightly modified version of this chapter has been published as *Leendertse, J., van Rijnsoever, F. J., & Eveleens, C. P. (2021). The sustainable start-up paradox: Predicting the business and climate performance of start-ups. Business Strategy and the Environment, 30(2), 1019-1036. https://doi.org/10.1002/bse.2667*

5.1. Introduction

New sustainable technologies and business models are necessary for the transition to a carbon neutral economy (Gibbs, 2006; Niemann, Dickel, & Eckardt, 2020; Schaltegger, Hansen, & Lüdeke-freund, 2016). These are likely to be introduced by sustainable entrepreneurs (Cohen & Winn, 2007; Shane & Venkataraman, 2000), which makes entrepreneurship a critical component for the development of a carbon neutral economy (Dean & McMullen, 2007; Gibbs, 2006; Loorbach & Wijsman, 2013). Hence, governments and universities strongly support environmentally sustainable entrepreneurship (Gast, Gundolf, & Cesinger, 2017; Kanda, Hjelm, & Bienkowska, 2014). To effectively support these start-ups it is crucial to understand when sustainable start-ups contribute to the transition to a carbon neutral economy (Gast et al., 2017; Loorbach & Wijsman, 2013). A first condition is that the start-up's business model must have the potential to reduce greenhouse gas emissions, this is the start-up's climate performance. Second, to be able to significantly contribute to climate mitigation, sustainable start-ups need to grow, they need to maintain a healthy business performance (Bjornali & Ellingsen, 2014; Calel & Dechezlepretre, 2013; Meyskens & Carsrud, 2013). Climate mitigation and business performance are thus both crucial performance indicators for environmentally sustainable start-ups (Gast et al., 2017; Schaltegger & Wagner, 2011; Stubbs, 2017). Based on Bjornali & Ellingsen (2014), we define an environmentally sustainable start-up as: *an entrepreneurial venture which significantly reduces greenhouse gas emissions by exploiting technological knowledge*.

The business performance of start-ups is a widely studied topic in entrepreneurship (Shane & Venkataraman, 2000; Song, Podoynitsyna, van der Bij, & Halman, 2008). In contrast, no research has yet studied what factors determine the climate performance of start-ups (Bjornali & Ellingsen, 2014; Meyskens & Carsrud, 2013). Studies on corporate firms show that climate performance easily goes at the expense of business performance (Dean & McMullen, 2007; Pinkse & Kolk, 2010). At the same time business performance is required, the start-up's product or service needs to be sold, for the start-up to contribute to climate mitigation (Bjornali & Ellingsen, 2014). There thus appears to be a paradox between the two performance dimensions. A possible explanation for this paradox is that large corporates rely strongly on existing routines, and that they lack the capabilities to align both performance dimensions (Van Mossel, Van Rijnsoever, & Hekkert, 2018). Yet, as startups are relatively unburdened by an organizational history, it is unknown if this problem also applies to start-up firms. In particular, some authors have argued that the relation between climate and business performance is context specific (Flammer, 2015; Hang, Geyer-Klingeberg, & Rathgeber, 2018; McMullen, 2018; Russo Spena & Di Paola, 2020). We aim to find out whether and when environmentally sustainable start-ups encounter the aforementioned paradox between climate and business performance.

A critical factor to consider in this context is technology, which is commonly at the root of climate performance (Bjornali & Ellingsen, 2014; Gerlach, 2003; Stirling, 2010; Zhang, Zhou, & Choi, 2013), and also considered a key source of a start-up's competitive advantage (Aharonson & Schilling, 2016; Debackere, Luwel, & Veugelers, 1999a; Deeds, 2001; Zahra, 1996). However, technology has so far received little attention as an independent variable in the start-up performance literature. There are a few exceptions that do study technological novelty in start-ups, however, these studies do so in the form of entrepreneur self-assessment (Hyytinen, Pajarinen, & Rouvinen, 2015; Soetanto & Jack, 2013) which leaves room for a content driven method to measure technological novelty. We aim to fill this research gap by considering the effects of two technology dimensions, technology type (hardware or software) and the novelty of the technology, on both types of performance.

This leads to the following research question: *What is the influence of the technology characteristics of sustainable start-ups on their business and climate performance?* We quantitatively test the influence of these variables on performance using a sample of 197 Western-European start-ups. Because start-ups are small in the first years of their business, their emission reductions will inherently also be small during these years (Hyytinen et al., 2015). We therefore consider the *potential climate performance* rather than the achieved climate performance (Bjornali & Ellingsen, 2014; Rasmussen et al., 2012).

This study has two main contributions. First and foremost, by including the climate dimension of performance, this study takes a new step towards a more holistic evaluation of start-up performance, which includes their societal contributions as well as their business performance (Horne, Recker, Michelfelder, Jay, & Kratzer, 2020; Tiba, van Rijnsoever, & Hekkert, 2019; Zahra, Gedajlovic, Neubaum, & Shulman, 2009). Second, by focusing on the important but complex role of technology in start-ups we contribute to the technological trajectory literature (Fleming & Sorenson, 2001).

From a practical perspective, this study helps entrepreneurs, business coaches investors, and policy makers understand the influence of sustainable start-ups' technologies on their business and potential climate performance. Using our results, they can make more informed decisions when investing in and advising to sustainable start-ups.

5.2. Theory

Start-ups are small and young entrepreneurial ventures which are in the process of exploring a technology to develop their business (Bjornali & Ellingsen, 2014; Fontes & Coombs, 2001; Klotz, Hmieleski, Bradley, & Busenitz, 2013). This study focuses on *sustainable start-ups*, which are hybrid organisations who besides developing a business also contribute to solving social and environmental problems (McMullen & Warnick, 2016; Munoz & Cohen, 2018; Stubbs, 2017). While sustainable start-ups all face similar challenges in balancing their business ambitions with a societal purpose, they differ empirically (de Lange, 2017). In particular, the literature on sustainable entrepreneurship identifies social and environmental entrepreneurship as two distinct categories (Belz & Binder, 2017; Bocken, 2015; de Lange, 2017). In this study we focus on environmental entrepreneurship (Dean & McMullen, 2007; Gast et al., 2017), which has been defined as "the process of discovering, evaluating, and exploiting economic opportunities that are present in environmentally relevant market failures" (Dean & McMullen, 2007, p. 58). More specifically, we look at start-ups that help reduce CO_2 equivalent (CO_2e) emissions (Bjornali & Ellingsen, 2014; Meyskens & Carsrud, 2013). Based on Bjornali & Ellingsen

(2014), we define an environmentally sustainable start-up as: *an entrepreneurial venture which significantly reduces greenhouse gas emissions by exploiting technological knowledge*. In the rest of this study we refer to these as sustainable start-ups.

5.2.1. Start-up performance

The performance of a start-up is defined as whether the start-up achieves its desired purpose (Wright & Stigliani, 2012). Sustainable start-ups desire to both exploit a market opportunity and to reduce the impact of climate change (Bjornali & Ellingsen, 2014; Parrish, 2010). Therefore, *business* and *climate performance* constitute two different dimensions of performance (Bennett, 1991). In the next sections we explain how two technology characteristics, the *type of technology* and the *technological novelty*, are expected to influence business and climate performance. Fig. 21 displays our hypothesized relationships.

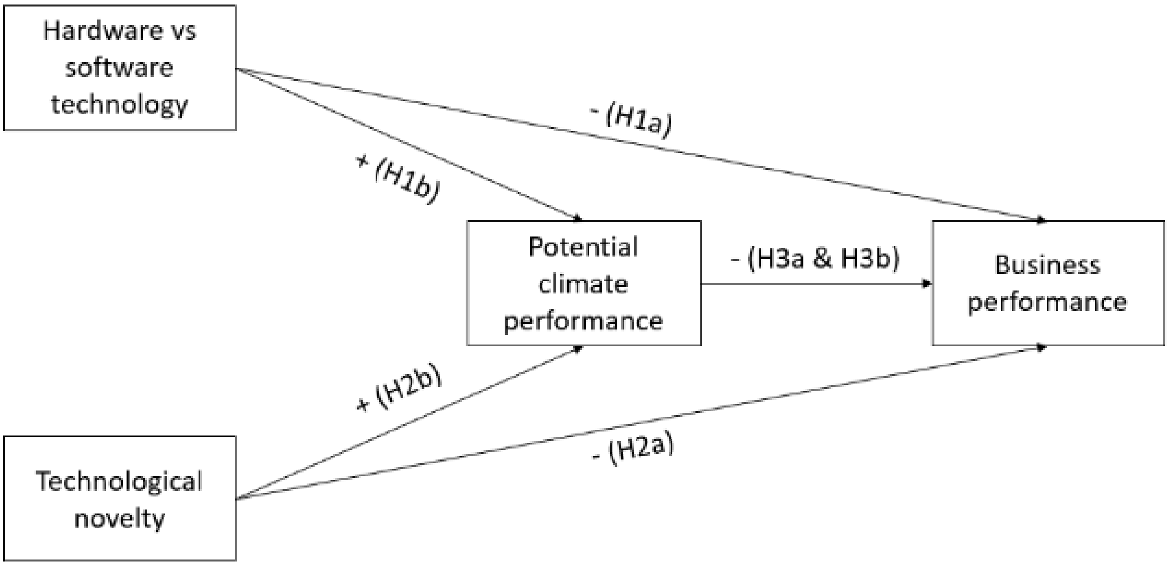

Fig. 21: Conceptual model

5.2.2. Type of technology

Digital, software, technologies have unique characteristics that make them fundamentally different from physical, hardware, technologies (Nambisan, 2017). In entrepreneurial practice start-ups are therefore often judged based on whether their product is based on a digital or physical technology (Alasdair, 2015; Block & Sandner, 2009; Lindtner, Hertz, & Dourish, 2014). We therefore study the difference in performance between these technology types. We expect start-ups with a software technology to have a higher business performance for three reasons. First, they are considered to be more easy to scale because their digital nature doesn’t require the production of physical products (Nambisan, 2017; Zhang, Lichtenstein, & Gander, 2015). This makes it easier for software technology start-ups to reach a larger market segment. Second, digital technologies have fast learning curves which enables them to grow quicker than other firms (Zhang et al., 2015). Finally, the physical nature of hardware technologies often results in a need for larger upfront investments to produce and purchase the product (Eveleens, 2019). This results in barriers to the adoption of the product. These arguments are in line with Chatterjee & Hambrick (2007) who find that start-ups in the computer software industry perform better than those in the computer hardware industry. As such, we arrive at the following hypothesis:

Hypothesis 1a: Start-ups with a hardware technology have a lower business performance than start-ups with a software technology

As mentioned above, there is no previous literature on the influence of technology type on the potential climate performance of start-ups. However, we can deduce arguments by looking at findings from other empirical fields. For example in a study of the electricity value chain, Moore and Wüstenhagen (2004) show that most of the opportunities for sustainable innovation concern hardware technologies, indicating that hardware technologies have a larger potential climate performance. Furthermore, hardware technologies are often replacements of the existing process or product, while software technologies often make existing processes and products more efficient (Hellström, 2007). We argue that, although efficiency increase is important, the replacement of existing processes and products by hardware technologies will lead to larger reductions in CO_2e emissions because CO_2e emissions are very much driven by physical processes such as fossil fuel burning and industry (Raupach et al., 2007). Furthermore, hardware technologies are more likely to be radical and thus to have a larger impact.

Hypothesis 1b: Start-ups with a hardware technology have a higher potential climate performance than start-ups with a software technology

5.2.3. Technological novelty

Start-ups with a more novel technology have a high technological potential and as a result novel technologies have the potential to gain a competitive advantage (Debackere, Luwel, & Veugelers, 1999b; Deeds, 2001; Harrigan & DiGuardo, 2014; Zahra, 1996). However, novel technologies are at the beginning of technological trajectories, which increases the time needed to develop the technology and the risks associated with developing the technology (Fleming, 2001; Hyytinen et al., 2015; Weissbrod & Bocken, 2017). Customers are often reluctant to adopt these high risk technologies, which reduces the firms' business performance (Fleming, 2001; Marra, Pannell, & Abadi, 2003; Verhoeven, Bakker, & Veugelers, 2016). Start-ups with less novel technologies, on the other hand, build closely on technologies in existing technological trajectories. As such, they can be expected to benefit from economies of scale and learning effects obtained through experience with these other technologies (Yu, Van Sark, & Alsema, 2011; Zhong & Verspagen, 2016). This makes these technologies more competitive on the market (Anandarajah & McDowall, 2015; Rogner, 1998). Furthermore, a higher similarity to other technologies is likely to increase societal confidence in the product (Amezcua, Grimes, Bradley, & Wiklund, 2013). This is supported by Hyytinen et al. (2015), who find that more innovative start-ups are likely to encounter a greater liability of novelty, which makes them less likely to achieve high business performance. Also, Soetanto & Jack (2016) find that start-ups with a strategy of discovering new knowledge, have a lower business performance than start-ups that optimize existing technologies. This leads to the following hypothesis:

Hypothesis 2a: Start-ups with a more novel technology have a lower business performance

For novel technologies which are at the start of technological trajectories learning effects have not yet occurred (Nemet, 2006; Rogner, 1998; Yu et al., 2011). Novel technologies thus often combine their high risks with a large technological potential. Because the risks associated with exploring novel technological options are so high, we expect that a start-up will only explore a novel technology if it has a large technological potential. The larger technological potential of these start-ups also means that they have a larger potential to mitigate climate change. We thus hypothesize that start-ups with a more novel technology have a larger potential to reduce CO_2e emissions (Aghion et al., 2012; Aghion et al., 2014; Bjornali & Ellingsen, 2014; Nemet, 2009).

Hypothesis 2b: Start-ups with a more novel technology have a higher potential climate performance

5.2.4. Mediation of climate on business performance

To develop this section we combine the existing sustainable entrepreneurship literature, which is still limited on this topic, with the more developed CSR literature. A similar approach in theory development was successfully implemented by de Lange (2017). Research on corporates shows that the climate performance of firms influences their business performance (Hoang, Przychodzen, Przychodzen, & Segbotangni, 2020; Ong, Soh, Teh, & Ng, 2015; Pinkse & Kolk, 2010; Qiu, Shaukat, & Tharyan, 2016). Linder, Björkdahl, & Ljungberg (2014) find that environmental oriented firms have lower economic performance than their counterparts. While, Flammer (2015) shows that, under certain conditions, adopting CSR policies can have a positive effect on the business performance. This indicates that the two performance dimensions are not independent and that the relation between them is context specific (Hang et al., 2018; McMullen, 2018; Niemann et al., 2020). Therefore we, in this section, discuss the influence of potential climate performance as a mediating variable on the relation between technology characteristics and business performance.

The product of a sustainable start-up is considered more difficult and costly to implement than that of a regular start-up (Giudici, Guerini, & Rossi-Lamastra, 2017), which forms a barrier to a scalable business model. As a result, sustainable start-ups add more risk compared to other start-ups which causes investors to avoid climate sustainability start-ups (de Lange, 2017; Martin & Moser, 2016). Several scholars argue that this is the case because sustainable start-ups have to balance their economic and sustainability objectives and experience tensions in doing so (Jolink & Niesten, 2015; Smith, Gonin, & Besharov, 2013; Stubbs, 2017). We therefore hypothesize that the potential climate performance has a negative influence on the business performance of sustainable start-ups.

We have argued that technology influences the business and climate dimensions of the performance of sustainable start-ups, and in addition that the potential climate performance has a negative influence on the business performance. However, in the literature on larger firms we also find a strong context specific component to the relation between climate and business performance (Flammer, 2015). We therefore include the potential climate performance as a partial mediator in the relation between technology and business performance:

Hypothesis 3a: Part of the relation between a start-up's type of technology and its business performance is mediated by the start-up's potential climate performance, such that hardware relates positively to potential climate performance, which subsequently relates negatively to business performance.

Hypothesis 3b: Part of the negative influence of a more novel start-up technology on the start-up's business performance is mediated by the start-up's potential climate performance, such that a more novel technology leads to a higher climate performance which subsequently relates negatively to business performance.

5.3. Methodology

5.3.1. Research design and data collection

To test our hypotheses, we collected data from 197 start-ups that participated in three regions of the Climate-KIC accelerator program 1) the Netherlands, 2) the DACH (Germany, Austria, Switzerland), and 3) the Nordics (Denmark, Norway, Sweden, Finland) between 2012-2016. The start-ups in this program are especially suited for this research because the program only selects young entrepreneurial ventures with a positive climate impact. Using the Climate-KIC accelerator as a sampling frame thus helps us select only start-ups that meet our definition of sustainable start-ups (Climate-KIC, 2017). Furthermore, this allows us to gain access to detailed information on a large sample of sustainable start-ups, which is hard to achieve due to their (relatively) limited number.

We collected data from three sources: (1) The Climate-KIC evaluation surveys, which were conducted about each start-up's performance in 2014-2016, are used as the data source for the business performance variables. (2) We use archival data from the Climate-KIC accelerator in the form of the application forms from the time the start-up applied to the accelerator. These forms are text-mined to collect the information for the independent and control variables as well as for the climate dependent variable. Due to the use of archival data the measurement of the independent and control variables takes place prior to the business performance variables. (3) A combination of public sources, such as the Chamber of Commerce and LinkedIn, are used to fill in missing information. We impute remaining missing variable using multivariate imputation by chained equations (Buuren & Groothuis-Oudshoorn, 2011; Rubin, 1987, pp. 76–77).

5.3.2. Variables

5.3.2.1. Dependent variable: Business performance

Business performance is a multidimensional concept because start-ups take different paths in growing their business, they prioritize different dimensions of business performance at different points in time (Davidsson, Steffens, & Fitzsimmons, 2009). Hence, no single dimension can sufficiently capture business performance (Daily & Dalton, 1992; Murphy, Trailer, & Hill, 1996; Wiklund & Shepherd, 2003). Therefore, we use *firm size, revenues,* and *investments* as three dimensions of business performance. In doing so we follow the advice of Eveleens et al. (2017) and Wiklund and Shepherd (2003) to include multiple measures of business performance in studies on start-up performance.

We use firm size and revenues as dimensions of business performance to illustrate the achieved growth of the firm. Similar to existing studies, we operationalize firm size through a count of the *number of employees* who are employed by the start-up in the year of the performance survey (Eveleens et al., 2017; Groenewegen & De Langen, 2012; Peña, 2004). The revenues are measured as the absolute amount of turnover created by the company in the year of the performance survey (Groenewegen & De Langen, 2012; Rothaermel & Thursby, 2005; Sullivan & Marvel, 2011). The revenue variable is measured on a four-level ordinal scale (0 = no revenues, 1 = €0-10,000, 2=€10,000-100,000 , 3 = €> 100,000).

Because the climate sector is very capital intensive, start-ups need external funding to achieve future growth (Bjornali & Ellingsen, 2014; Bocken, 2015; Rothaermel & Thursby, 2005). The *investments* thus represent the potential growth of a start-up. We operationalize the *investments* as the cumulative amount of external investments made into the company between the start-ups foundation and the moment of the performance survey. This variable is also measured on a four-level ordinal scale (1 = €0-250,000, 2 = €250,000-500,000, 3=€500,000-1 million, 4 = €> 1 million).

5.3.2.2. Dependent variable: Climate performance

In studies on environmental initiatives, the climate performance is measured as the achieved reduction in the amount of CO_2 equivalent (CO_2e) emissions[55] (Cohen & Winn, 2007; Gohar & Shine, 2007; Meyskens & Carsrud, 2013). Therefore, we operationalize potential climate performance as the *potential reduction in CO_2e emissions* caused by a start-up's technology in comparison to the conventional alternative (Bjornali & Ellingsen, 2014; Rasmussen et al., 2012).

The assessment of the start-up's climate performance took place in the form of expert coding by the authors and industry experts (Hallgren, 2012). As part of their application to the Climate-KIC accelerator the start-ups provide descriptions of their business idea and how their business will contribute to reducing the emission of greenhouse gases. We use these descriptions to assess the start-ups' potential to reduce CO_2e emission. The authors reviewed each start-up's potential to reduce CO_2e emission if their business idea becomes successful. We then scored this potential on a 5-point scale, in which a one stood for a very low potential and a five for a very high potential. This method allows us to circumvent the problem that start-ups often lack the resources to collect and report data on their climate performance (Horne et al., 2020; Kratzer, 2020).

To increase the reliability of the measure we verified the author assessments with those of a group of experts from Climate-KIC. The expert scores were only available for 127 out of the 197 start-ups and could thus not be used as the climate performance measure. However, by calculating the inter-rater-reliability (IRR) between the expert and author scores we could, through one-way, single-measure Inter Class Correlations (ICC), verify the reliability of the author scores (Hallgren, 2012). The ICC values between the author scores and the panel member mean is 0.627 showing a good IRR and thus proving that the climate performance assessment of the author is a reliable measure (Cicchetti, 1994; Hallgren, 2012).

5.3.2.3. Independent variable: Technology

Typically, patents are the most frequently used measure to study technology (Fontana, Nuvolari, & Verspagen, 2009; Harhoff, Narin, Scherer, & Vopel, 1999; Verhoeven et al., 2016). However, patents are not a reliable indicator for start-up's, because they often do not file for them (Graham & Sichelham, 2008; Helmers & Rogers, 2011). To operationalise both technology characteristics we instead use the technology and product descriptions from the start-up's application form to the Climate-KIC accelerator. This form of archival data presents a unique database with access to descriptions of the technology at the time the start-up entered the accelerator.

To measure *technology type*, we coded whether or not the start-up uses hardware (physical) technology (software = 0, hardware = 1). Combinations were coded as hardware because of the

[55] CO_2-equivalent is an often-used measure to calculate the climate impact of emissions based on their global warming potential (Olivier, Schure, & Peters, 2017).

expected capital costs that comes with hardware products. We performed a robustness test by including hardware-software combinations as a separate category. This did not alter the results and the coefficients showed that the hardware-software combination start-ups were indeed highly similar to the hardware start-ups.

The few existing start-up studies that measure technological novelty do so in the form of self-assessment by the start-ups (Hyytinen et al., 2015; Soetanto & Jack, 2013). We instead use the technology descriptions to employ a more data driven method. In this study, *technological novelty* is a start-up characteristic which resembles how the technological diversity of the system changes due to the introduction of that particular start-up's technology. This measure thus reflects how much technological novelty the start-up adds to the technological system, it measures the change in *"the evenness in a distribution of elements among a number of categories in a system"* (Van Rijnsoever, Van Den Berg, Koch, & Hekkert, 2015, p. 1096). As such, measuring the diversity change caused by a start-up requires mapping the technological system and determining the position of each start-up within this system. In this study we form the technological system through the technological descriptions of 920 sustainable start-ups who applied to the Climate-KIC accelerator. This broadened set of start-ups represent the range of possible technological options for climate-focused start-ups. Including an even broader set of companies by using website texts proved to be unfeasible because most websites contained very little information on technologies.

Previous studies have shown that text-mining is a particularly well suited approach to map technological systems because it can be used to accurately assess a technology's complex features and identify patterns between different technologies (Aharonson & Schilling, 2016; Arts et al., 2013; Blei, 2011; Páez-Avilés et al., 2016). The technology description sections of the application forms are well suited for text-mining because they are similar in length to the abstracts which are often used as the input in text-mining models (Grün & Hornik, 2011; Páez-Avilés et al., 2018; Zhao et al., 2015).

We use the latent Dirichlet allocation probabilistic topic model (LDA) (Blei, 2011; Lee, Kihm, Choo, Stasko, & Park, 2012; Steyvers & Griffiths, 2007). LDA is a text-mining approach which analyses the words of documents to discover the themes that run through the documents and the connections between these themes (Blei, 2011). This methodology is outlined in (Blei, 2011) and has successfully been applied in various studies such as a sustainable entrepreneurship literature review (Tiba et al., 2019) and an assessment of nanotechnology innovation projects (Páez-Avilés et al., 2018).

To run the LDA we first performed the necessary data transformation steps (Feinerer, 2017; Meyer et al., 2008). We then use the Gibbs sampling algorithm to run the LDA (Blei, 2011; Srivastava & Shami, 2009; Su & Liao, 2013). To determine the appropriate amount of topics, we estimate multiple models (Blei & Lafferty, 2009; Su & Liao, 2013). The appropriate amount of topics is determined by the first time where the rate of perplexity change (RPC) is smaller than the following number of topics (Zhao et al., 2015). This is the case for the model with 14 topics (Appendix A). The LDA thus gives 14 topics (clusters of words) and for each document (start-up technology) the percentage with which they fit each topic. To characterise the topics, the 10 most frequent words for the first five topics are shown in table 24 while the complete topic overview is depicted in Appendix A. The LDA is a content based approach and these topics and the words they contain are thus determined by the algorithm.

To calculate the diversity we use the Shannon-Weaver entropy index, which contains variety and balance (Shannon, 1948) and has been applied successfully in other technology studies (Páez-Avilés et al., 2018; Van Rijnsoever et al., 2015).

$$H = -\sum_{i=1}^{R} p_i \, lnp_i \tag{1}$$

Here, H is the entropy value for diversity and p is the proportion of start-ups with a specific topic (i) (Páez-Avilés et al., 2018; Stirling, 2007). The technological novelty of a start-up (ΔH) can be calculated through the difference between the entropy of the population of sustainable start-ups (H_1) and a hypothetical population in which that particular start-up does not exist (H_0).

$$\Delta H = H_1 - H_0 \tag{2}$$

Table 24. The ten most frequent (stemmed) terms for the first five topics resulting from the topic modelling of the technology descriptions of 920 sustainable start-ups.

(Offshore) Wind	*Water management*	*Heating*	*Online applications*	*Transportation*
wind	water	heat	people	transport
storage	treatment	engine	carbon	app
module	filter	cool	online	clean
turbine	pump	fuel	climate	smartphone
tank	flow	gas	find	europe
air	drink	thermal	social	park
ship	region	air	shop	match
scalable	reus	hydrogen	footprint	rout
compress	shower	exchange	marketplace	driver
pollute	human	oil	engage	travel

5.3.2.4. Control variables

We include *start-up age* because previous research finds a positive significant relation with business performance (Ortín-Ángel & Vendrell-Herrero, 2014; Soetanto & Jack, 2016, 2013; Song et al., 2008). Furthermore, although all start-ups in our sample were less than 10 years old at the moment we measured their performance the start-ups in our sample vary in age. To isolate this effect we control for start-up age which we operationalize as the number of years between foundation and the performance survey.

The *number of founders* is included because previous research finds a positive significant relation with business performance (Klepper, 2001; Soetanto & Jack, 2013). This is operationalized as a count variable of the number of founders at the time of founding. Furthermore, the founding team's level of experience as a measure of human capital is positively related to start-up business performance (Shepherd & Wiklund, 2006; Unger, Rauch, Frese, & Rosenbusch, 2011). We operationalize this through a count variable of the cumulative *years working experience* (Colombo & Grilli, 2010; Rauch & Rijsdijk, 2013).

To account for specific experience, we use a binary indicator to indicate whether any founder had *experience as a start-up founder* (Cassar, 2014; Shane & Khurana, 2003). Similarly, *industry experience* is operationalised as a binary measure that represents whether any founder has working experience in an industry relevant to the start-up (Dahl & Reichstein, 2007; Toft-Kehler, Wennberg, & Kim, 2014). Finally, *management experience* is also operationalized through a binary variable indicating whether the founding team has previous management experience (Dencker & Gruber, 2015). These three variables are author coded based on the resume of all founders, and in the case of industry-experience through a combined review with the activities of the start-up.

Furthermore, we control for the *share of males* in the founding team, because previous studies show that founding teams with a higher share of males have a higher business performance (Chowdhury, 2005; Kanze, Huang, Conley, Higgins, & Tory Higgins, 2018; Malmström, Johansson, & Wincent, 2017; Verheul & Thurik, 2001). Previous studies also find that the market environment influence start-up performance (Schwartz & Hornych, 2010; Song et al., 2008; Wright & Stigliani, 2012). Therefore, we include the *type of market* as a control variable, this is operationalized as a binary variable that represents whether the start-up sells its products to businesses (B2B) or consumers (B2C) (B2B = 0, B2C = 1). Finally, there are small differences between the accelerator programs and they are located in countries with different institutional contexts and cultures (Climate-KIC, 2017). As such a categorical control variable which represents the *accelerator region* is also used.

5.3.3. Data analysis

13 of the 197 start-ups in our sample had ceased to exist at the time of the survey. The sample size for the business performance models is thus 184[56], while the sample for the potential climate model is 197. The descriptive statistics and correlations are shown in Table 25. To test the hypotheses, we perform multiple regression analyses. The *number of employees* is an overdispersed count variable for which we use a negative binomial model. The *revenues, investments* and *climate performance* variables are ordinal by nature. Therefore, we use an Ordinal Logit Model (OLM) for these dependent variables. We use the McFadden Pseudo R^2 to report the performance of the respective models (Hoetker, 2007; Jackman, 2017; Zeileis & Hothorn, 2002). For each of the analyses we verify that the appropriate assumptions hold. The Spearman's correlations show no particularly worrisome correlations and the Variance inflation factor (VIF) scores are all below 2. As such there is no problem with multicollinearity (Field, Miles, & Field, 2012). Furthermore, scatterplots show that the residuals are homoscedastic, and there are no outliers as no observations have a Cook's Distance larger than 1 (Cook & Weisberg, 1982; Field et al., 2012). For the OLM analyses we also verified that the parallel regression assumptions as outlined in Ari & Yildiz (2014) hold.

To study the mediating effect of the potential climate performance we use the *'mediation'* package in R (R Core Team, 2019; Tingley, Yamamoto, Hirose, Keele, & Imai, 2014). This package implements the causal mediation analyses as outlined by Imai, Keele, Tingley, & Yamamoto (2011) and allows for the use of NBM and OLM regressions to perform the causal mediation analyses (Tingley et al., 2014). We do not use the method of Baron & Kenny (1986), as this does not appropriately test the significance of the indirect effect, nor the Sobel test, as this assumes a normal distribution of standard errors, which

[56] A robustness check with 197 start-ups, which includes the non-surviving start-ups as having zero employees showed very similar results to the outcomes presented in this study.

is not the case (Aguinis, Edwards, & Bradley, 2017; Imai, Keele, & Tingley, 2010; Tingley et al., 2014). In the mediation analyses we include the same control variables as in the regression analyses. Finally, we account for the six potential issues in causal mediation analyses outlined by Aguinis, Edwards, & Bradley (2017).

5.1. Results

5.1.1. Regression analyses

The results of the regression models are shown in Table 26. We find that the McFadden pseudo R^2 values for the firm size model (0.06), the revenues model (0.10) the investments model (0.12) and the climate model (0.07) indicate acceptable to good model fits (McFadden, 1974).

The results show that start-ups with a hardware technology perform significantly worse than their software counterparts for firm size and revenues ($p<0.01$). Start-ups with a software technology thus have higher growth than those with a hardware technology. However, software technology start-ups do not yield more investments. This might be due to the fact that because software start-ups often do not need high investments for manufacturing they spend less time focused on acquiring funding than start-ups with a partially or entirely physical technology who have a higher capital requirements. Hypothesis 1a is therefore partly supported. Start-ups with a hardware technology have significantly higher potential to reduce CO_2e emissions than their software counterparts ($p<0.01$), which lends support to hypothesis 1b.

The technological novelty variable does not have a significant influence on the firm size, revenues, and investments of a start-up. The results therefore do not support hypothesis 2a. A potential explanation could be that while generally risky, a novel technology sometimes has more potential to gain competitive advantage (Debackere et al., 1999a; Deeds, 2001; Harrigan & DiGuardo, 2014; Zahra, 1996), which balances the effect on start-up business performance. The influence of technological novelty on the potential climate performance is positive and significant ($p<0.001$), which supports hypothesis 2b.

Table 25. Descriptive statistics and correlations about sustainable start-ups

#		*n*	*Mean*	*S.D.*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Number of employees	184	5.57	5.01	1																
2	Revenues	180	1.26	1.18	0.50	1															
3	Investments	141	1.65	1.10	0.43	0.24	1														
4	Potential reduction in CO_2 emission	197	2.87	1.05	0.05	-0.06	0.17	1													
5	Technology type	197	0.71	0.46	-0.20	-0.19	0.06	0.25	1												
6	Technological novelty	197	0.29	1.93	0.06	0.00	0.12	0.23	0.04	1											
7	Start-up age	197	2.79	1.87	0.18	0.36	0.46	-0.06	0.06	0.04	1										
8	Number of founders	197	2.51	0.95	0.24	-0.06	0.00	-0.10	-0.07	0.03	-0.08	1									
9	Years working experience	196	19.30	19.03	-0.05	-0.11	-0.02	0.07	-0.02	-0.10	0.04	0.18	1								
10	Start-up experience	196	0.47	0.50	0.02	-0.02	0.10	0.09	0.03	0.04	0.05	0.08	0.46	1							
11	Industry experience	195	0.58	0.49	-0.06	-0.03	-0.16	0.07	-0.07	-0.03	-0.06	0.08	0.50	0.12	1						
12	Management experience	195	0.43	0.50	0.03	-0.01	0.00	0.12	-0.01	-0.02	0.06	-0.06	0.65	0.36	0.26	1					
13	% of males	197	0.89	0.23	0.10	0.15	0.17	0.03	0.03	0.00	0.13	-0.12	-0.10	0.02	0.03	0.08	1				
14	Market type	197	0.22	0.41	0.10	0.10	0.02	-0.06	-0.06	-0.08	-0.04	0.05	-0.16	0.02	-0.18	-0.11	0.01	1			
15	Netherlands	197	0.57	0.50	-0.10	0.05	0.11	-0.11	0.09	0.02	0.25	-0.29	-0.16	0.00	0.01	0.00	0.11	-0.01	1		
16	Germany, Austria, Switzerland	197	0.24	0.43	0.23	0.05	-0.02	0.04	-0.21	0.04	-0.27	0.18	-0.06	-0.22	0.04	-0.07	-0.09	0.05	-0.64	1	
17	Nordics	197	0.19	0.40	-0.12	-0.12	-0.11	0.09	0.12	-0.07	-0.02	0.18	0.26	0.24	-0.06	0.07	-0.04	-0.04	-0.56	-0.27	1

Table 26. Results of the NBM with the number of employees and the OLM models with investments and potential climate performance as the dependent variable.

	Control # of employees NBM	*# of employees NBM*	*Control Revenues OLM*	*Revenues OLM*	*Control Investments OLM*	*Investments OLM*	*Control Climate OLM*	*Climate OLM*
Intercept	0.36 *(0.29)*	0.56. *(0.29)*						
Technology type		-0.33** *(0.12)*		-0.87** *(0.32)*		0.51 *(0.43)*		1.00** *(0.30)*
Technological Novelty		0.21 *(0.24)*		0.72 *(0.68)*		-0.14 *(0.82)*		2.08*** *(0.62)*
Start-up age	0.12*** *(0.03)*	0.12*** *(0.03)*	0.46*** *(0.09)*	0.47*** *(0.09)*	0.44** *(0.13)*	0.45** *(0.13)*	-0.00 *(0.07)*	-0.01 *(0.07)*
Number of founders	0.20** *(0.06)*	0.20*** *(0.06)*	-0.07 *(0.16)*	-0.08 *(0.16)*	0.10 *(0.20)*	0.12 *(0.21)*	-0.24 *(0.16)*	-0.23 *(0.16)*
Years working experience	-0.01. *(0.00)*	-0.01 *(0.00)*	-0.03* *(0.01)*	-0.03* *(0.01)*	0.00 *(0.01)*	0.00 *(0.01)*	-0.01 *(0.01)*	-0.02 *(0.01)*
Start-up Experience	0.16 *(0.12)*	0.12 *(0.12)*	0.23 (0.33)	0.18 (0.33)	0.23 *(0.40)*	0.330 *(0.43)*	0.30 *(0.31)*	0.35 *(0.31)*
Industry Experience	-0.24. *(0.12)*	-0.25* *(0.12)*	0.40 *(0.33)*	0.41 *(0.33)*	-0.74. *(0.42)*	-0.72. *(0.42)*	0.31 *(0.31)*	0.50 *(0.31)*
Management Experience	0.25. *(0.14)*	0.22 *(0.14)*	0.20 *(0.39)*	0.14 *(0.39)*	-0.17 *(0.49)*	-0.16 *(0.50)*	0.35 *(0.36)*	0.54 *(0.36)*
Market type	0.25* *(0.13)*	0.24. *(0.13)*	0.60. (*0.34)*	0.57 (*0.35)*	-0.21 *(0.46)*	-0.23 *(0.46)*	-0.21 *(0.32)*	-0.24 *(0.32)*
Share of males	0.48. *(0.25)*	0.52* *(0.24)*	0.94 *(0.67)*	0.99 *(0.68)*	1.72 *(1.12)*	1.71 *(1.13)*	0.28 *(0.56)*	0.11 *(0.55)*
Accelerator DACH	0.40** *(0.14)*	0.36** *(0.14)*	0.65. *(0.37)*	0.53 *(0.38)*	0.41 *(0.48)*	0.49 *(0.50)*	0.47 *(0.34)*	0.79* (0.35)
Accelerator Nordics	-0.21 *(0.15)*	-0.18 *(0.15)*	-0.22 (0.40)	-0.14 *(0.41)*	-0.95. (0.53)	-1.03. *(0.55)*	0.72. *(0.39)*	0.79* *(0.38)*
n	184	184	184	184	184	184	197	197
Additional df		2	2	2		2		2
LogLikelihood	-473.34	-469.31*	-220.58	-216.79*	-162.75	-161.74	-276.34	-262.66***
McFadden R^2	0.05	0.06	0.09	0.10	0.11	0.12	0.02	0.07

*'***' $p < 0.001$, '**' $p < 0.01$, '*' $p < 0.05$, '.' $p<0.1$*

5.1.2. Mediation analyses

Table 27. Mediation results for the influence of having a hardware instead of a software technology (technology type) and the level of technological novelty on business performance.

	Firm size	*Revenues*	*Investments*[57]
Causal Mediation Effect Technology Type	0.44.	-0.01	0.11*
Direct Effect Technology Type	-2.19*	-0.47**	0.11
Total Effect Technology Type	-1.75*	-0.48**	0.22
Causal Mediation Effect Technological Novelty	0.38	-0.13	0.24*
Direct Effect Technological Novelty	-0.15	0.40	-0.06
Total Effect Technological Novelty	0.23	0.27	0.18
# of bootstraps	10,000	10,000	10,000

*'***' p < 0.001, '**' p < 0.01, '*' p < 0.05, '.'p<0.1*

5.1.2.1. Technology type

From the regression analyses we found that having hardware products increases potential climate performance and decreases the start-ups' firm size and revenues (table 25). The results of the mediation model (table 27) also shows that the total effect from having a hardware technology on firm size and revenues is negative and significant ($p<0.05$). We find that the causal mediation effect for firm size is positive, although only significant at $p<0.1$. This is an example of inconsistent mediation, which means that the direct effect of the independent variable has an opposing sign to the indirect effect (Aguinis et al., 2017; MacKinnon, Fairchild, & Fritz, 2007; van Balen, Tarakci, & Sood, 2019). The negative direct effect ($p<0.05$), is thus larger than the total effect. This means that although firm size is negatively affected by having a hardware technology, there is a positive indirect effect. Namely, hardware technology improves climate performance, which in turn positively influences firm size.

For the investments, the total effect and direct effect of having a hardware technology are not significant. However, similar to the firm size model, the causal mediation effect is significant and positive ($p<0.05$).

[57] These coefficients are calculated based on an NBM model for the sake of simplicity in reporting. We also performed the OLM model and verified the relevant assumptions. This gave the same results, however for the sake of clarity we report the outcomes of the NBM model.

Having a hardware technology thus increases the potential climate performance which in turn increases the investments in the start-up.

We thus find that the potential climate performance serves as a significant mediator on the relation between technology type and firm size ($p<0.1$) and investments ($p<0.05$). However, because the direction of the mediation effect is opposite to the hypothesized effect, hypothesis 3a is rejected. While we hypothesised that potential climate performance negatively affected business performance, our results suggest that potential climate performance can actually contribute to business performance.

5.1.2.2. Technological novelty

In the mediation analyses for technological novelty we find no significant effects on firm size and revenues. This is in line with our regression models (Table 26).

For the investments we find that the positive total effect of technological novelty is not significant. However, the indirect effect of technological novelty through potential climate performance on the investments is positive and significant ($p<0.05$). The total effect is not significant due to the presence of a negative direct effect, which is not significant. So, although technological novelty does not have a total effect on investments, there is, through improving the climate performance, a positive indirect effect on the investments.

We thus find some support that the potential climate performance serves as a mediator in the relation between technological novelty and business performance, but this only applies to the investments. However, the direction of the mediation effect is opposite to the hypothesized effect, and hypothesis 3b is thus rejected.

5.1.3. Control variables

Regarding the control variables in the regression models, we find that *start-up age* has a positive effect on all business performance measure, which is significant ($p<0.01$). A larger *initial founding team* has a positive, significant effect on firm size ($p<0.001$). Furthermore, a larger percentage of males has a positive effect on firm size ($p<0.05$). These findings are in line with previous literature (Malmström et al., 2017; Soetanto & Jack, 2013; Song et al., 2008). Start-ups selling their products to *consumers* have a significantly larger number of employees than their counterparts who deliver to *businesses* ($p<0.1$). Furthermore, we find that start-ups from the *DACH* region are significantly larger than their counterparts from the *Netherlands* and *Nordics* ($p<0.01$). A potential explanation that came up when talking to start-ups from this region is the fact that these start-ups are dealing with a larger home market. As a result, they require larger teams to travel to different parts of their market. Start-ups from the *DACH* region and *Nordics* both have a higher climate potential than their Dutch counterparts ($p<0.05$). Contradictory to the existing literature is the finding that, having experience in the same industry has a significant negative effect on the number of employees ($p<0.05$) and the investments ($p<0.1$). One potential explanation is that we included relevant experience which is obtained working at a university in our industry experience variable. This could have led to the negative influence of industry experience on business performance because previous research has shown that ventures started from universities generally perform worse than other start-ups (Harrison & Leitch, 2010). Finally, we also find a significant negative effect of the cumulative years of working experience on the revenues.

5.1.4. Robustness tests

As a first robustness test we used a binary investment measure (0= no investments, 1 = investments) to test the robustness of this variable. The results were not significantly different from the investment model as reported in this study. To test the reliability of the technological novelty variable, we performed two robustness checks. First, we use the alternative VEM algorithm to perform the LDA (Grün & Hornik, 2011). Second, we constructed the technological diversity change variable based on the 197 start-ups included in this research, instead of the larger set of 920 start-ups. In both cases the results of the regression models were very similar to our original results. Subsequently, we tested for fluctuations over the different years, during which the content of the accelerator program or the economic situation could have changed. We did this by including dummies for the year in which the start-up entered the accelerator. These dummies were not significant and did not change our findings. Finally, because hardware and high novelty technologies are considered to take longer to get to market than software and low novelty technologies we performed a robustness test in which we added the interaction effect between age and both technology type and the novelty of a technology. None of these interaction terms were significant and our results remained the same.

In our study we focus on the business performance of sustainable start-ups that are up to 10 years old. We believe that this is an appropriate timeline given that start-ups are often pressed for short term financial results (Clercq et al., 2006; Steier & Greenwood, 2000). However, hardware and novel technologies are capital intensive and as a result it can take longer for start-ups relying on these technologies to reach a high business performance (Hyytinen et al., 2015; Zhang et al., 2015). However, there is the possibility that the influence of is different for the long term business performance of these start-ups. We partially accounted for this by including age as a control variable and through the robustness test that includes an interaction between age and each of the technology variables.

5.2. Discussion

In this study, we analyzed what factors predict the potential climate performance of sustainable start-ups, and if these contradict business performance. In particular, we focused on the influence of technology characteristics, as these are crucial for both forms of performance. The results provide support for the notion that the business and climate dimensions of performance for sustainable start-ups are fundamentally different from each other. We find that the technology characteristics and also the control variables, have contradictory effects on potential climate and business performance. The negative influence of climate performance which large, established businesses encounter (Linder et al., 2014; Pinkse & Kolk, 2010) is thus likely not only a result of corporates relying on existing routines (Van Mossel et al., 2018). Instead, the tensions between economic and sustainability objectives are also encountered by sustainable start-ups (Jolink & Niesten, 2015; Smith et al., 2013; Stubbs, 2017). At the same time, business performance is necessary to translate potential into actual climate performance (Bjornali &

Ellingsen, 2014; Calel & Dechezlepretre, 2013; Meyskens & Carsrud, 2013). We thus confirm the existence of a paradox between the climate and business performance of sustainable start-ups.

By delving into this paradox, we show how technology influences the complex dynamic between the potential climate and business performance of sustainable start-ups. We confirm that the physical nature of hardware technologies increases the potential climate performance of sustainable start-ups (Raupach et al., 2007). On the other hand, the scalability of digital technologies (Nambisan, 2017; Zhang, Lichtenstein, & Gander, 2015) increases the size of these start-ups. Finally, being at the beginning of technological trajectories causes start-ups with more novel technologies to have a higher potential climate performance (Aghion et al., 2014; Bjornali & Ellingsen, 2014). Technology characteristics are thus a key variable in research on both dimensions of start-up performance, particularly for sustainable start-ups.

However, we also find that potential climate performance serves as a positive mediator in the relationship between the technology characteristics and business performance for sustainable start-ups. Our findings thus confirm previous arguments that the relation between climate and business performance is strongly context specific (Hang et al., 2018; McMullen, 2018). In particular, our study helps to understand the context specific conditions under which sustainable start-ups, as hybrid organisations, prosper (McMullen, 2018). We provide evidence that the sustainable start-up paradox is dependent on the start-up's technology. Namely, sustainable start-ups can partly escape the paradox of maximising climate and business performance by using novel and hardware-based technologies, we find this particularly for the investments.

A possible explanation for this finding is given by de Lange (2019) who finds that investors in sustainable start-ups purposely try to serve as change agents through their investments. These investors choose those sustainable start-ups that have the biggest impact potential because they also value the societal impact (de Lange, 2019; Martin & Moser, 2016). Another explanation is that the sustainable start-ups with the highest potential climate performance are (partly) able to escape the paradox between business and climate performance because the societal urge to mitigate climate change increases the demand for their products/services (de Lange, 2017).

5.2.1. Limitations and further research

A first limitation is that our sample contains a disproportionate number of surviving start-ups. This survival bias made it unfeasible to study the difference between surviving and non-surviving start-ups (Cader & Leatherman, 2011). Hence, our results should be interpreted as a study on the influence of technology on the performance of surviving firms. We encourage future research to study the influence of the type of technology and the level of technological novelty on survival. In particular, the survival bias could be the reason why our results did not confirm with hypothesis 2a which, based on the findings of Hyytinen et al. (2015) regarding innovativeness and survival rates, argues that high novelty start-ups have lower business performance. Furthermore, it would be relevant to study whether the relations between technology characteristics and potential climate performance hold when including non-surviving firm.

A further concern caused by this sampling strategy could be that the results have limited generalizability towards sustainable start-ups not participating in incubation or accelerator programs. However, this is likely not problematic. Climate technologies are generally very resource intensive, and therefore sustainable start-ups encounter large liabilities of newness and smallness (Bjornali & Ellingsen, 2014; Eyraud, Clements, & Wane, 2013; Hyytinen et al., 2015). The start-ups often require additional resources to overcome these liabilities which they acquire by entering accelerators and incubators (Klofsten et al., 2016; Shane & Khurana, 2003; van Rijnsoever et al., 2016; van Weele et al., 2017). It can thus be expected that the majority of sustainable start-ups use the support of an acceleration or incubation program. An advantage of this sampling frame is that it allowed us to obtain a substantial sample of sustainable start-ups, which is a challenge given their relatively limited number. A limitation to the generalizability is that we look particularly at start-ups in developed Western European countries. Future research should test if our findings hold in other institutional contexts, because other studies show that the context has a clear influence on the frequency and quality of sustainable start-ups (Spence, 2011; Tiba, 2020).

In our study we focus on the business performance of sustainable start-ups that are up to 10 years old. We believe that this is an appropriate timeline given that start-ups are often pressed for short term financial results (Clercq et al., 2006; Steier & Greenwood, 2000). However, hardware and novel technologies are capital intensive and as a result it can take longer for start-ups relying on these technologies to reach a high business performance (Hyytinen et al., 2015; Zhang et al., 2015). However, there is the possibility that the influence of technology type and the novelty of a technology is different for the long term business performance of these start-ups. We partially accounted for this by including age as a control variable and through the robustness test that includes an interaction between age and each of the technology variables. Nevertheless we acknowledge that we do not look at the long term business performance of sustainable start-ups. This is a potential limitation of our study and we thus recommend future research to study if the technology type and the novelty of the technology have a different effect on the long term business performance of sustainable start-ups. Particularly interesting would be a time series analyses.

The climate measure in the form of the potential to reduce CO_2e emissions proved reliable using expert scores as a verification. However, it could be argued that quantitative numbers would, nevertheless, be preferable. These estimations could then be combined with the revenues of the start-ups, which would allow for the calculation of the ex-post *realized* climate performance. However, constructing such measures requires individual collaboration from each start-up, which was not available. Furthermore, as we study start-ups, there is an inherent degree of uncertainty about their CO_2e reductions because their production process and business model are still in development. We therefore elected to use subjective assessment scores instead. Future research could further delve into different measures for climate performance and possibly calculate the realised CO_2e reductions ex post.

5.2.2. Practical implications

Achieving (1) climate performance and (2) business performance simultaneously is not straightforward as both require different strategies. In terms of technological characteristics, our study shows that by using novel and hardware-based technologies, sustainable start-ups may partly escape the paradox of maximising both climate and business performance. Additionally, having high climate ambitions partly alleviates the negative effect of hardware technologies on business performance. We therefore advice sustainable start-ups who exploit a hardware technology to dream and act 'climate-big'.

For external stakeholders, such as business advisors, investors, or incubators, our study also has implications. Because the antecedents of climate performance and business performance are different, these stakeholders can have an impact on both forms of performance by focusing on particular antecedents. Specifically, investors can urge sustainable start-ups to follow a technological strategy that is focused on software to maximise business performance. Incubators that may have a predominantly societal goal may instead urge sustainable start-ups to follow a hardware-based strategy to maximise climate performance. If external stakeholders' aim is to maximise both forms of performance, we advise to invest in sustainable start-ups with a hardware technology and high climate potential.

This research also shows that there are fundamental differences in the performance of start-ups based on their type of technology and it's novelty. We argue that start-up support programmes should then also differentiate the support they offer to these start-ups. This is in line with earlier findings that different types of start-ups require different types of support (Soetanto & Jack, 2013; van Weele, van Rijnsoever, Groen, & Moors, 2019).

These results also have implications for policymakers. In particular, our results show that economic and climate ambitions are not easily combined. This challenges the idea of 'green growth' (Hockerts & Wüstenhagen, 2010). If the goal is, primarily, to stimulate start-ups for economic growth, we recommend policymakers to facilitate entrepreneurship based on software technologies. However, if the goal is to pursue green growth by combining climate potential and business performance we recommend to focus on sustainable start-ups with a hardware and novel technology. The results show that deviating from existing technological trajectories is beneficial for society as it results in start-ups with more climate potential, however, doing so does not benefit the business performance of the start-up. To mitigate the business risk of these sustainable start-ups governments should provide them with additional support. One way to do so is through co-investing and taking equity. If some of the sustainable start-ups become profitable, at least part of this investment is publicly retained. In particular, results suggest that having a diverse portfolio of sustainable start-ups can pay off. The limitations of some start-ups may be complemented by the strengths of other start-ups, thereby reducing the risks of the overall investment portfolio. The profits from the low-sustainable start-ups with software technology can then be re-invested into sustainable start-ups with a hardware technology. Finally, another strategy is to reduce the business performance liabilities of start-ups with a hardware technology. This could be done by subsidizing or giving investment guarantees for manufacturing investments or by investing in shared manufacturing facilities that can be used by start-ups.

6. Conclusions

In T3.1 we focused on the factors and actors in the local environment that create conditions for developing and implementing new business models, and what factors are barriers to such business model development. We did so by analysing the entrepreneurial ecosystems and its influence on generic and sustainable entrepreneurship. In addition, we studied what components a region would need to focus its entrepreneurial ecosystem towards transformative entrepreneurship. Finally, we studied what factors influenced the performance of sustainable entrepreneurs in developing business models.

We developed a tool that outlines the state of the entrepreneurial ecosystem in 274 European regions and present this in chapter 2. This tool also allows us to compare the LHs and FCs of the IRIS project. It is important to note that this analysis is performed at the NUTS-2 regional level and thus also encompasses the region in which the IRIS city is embedded. The quality of the EEs in the IRIS-regions is shown in Fig. 22 and shows that Utrecht (NL31 – Utrecht) is the clear top performer followed by Gothenburg (SE23 – Västverige), Vaasa (FI19 – Länsi-Suomi), Nice (FRL0 – Provence-Alpes-Côte d'Azur), Alexandroupolis (EL51 Anatoliki Makedonia, Thraki), Tenerife (ES70 – Canarias), and Focsani (RO22 – Sud-Est). Utrecht performs exceptionally well as it is also in the top 10 European regions (see Fig. 4). Focsani on the other hand scores is among the 10 regions with the lowest score for its EE (see Fig. 5). Of particular interest is also that FC Vaasa has a stronger performing EE than LH Nice.

For the IRIS LH of Utrecht the high scores in Culture, Physical Infrastructure, and Leadership stand out most with the only below average score being Knowledge. The high score on Physical Infrastructure is a representation of the very central location of Utrecht in the Netherlands, which is also recognized in interviews in Utrecht as an important strength of the region. Leadership, which also stands out, is an indication of the high number of coordinators of H2020 Public Private Consortia. This means that many actors in Utrecht take an active role in bringing together actors from the public and private sector. The surprisingly low score on Knowledge (given that Utrecht University is a top university worldwide) is the result of low R&D investments in the region. This appears to be the most important point for improvement in the Utrecht Region. These R&D investments (Knowledge) and also Talent are the two major strengths of the Gothenburg ecosystem. As such, these are points to look to by the other IRIS cities on how they can improve their local ecosystem. We also see that while Vaasa's absolute number of start-ups (62) appeared to lag it's potential given the quality of the EE this is much less the case when looking at the Crunchbase output variable (1.20). The number of start-ups in the Vaasa region is lower due to the lower number of inhabitants in that region.

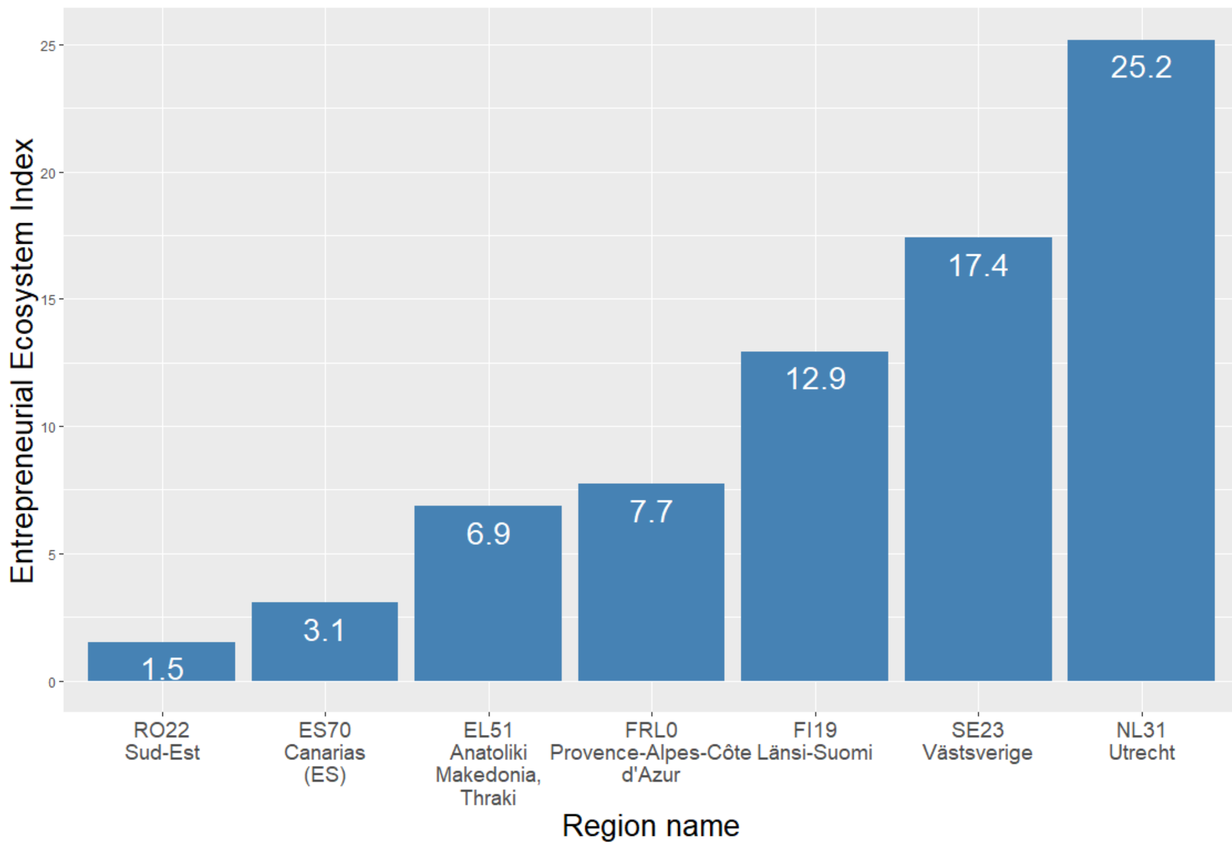

Fig. 22. Quality of the entrepreneurial ecosystems that are part of the IRIS project.

When zooming in in the actual entrepreneurial activities, measured as the number of start-ups founded in a timeframe according to Crunchbase, in the IRIS cities we get a similar overview. We find that Utrecht and Gothenburg do not only have the strongest EE, they also have the highest amount of entrepreneurial activity. Next, we see that Nice does outperform Vaasa regarding the amount of entrepreneurial activity. This is partly a function of the region being larger, but does correspond better with the LH, FC distinction in the initial IRIS application.

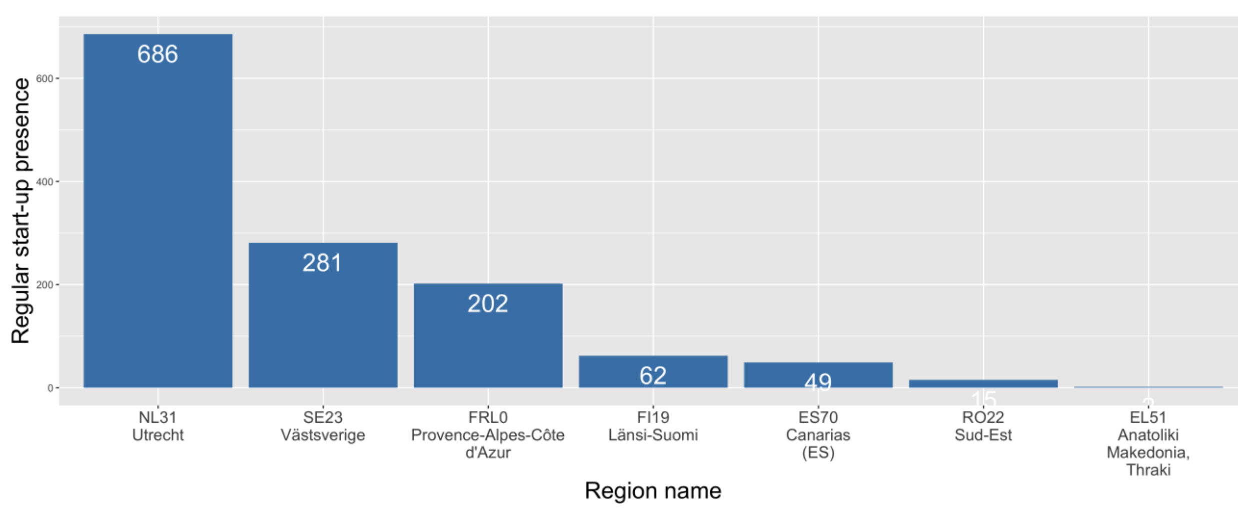

Fig. 23. Number of regular start-ups founded in IRIS regions from 2017-2021

When we move to sustainable entrepreurship and look at the number of start-ups that are addressing environmental sustainability we find the same order of the cities. Of particular note is the higher share of SSUs in the Gothenburg region than in the Utrecht region. In addition, it stands out that 3 of the 4 FC cities did not have any start-ups in them that were identified as environmentally sustainable. The 3.8% of start-ups that are environmentally sustainable in the Utrecht region and the 5.4% in the Nice region are also below the 6.2% which was found for Europe overall. The Gothenburg region, with 7.8% environmentally sustainable start-ups and the Vaasa region with 8.1% both do outperform the European region. It will be interesting to see if the IRIS projects leads to a change over time as start-up foundation is generally a delayed function of the quality of the regions.

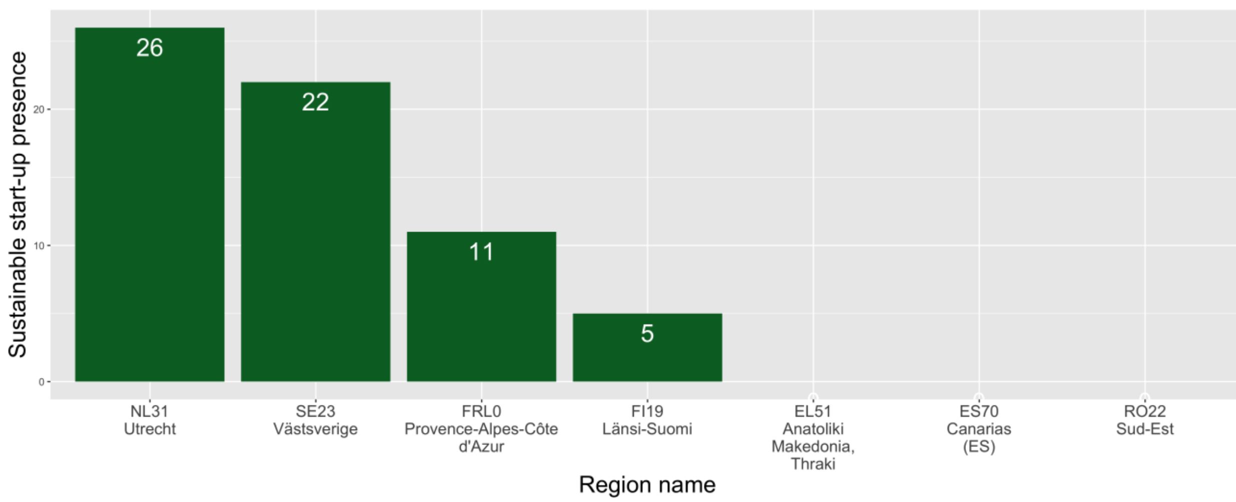

Fig. 24. Number of sustainable start-ups founded in IRIS regions from 2017-2021

6.1. Conclusions

This section describes the core conclusions of the four chapters included in this deliverable.

6.1.1. Assessment of regional European entrepreneurial ecosystems

This chapter quantifies and qualifies regions with an entrepreneurial ecosystem approach. Quantification involved measuring the ten key elements of entrepreneurial ecosystems with a wide range of data sources. Qualification involved applying a network methodology to provide insight into the interdependencies between the elements and the construction of an Entrepreneurial Ecosystem Index to approximate the overall quality of entrepreneurial economies. Finally, we related the elements and the index to entrepreneurial outputs.

As such this chapter provides an *assessment of regional entrepreneurial ecosystems*. In this chapter, we bridge the entrepreneurial ecosystem metrics gap. This is important for two reasons. First, metrics are needed to empirically test which elements of the local environment influence the creation of entrepreneurship. Second, these metrics allow for comparing entrepreneurial ecosystems, to identify strong performance and to learn from best practices in other regions. Entrepreneurial ecosystems consist of the actors and factors that enable entrepreneurship. We operationalize the elements and outputs of entrepreneurial ecosystems for 273 European regions. The ecosystem elements show strong and positive correlations with each other, confirming the systemic nature of entrepreneurial economies and the need for a complex systems perspective. Our analyses show that physical infrastructure, finance, formal institutions, and talent take a central position in the interdependence web, providing a first indication of these elements as fundamental conditions of entrepreneurial ecosystems. The measures of the elements are used to calculate an index that approximates the quality of entrepreneurial ecosystems. This index is robust and performs well in regressions to predict entrepreneurial output. The entrepreneurial ecosystem approach and the metrics we present, provide a lens for public policy to better diagnose, understand and improve entrepreneurial economies. Furthermore, we present a full overview of how all 273 European regions score on each of the ten entrepreneurial ecosystem elements as well as on entrepreneurial outputs. This data can be used as a tool by policy makers to assess how well their region fares regarding the factors and actors that contribute to entrepreneurship.

6.1.2. Identifying and assessing sustainable entrepreneurial ecosystem

In the second chapter we focus on the *assessment and operationalization of sustainable entrepreneurial ecosystems*. This chapter builds on the findings from the first chapter regarding how the local environment influences entrepreneurship. We shift our focus more to a specific type of entrepreneurs, sustainable entrepreneurs. Sustainable entrepreneurs introduce new sustainable technologies and business models to the market. They thereby can help with tackling grand environmental challenges and are key in building smart cities. In particular, we answered the question: *What entrepreneurial ecosystem elements determine the presence of sustainable start-ups in a region?* We conceptualized an SEE as combination of the existing EE framework of Stam (2015) with the innovation systems literature (Carlsson and Stankiewicz, 1991; Hekkert et al., 2007; van Rijnsoever et al., 2015). Specifically, we use the (1) actors and resources, and (2) institutional regime concepts to structure the SEE and propose additional elements that influence sustainable entrepreneurship on top of the quality of the regular EE.

We first find that the quality of a regular EE has a strong positive influence on the presence of SSUs and on the prevalence of SSUs. This confirms that the quality of an EE is more important for SSUs than for regular start-ups. This aligns with the expectations that, because SSUs encounter additional market and institutional constraints and must balance economic and environmental aspirations they benefit more from a supportive EE than their regular counterparts.

Second, we find that the presence of fellow start-ups and favourable actors and resources have a strong positive influence on the presence of SSUs in the future. This confirms our expectations that start-ups can help SSUs overcome their constraints by exchanging knowledge and by connecting them to relevant networks, resources, and markets We find limited evidence for the effect of institutions on the presence of SSUs. It is likely that this effect is supplanted by sustainability-oriented actors and resources as these are influenced by these institutions. In line with the layers of the model proposed by Stam (2015), the effect of institutions thus might work indirectly on the presence of SSUs.

We propose an SEE framework that expands the EE framework by Stam (2015) to sustainable entrepreneurship and show that this allows us to identify additional factors that influence the presence of SSUs in a region. The combination of the EE and innovation systems literature proved to be a fruitful approach. Finally, we identify the amount of environmentally sustainable start-ups in each region, thus providing an overview of the current activities in each region.

6.1.3. The Entrepreneurial Ecosystem in a Multi-Level Perspective on Transitions

In the third chapter we take a qualitative approach. We develop and apply a method to look in depth at *how the local entrepreneurial ecosystem can play a role in the transition to a more sustainable society*. In this chapter we combine the entrepreneurial ecosystem with the multi-level perspective on transitions (MLP). In particular we aimed to answer the following research question: *What configuration(s) of the EE encourages transformative entrepreneurship, which subsequently supports the urban transition to sustainability?* To answer this research question, we conducted 44 semi-structured interviews: 20 in Rotterdam and 24 in Vaasa. We use two case studies (IRIS city Vaasa in Finland, and non-IRIS city Rotterdam in the Netherlands) to see if there are different configurations. Furthermore, by using these cases we test whether the qualitative method designed to analyse the local ecosystems bares fruit. This chapter integrates findings of 44 semi-structured interviews with relevant actors. Based on the findings, we propose a *transformative entrepreneurial ecosystem* (TEE) framework that combines EE and MLP theory and depicts the generalizable configuration of the entrepreneurial ecosystem that encourages entrepreneurship across multiple niches, which subsequently support the urban transition to sustainability. Besides transformative refinements to the ten original framework and systematic conditions of Stam's (2018) framework, this adds two new transformative conditions: 'Involvement of incumbents' and 'TEE branding'. The 'Involvement of incumbents' condition is added to acknowledge the main finding of the increasing importance of start-up - incumbent collaborations. Especially in the field of transformative entrepreneurship, the impact can seldom be scaled without this collaboration. The condition' TEE branding' shows the importance of promoting the successfulness of the TEE and promoting its (successful) transformative entrepreneurs to the external environment. By developing this conceptual TEE framework, we present policy makers with a tool to analyse their cities in more depth. As such, the tool also shows how to build on quantitative findings with qualitative insights. This method can be applied in more cities to gain insight in how the entrepreneurial ecosystem is or can contribute to transistions. We argue that this is important because the TEE can embody and connect the multiple transition areas of which the urban transition to sustainability consists.

6.1.4. Sustainable start-up performance

In the fourth chapter we zoom in from the meso-perspective of regions and cities to the *performance of the individual start-ups* that develop new sustainable business models. Sustainable start-ups introduce new sustainable technologies and business models that facilitate the transition to a carbon neutral economy. To understand how to create viable sustainable start-ups, we study what factors predict their business performance and climate performance (i.e. the ability of the start-up to reduce CO_2e emissions), and if these contradict. A critical factor we consider is technology, which is commonly at the root of climate performance, and important for business performance because it influences a start-up's competitive advantage. Using a sample of 197 sustainable start-ups, we find a paradox between business and potential climate performance. By delving into this paradox, we show how technology influences the complex dynamic between the potential climate and business performance of sustainable start-ups. We confirm that the physical nature of hardware technologies increases the potential climate performance of sustainable start-ups. On the other hand, the scalability of digital technologies increases the size of these start-ups. Finally, being at the beginning of technological trajectories causes start-ups with more novel technologies to have a higher potential climate performance. Technology characteristics are thus a key variable in research on both dimensions of start-up performance, particularly for sustainable start-ups.

However, we also find that potential climate performance serves as a positive mediator in the relationship between the technology characteristics and business performance for sustainable start-ups. Our findings thus confirm previous arguments that the relation between climate and business performance is strongly context specific. In particular, our study helps to understand the context specific conditions under which sustainable start-ups, as hybrid organisations, prosper. We provide evidence that the sustainable start-up paradox is dependent on the start-up's technology. Namely, sustainable start-ups can partly escape the paradox of maximising climate and business performance by using novel and hardware-based technologies, we find this particularly for the investments.

6.2. Recommendations

6.2.1. Recommendations for policy makers

Policy makers can use the measures we present as an essential input for ex-ante policy diagnosis: to discover the weaknesses and strengths of entrepreneurial ecosystems. These weaknesses and strengths are always relative to other relevant regions: the benchmark. This is why the construction of large-scale datasets is a necessity for regional policy. Benchmarking the region could trigger policy by learning from regions that have comparable, entrepreneurial ecosystems. By using data to show how the various parts of the ecosystem for entrepreneurship (or any subject for that matter) are doing, we offer policy makers the opportunity to better understand their region. In other words, the usefulness of an ecosystem index lies in the use of the underlying data and how it can help to better understand the ecosystem and how it can be improved. Tackling the weakest elements of entrepreneurial ecosystems is likely to provide the most efficient and effective way of improving the overall quality of the entrepreneurial ecosystem.

For the IRIS cities we identify the following weakest links. In Utrecht, the knowledge element clearly has the lowest score, given that there are relatively low R&D investments in the region. For Gothenburg, the lowest scores are Networks, Physical Infrastructure, Demand, and Leadership. While the local demand element is hard to improve this makes it important to look at how Gothenburg entrepreneurs can access larger markets outside of the own region. The networks, and leadership elements could be addressed relatively simultaneously as leadership also relates to the connection of actors and thus the facilitation of networks. For Vaasa the lowest scores are Physical Infrastructure, Leadership, Demand, and Intermediaries. This has similar implications as in Gothenburg with the addition that Entrepreneurial Support Offices can be a fruitful avenue to improve the ecosystem. In Nice, the Formal Institutions, Networks, Leadership, and Intermediaries are the lowest scoring dimensions. In Alexandroupolis Formal institutions, Physical Infrastructure, and Demand are the lowest scores but overall the scores here are much lower. The amount of Leadership is a notable strength here. In Tenerife Knowledge and Networks are the lowest scoring elements but there is not really a stand out element. Finally, Focsani has low scores (<0.3) all across the board, making it hard to pinpoint the weakest (or several weakest) elements.

However, a limitation in applying our metrics is that they provide insight into where to look for improvement, but not how this improvement should be achieved. It is thus important to combine these metrics with qualitative insights about particular entrepreneurial ecosystems. We therefore provide a process-based recommendation. Use the diagnosis behind the entrepreneurial ecosystem index as the starting point. Sit down with each other, entrepreneurs, companies, ROMs, provinces, municipalities, universities, colleges, etc., and discuss the diagnosis: Which weak elements are recognized (or not)? What is this due to? How could it be better? Do all stakeholders agree or do we/they have a difference of opinion? How can we improve this region together? By making use of this dialogue, it is possible to deepen the diagnosis and subsequently convert it into points for improvement. Then compile the interventions (both formal and informal policies) based on this dialogue. Please don't jump to conclusions, but use our (and other) research to start the conversation.

The data we present is the starting point of a strategy to improve the EEs in the IRIS cities, and can be used by the policy makers to start the dialogues and design the interventions based on this research. As such, we provide important (but not all) evidence for evidence-based policy making in entrepreneurial ecosystems.

Regarding the study on sustainable entrepreneurial ecosystems policy makers can use our results to establish policies that help build ecosystems for sustainable entrepreneurship in their region. In line with our results, a first step is to focus on building a strong entrepreneurial ecosystem. In addition, we find that there are additional elements beyond the regular EE that matter for SSUs. Especially, supporting actors and resources active in a region is particularly important for SSUs. Actors provide SSUs with access to markets, resources, and thereby help them overcome the constraints they face. We identify two specific actor types that are important. First, the number of regular start-ups. Second, the presence of sustainability-oriented actors and the resources they control. Stimulating the presence of both types of actors are thus potential avenues to a higher presence of sustainable start-ups. As a second contribution we show the amount of SSUs currently present in each region and the top performing regions. This allows policy makers to look not only at how their regions are doing, but also to identify and learn from other regions that have a high presence of SSUs.

Based on the qualitative study we find that entrepreneurial ecosystems for transformative entrepreneurship requires strategic coordination because of its purposiveness. For the two cases we find that strategic coordination consists of ecosystem-level collaboration and transformative leadership. This requires going beyond the nurturing of new technologies and taking a more holistic approach to developing the TEE that in turn enables bottom-up sustainable value creation as a whole.

Our results from the study into sustainable start-up performance show that economic and climate ambitions are not easily combined. This challenges the idea of 'green growth' (Hockerts & Wüstenhagen, 2010). If the goal is, primarily, to stimulate start-ups for economic growth, we recommend policymakers to facilitate start-ups that are working with software technologies as these had higher business performance than hardware start-ups. However, if the goal is to pursue green growth by combining climate potential and business performance we recommend to focus on sustainable start-ups with a hardware and novel technology. The results show that deviating from existing technological trajectories is beneficial for society as it results in start-ups with more climate potential, however, doing so does not benefit the business performance of the start-up. To mitigate the business risk of these sustainable start-ups governments should provide them with additional support. One way to do so is through co-investing and taking equity. If some of the sustainable start-ups become profitable, at least part of this investment is publicly retained. In particular, results suggest that having a diverse portfolio of sustainable start-ups can pay off. The limitations of some start-ups may be complemented by the strengths of other start-ups, thereby reducing the risks of the overall investment portfolio. The profits from the low-sustainable start-ups with software technology can then be re-invested into sustainable start-ups with a hardware technology. Finally, another strategy is to reduce the business performance liabilities of start-ups with a hardware technology. This could be done by subsidizing or giving investment guarantees for manufacturing investments or by investing in shared manufacturing facilities that can be used by start-ups.

6.2.2. Recommendations for entrepreneurship support actors

Entrepreneurial ecosystem actors such as business advisors, investors, or incubators can use the results of the meso-analysis into entrepreneurial ecosystems in a similar way to policy makers, we recommend them to look at what they can do to improve the local ecosystem as a better ecosystem is a clear driver of entrepreneurial activity. Regarding the performance of sustainable start-ups our study also has implications. Because the antecedents of climate performance and business performance are different, these stakeholders can have an impact on both forms of performance by focusing on particular antecedents. Specifically, investors can urge sustainable start-ups to follow a technological strategy that is focused on software to maximise business performance. Incubators that may have a predominantly societal goal may instead urge sustainable start-ups to follow a hardware-based strategy to maximise climate performance. If external stakeholders' aim is to maximise both forms of performance, we advise to invest in sustainable start-ups with a hardware technology and high climate potential.

This research also shows that there are fundamental differences in the performance of start-ups based on their type of technology and it's novelty. We argue that start-up support programmes should then also differentiate the support they offer to these start-ups. This is in line with earlier findings that different types of start-ups require different types of support (Soetanto & Jack, 2013; van Weele, van Rijnsoever, Groen, & Moors, 2019).

6.2.1. Recommendations for entrepreneurs

Finally, for entrepreneurs our meso-studies can help them understand what factors are needed in a supportive ecosystem and to, if certain resources are not present, look across the boundaries of the own entrepreneurial ecosystem from an early stage. Based on the start-up performance study we have specific recommendations based on the fact that achieving (1) climate performance and (2) business performance simultaneously is not straightforward as both require different strategies. In terms of technological characteristics, our study shows that by using novel and hardware-based technologies, sustainable start-ups may partly escape the paradox of maximising both climate and business performance. Additionally, having high climate ambitions partly alleviates the negative effect of hardware technologies on business performance. We therefore advice sustainable start-ups who exploit a hardware technology to dream and act 'climate-big'.

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Annex Chapter 3

Appendix A

Description of data

Table A1.

Description of indicator data sources

Element	Indicators	Measurement and description	Source	Geographical level	Year
Formal institutions	Quality of Governance indicators for Corruption, Impartiality, and Quality and accountability	Average of z-score for the three indicators (Corruption, Impartiality, and Quality and accountability) based on survey answers	Quality of Government Index	NUTS 2 NUTS 1 for BE, DE, EL, SE, and UK Country for IE and LT	2017
Formal institutions	Ease of doing business index	Index based on several dimensions: starting a business, dealing with permits, registering property, credit access, protecting investors, taxes, trade, contract enforcement and closing a business	World Bank Doing Business Report	Country	2015
Entrepreneurship culture	Entrepreneurial motivation	Percentage of early stage entrepreneurs motivated by a desire to improve their income or a desire for independence	Global Entrepreneurship Monitor	Country	2014

Entrepreneurship culture	Cultural and social norms	The extent to which social and cultural norms encourage or allow actions leading to new business methods or activities that can potentially increase personal wealth and income. Rating: 1=highly insufficient, 5=highly sufficient	Global Entrepreneurship Monitor	Country	2014
Entrepreneurship culture	Innovative and creative	Percentage of respondents that agree to: it is important to think of new ideas and be creative	European Social Survey	NUTS 2 NUTS 1 for DE, UK Missing for FRM0, ITF2, LU00, MT00, PT20, PT30	2008 - 2016
Entrepreneurship culture	Trust	Survey question on scale 0-1: Most people can be trusted	European Social Survey	NUTS 2 NUTS 1 for DE, UK Missing for FRM0, ITF2, LU00, MT00, PT20, PT30	2008 - 2016
Entrepreneurship culture robustness	Birth of new firms	Number of new firms per capita	Eurostat, OECD and national statistics offices	NUTS 2 NUTS 1 for DE and UK Country for EL	2010-2016

Networks	Innovative SMEs collaborating with others	Percentage of innovative SMEs in SME business population collaborating with others	RIS & EIS (for countries which are a NUTS 2 region) (also available in RCI)	NUTS 2 NUTS 1 for BE, UK, FR, and AT	2016
Physical Infrastructure	Accessibility via road	Population accessible within 1h30 by road, as share of the population in a neighbourhood of 120 km radius	DG Regio (RCI)	NUTS 2	2016
Physical Infrastructure	Accessibility via rail	Population accessible within 1h30 by rail (using optimal connections), as share of the population in a neighborhood of 120 km radius	DG Regio (RCI)	NUTS 2	2014
Physical Infrastructure	Number of passenger flights	Daily number of passenger flights accessible in 90 min drive	Eurostat / Eurogeographics / National Statistical Institutes (RCI)	NUTS 2	2016
Physical Infrastructure	Household access to internet	Percentage of households with access to internet	Eurostat (RCI)	NUTS 2	2018
Finance	Venture capital	The average amount of venture capital for the last five years per capita	Invest Europe	NUTS 2	2014-2019
Finance	Credit constrained SMEs	Percentage of SMEs that is credit constrained because they either were rejected for loans or received less, or were discouraged to apply because it was too	Investment Survey European Investment Bank	Country	2018

		expensive or they expected to be turned down.			
Leadership	The presence of actors taking a leadership role in the ecosystem	The number of coordinators on H2020 innovation projects per capita	CORDIS (Community Research and Development Information Service)	NUTS 2	2014-2019
Talent	Tertiary education	Percentage of total population that completed tertiary education	Eurostat	NUTS 2 NUTS 1 for BE, DE, and UK	2013
Talent	Lifelong learning	Percentage of population aged 25-64 participating in education and training	Eurostat	NUTS 2 NUTS 1 for BE, DE, and UK	2013
Talent	Business and entrepreneurship education	The extent to which training in creating or managing SMEs is incorporated within the education and training system The extent to which training in creating or managing SMEs is incorporated within the education and training system. Rating: 1=highly insufficient, 5=highly sufficient	Global Entrepreneurship Monitor	Country	2014
Talent	E-skills	Percentage of individuals in active population with high levels of e-skills	Eurostat	Country	2014

New knowledge	R&D expenditure	Intramural R&D expenditure as percentage of Gross Regional Product	Eurostat	NUTS 2	2015
Demand	Disposable income per capita	Net adjusted disposable household income in PPCS per capita (index EU average=100)	Eurostat	NUTS 2	2014
Demand	Potential market size in GRP	Index GRP PPS (EU population-weighted average=100)	Eurostat	NUTS 2	2016
Demand	Potential market size in population	Index population (EU average=100)	Eurostat	NUTS 2	2018
Intermediate services	Incubators	Percentage of incubators in total business population	Own data	NUTS 2	2019
Intermediate services	Knowledge intensive services	Percentage employment in knowledge-intensive market services	Eurostat	NUTS 2	2018
Productive entrepreneurship	Innovative new firms	Number of new firms registered in Crunchbase in the last five years per capita	Crunchbase	NUTS 2	2019
Productive entrepreneurship	High-value new firms (unicorns)	Absolute number of entrepreneurial firms valued above $1 billion founded in the last ten years	CB Insights & Dealroom	NUTS 2	2019

Appendix B

Methods

Table B1.

Correlation table

	Formal institutions	Culture	Networks	Physical infrastructure	Finance	Leadership	Talent	Knowledge	Demand	Intermediate	EE index add	EE index log	Crunchbase output
Culture	0.781****												
Networks	0.606****	0.457****											
Physical infrastructure	0.623****	0.596****	0.520****										
Finance	0.684****	0.657****	0.531****	0.761****									
Leadership	0.302****	0.329****	0.390****	0.461****	0.420****								
Talent	0.809****	0.693****	0.686****	0.586****	0.677****	0.455****							
Knowledge	0.463****	0.465****	0.406****	0.565****	0.633****	0.581****	0.452****						
Demand	0.469****	0.453****	0.439****	0.842****	0.661****	0.345****	0.348****	0.572****					
Intermediate	0.319****	0.359****	0.445****	0.592****	0.493****	0.653****	0.480****	0.441****	0.447****				
EE index add	0.796****	0.755****	0.729****	0.832****	0.836****	0.625****	0.802****	0.676****	0.699****	0.675****			
EE index log	0.801****	0.751****	0.709****	0.859****	0.856****	0.624****	0.805****	0.710****	0.736****	0.676****	0.985****		
Crunchbase output	0.461****	0.402****	0.469****	0.551****	0.497****	0.742****	0.617****	0.462****	0.359****	0.782****	0.696****	0.695****	
Unicorn output	0.170**	0.214***	0.127*	0.307****	0.364****	0.363****	0.269****	0.205****	0.258****	0.370****	0.351****	0.362****	0.401****

Note: *p<0.05; **p<0.01; ***p<0.001; ****p<0.0001

Fig.B1.

Pairwise scatter plot of output and index with clusters of regions

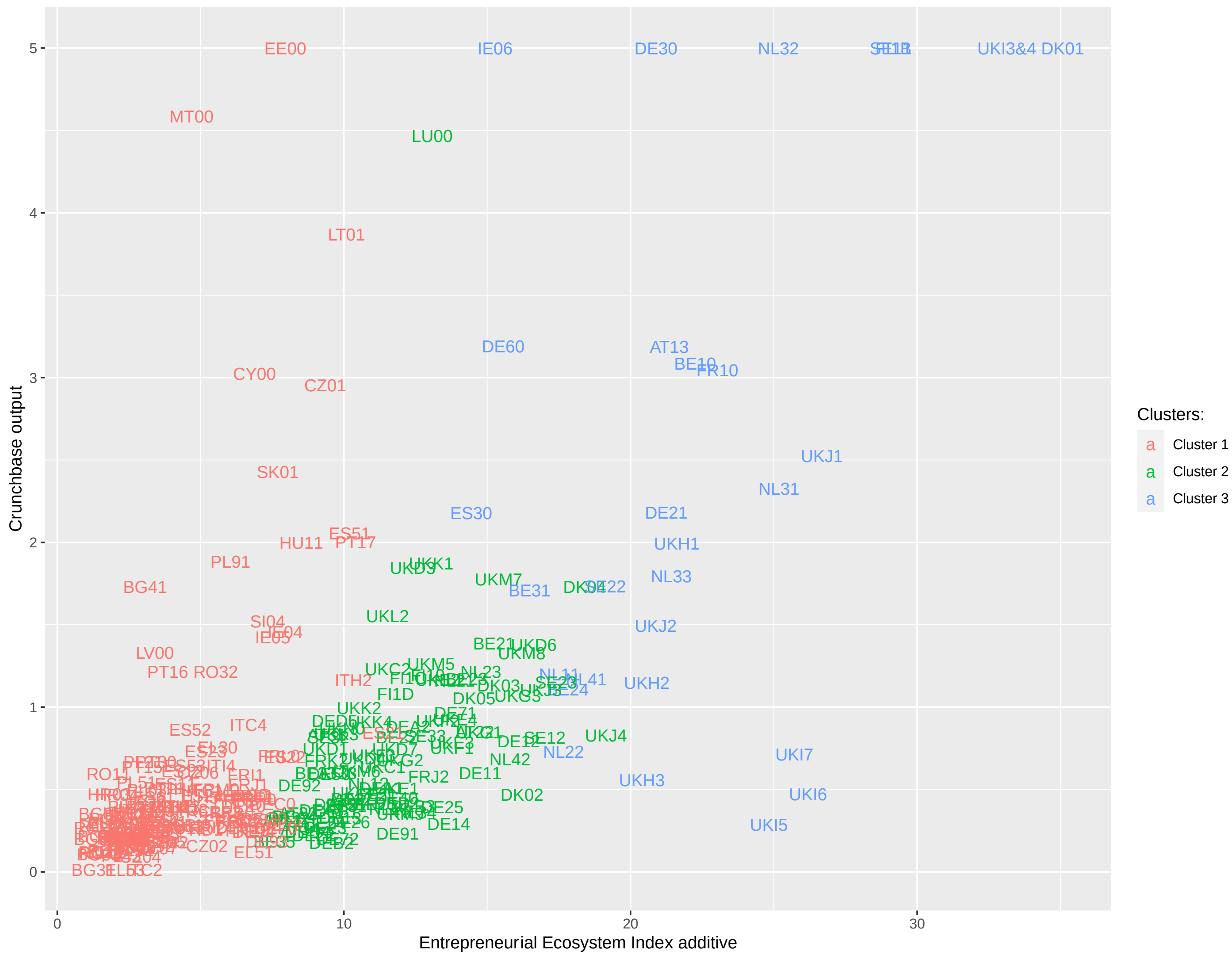

Table B2.

Regression results of the additive and logarithmic index on the Crunchbase output variable including non-linear effects

	Crunchbase output			
	(1)	(2)	(3)	(4)
EE index additive	0.097***	0.013		
	(0.013)	(0.025)		
EE index additive squared		0.003***		
		(0.001)		
EE index logarithmic			0.076***	0.148***
			(0.009)	(0.024)
EE index logarithmic squared				0.006***
				(0.001)
Observations	272	272	272	272
R^2	0.378	0.415	0.283	0.385
Adjusted R^2	0.376	0.410	0.280	0.380
F Statistic	164.043*** (df = 1; 270)	95.339*** (df = 2; 269)	106.371*** (df = 1; 270)	84.062*** (df = 2; 269)

*Notes: Clustered standard errors at country level in parentheses. * p<0.05 ** p<0.01 *** p<0.001*

Table B3.

Piecewise regression results of the additive and logarithmic index on the Dealroom output variable

	Dealroom output	
	(1)	(2)
EE index additive	0.057***	
	(0.015)	
Difference slope EE index additive	0.163***	
	(0.031)	
EE index log		0.042***
		(0.010)
Difference slope EE index log		0.544***
		(0.099)
Constant	0.239***	0.980***
	(0.079)	(0.136)
Observations	272	272
R2	0.447	0.477
Adjusted R2	0.441	0.472
F Statistic	72.262***(df=3;268)	81.605***(df=3;268)

Notes: Clustered standard errors at country level in parentheses.

** p<0.05 ** p<0.01 *** p<0.001*

Table B4.

Regression results of the additive and logarithmic index on the unicorn output variable. This is an overdispersed count variable and hence we used a quasipoisson regression.

	Unicorn output

	(1)	(2)
EE index additive	0.195***	
	(0.032)	
EE index logarithmic		0.358***
		(0.069)
Constant	-4.713***	-2.055***
	(0.645)	(0.393)
Observations	271	271
Dispersion parameter	0.959	0.924
R^2	0.240	0.274

Notes: Clustered standard errors at country level in parentheses.

$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Appendix C

Index robustness

As a first robustness test we do not execute any of the modifications outlined in section 3.16. This robustness test actually results in a higher R2 of 0.62 (Table C1). However, the results are now strongly influenced by the extreme values measured in several regions that we discussed in section 3.16. Therefore, we performed a second robustness test which follows the approach outlined in the methodology section but instead removes those regions with a value more than four standard deviations from the mean. This concerned Inner London (as a result of a high number of incubators, leadership, and Crunchbase firms), Braunschweig (as a result of the high R&D intensity) in Germany, and Hovedstaden (as a result of leadership) in Denmark (Table C2). Since we prefer not to discard observations of which the data is reliably measured, we also performed the regression with all observations after transforming the data. We transformed the data using the Tukey transformation (Tukey, 1957) for all the variables with a huge range of variation (standard deviations above 4), instead of only the output variable as we did in the main analysis (Table C3). The result of this transformation is a distribution of data which is close to a normal distribution, thus reducing the standard deviations from the variables with extreme values. Fourth, we used a categorical approach to create each of the index elements and the output by using quantiles to give each element a score from 1-10. The index then has a minimum value of 10 and maximum value of 100 (Table C4).

Furthermore, as discussed in section 4.3 we find that many of the top performing regions are regions in which a capital city is located (see Fig. 3). To test whether the explanatory power of our index holds after controlling for the influence of capital cities on the output variable we run the regressions with a capital city indicator added, which is a dummy variable indicating whether a region contains a capital city (no = 0, yes = 1). The results are displayed in Table C5 and indeed show that capital regions perform significantly better than non-capital regions ($p<0.001$). Nevertheless, the effect of the Entrepreneurial Ecosystem Index remains significant ($p<0.001$) and only shows a small decrease in coefficients. Next, we also performed a regression using the principal components discussed in section 4.1. This method does not build on the assumption that all ecosystem elements have equal weights and for PC1 we find highly similar outcomes as for our index (Table C6). Finally, we perform a regression in which we control for the GRP per capita, which is one of the existing measured we compared our index with in section 4.6. The results show that the regression with the index significantly outperforms the regression with only the GRP (Table C7). It is important to note that the GRP of a region is already included in our measure for demand. Nevertheless, it is only a small part of our index measure and we considered it important to test the robustness of our index when we control for economic development. In sum, the findings of all seven robustness tests are consistent with those presented in the main analysis, indicating the robustness of our chosen approach of calculating our index.

Table C1.

Regression with no transformation of extreme values

	Crunchbase output	
	(1)	(2)
EE index additive	0.525***	
	(0.065)	
EE index logarithmic		0.504***
		(0.100)
Constant	-4.240***	6.636***
	(0.577)	(1.175)
Observations	272	272
R^2	0.619	0.049
Adjusted R^2	0.619	0.045
F Statistic	438.82*** (df = 1; 270)	13.85*** (df = 1; 270)

Notes: Clustered standard errors at country level in parentheses.

*p<0.05; **p<0.01; ***p<0.001

Table C2.

Regression excluding observations with extreme values

	Crunchbase output	
	(1)	(2)
EE index additive	0.051***	
	(0.017)	
EE index logarithmic		0.035**
		(0.011)
Constant	-0.108	0.559 ***
	(0.115)	(0.119)
Observations	269	269
R^2	0.152	0.089
Adjusted R^2	0.149	0.086
F Statistic	47.77*** (df = 1; 267)	26.19*** (df = 1; 267)

Notes: Clustered standard errors at country level in parentheses.

*p<0.05; **p<0.01; ***p<0.001

Table C3.

Regression including Tukey transformation to variables with extreme values

	Crunchbase output	
	(1)	(2)
EE index additive	0.096***	
	(0.004)	
EE index logarithmic		0.071***
		(0.005)
Constant	-0.066	1.210***
	(0.060)	(0.052)
Observations	272	272
R^2	0.383	0.266
Adjusted R^2	0.381	0.264
F Statistic	167.87 *** (df = 1; 270)	98.03*** (df = 1; 270)

Notes: Clustered standard errors at country level in parentheses.

*p<0.05; **p<0.01; ***p<0.001

Table C4.

Regression with categorical calculation of the index

	Crunchbase output
	(1)
Categorical Index	0.092***
	(0.007)
Constant	0.471
	(0.413)
Observations	272
R^2	0.477
Adjusted R^2	0.475
F Statistic	245.98*** (df = 1; 270)

Notes: Clustered standard errors at country level in parentheses.

*p<0.05; **p<0.01; ***p<0.001

Table C5.

Regression with dummies for capital cities

	Crunchbase output	
	(1)	(2)

EE index additive	0.078***	
	(0.009)	
EE index logarithmic		0.059***
		(0.006)
Capital city	0.930**	1.141***
	(0.274)	(0.283)
Constant	0.039	1.065***
	(0.100)	(0.092)
Observations	272	272
R^2	0.456	0.410
Adjusted R^2	0.452	0.406
F Statistic	112.89*** (df = 2; 269)	93.53*** (df = 2; 269)

Notes: Clustered standard errors at country level in parentheses.

*p<0.05; **p<0.01; ***p<0.001

Table C6.

Regression with principal components

	Crunchbase output		
	(1)	(2)	(3)

Principal Component 1	0.289***	0.289***	0.289***
	(0.043)	(0.025)	(0.025)
Principal Component 2		0.394***	0.394***
		(0.001)	(0.001)
Principal Component 3			0.133***
			(0.009)
Constant	0.852***	0.852***	0.852***
	(0.092)	(0.025)	(0.025)
Observations	272	272	272
R^2	0.360	0.551	0.572
Adjusted R^2	0.357	0.548	0.567
F Statistic	151.61*** (df = 1; 270)	165.122*** (df = 2; 269)	119.46*** (df = 3; 268)

Notes: Clustered standard errors at country level in parentheses.

** p<0.05 ** p<0.01 *** p<0.001*

Table C7.

Regression with GRP as a control variable

	Crunchbase output		
	(1)	(2)	(3)
EE index additive		0.074^{***}	
		(0.018)	
EE index logarithmic			0.043^{***}
			(0.014)
GRP per capita	0.015^{***}	0.006^{**}	0.009^{***}
	(0.002)	(0.004)	(0.004)
Constant	-0.607***	-0.379	0.271
	(0.181)	(0.194)	(0.356)
Observations	273	271	271
R^2	0.281	0.400	0.326
Adjusted R^2	0.279	0.396	0.321
F Statistic	106.17^{***} (df = 1; 271)	89.362^{***} (df = 2; 268)	64.81^{***} (df = 2; 268)

Notes: Clustered standard errors at country level in parentheses.

$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$

Appendix D

Data appendix

NUTS2 code	Crunchbase output	Formal institutions	Culture	Networks	Physical infrastructure	Finance	Leadership	Talent	Knowledge	Demand	Intermediate	EE index additive	EE index log
AT12	0.44	1.09	0.32	1.44	1.34	0.81	0.40	1.13	1.48	1.83	0.47	10.32	-1.16
AT13	3.19	1.17	0.42	1.44	1.34	3.33	5.00	2.14	1.48	1.83	3.20	21.36	5.68
AT11	0.31	1.13	0.26	1.44	0.63	1.44	0.21	0.89	0.25	1.31	0.29	7.85	-4.99
AT21	0.41	1.05	0.46	2.10	0.24	1.78	0.53	1.08	1.81	0.68	0.37	10.10	-2.18
AT22	0.85	1.11	0.34	2.10	0.36	1.82	1.33	1.01	5.00	0.81	0.69	14.57	0.66
AT31	0.83	1.08	0.28	1.55	0.50	1.26	0.34	1.05	1.86	1.10	0.39	9.41	-2.49
AT32	0.36	1.20	0.81	1.55	0.42	1.34	0.28	1.15	0.40	0.86	0.40	8.41	-3.28
AT33	0.60	1.29	0.49	1.55	0.31	1.46	0.49	1.08	1.74	0.87	0.50	9.78	-1.73
AT34	0.26	1.32	0.57	1.55	0.72	1.18	0.19	1.04	0.52	1.14	0.25	8.48	-3.53
BE10	3.09	0.35	0.25	3.19	1.61	1.87	5.00	0.74	1.89	2.36	5.00	22.26	4.22
BE24	1.11	0.61	0.35	3.19	1.61	1.37	5.00	0.54	1.89	2.36	0.89	17.81	2.78
BE31	1.71	0.41	0.43	3.19	1.61	1.33	3.28	0.44	1.89	2.36	1.54	16.48	2.47
BE21	1.39	0.61	0.42	5.00	1.96	1.37	0.52	0.54	1.84	2.36	0.63	15.24	0.95
BE22	0.82	0.61	0.32	5.00	1.07	1.37	0.25	0.54	0.35	1.97	0.37	11.85	-2.98
BE23	1.17	0.61	0.38	5.00	1.13	1.37	1.53	0.54	1.02	2.32	0.40	14.29	0.32
BE25	0.41	0.61	0.29	5.00	0.86	1.37	0.19	0.54	0.28	1.67	0.29	11.10	-4.20
BE32	0.33	0.41	0.21	2.48	0.80	1.33	0.24	0.44	0.45	1.47	0.26	8.09	-5.49
BE33	0.60	0.41	0.19	2.48	1.38	1.33	0.33	0.44	0.69	1.31	0.46	9.03	-3.85
BE34	0.32	0.41	0.16	2.48	0.53	1.33	0.19	0.44	0.21	0.79	0.42	6.97	-7.28
BE35	0.18	0.41	0.30	2.48	0.65	1.33	0.26	0.44	0.32	1.14	0.25	7.58	-5.90
BG31	0.01	0.11	0.03	0.16	0.06	0.23	0.19	0.09	0.17	0.13	0.10	1.26	-21.96
BG32	0.11	0.22	0.03	0.16	0.08	0.19	0.18	0.10	0.16	0.17	0.16	1.45	-20.66
BG33	0.36	0.18	0.04	0.16	0.12	0.17	0.20	0.12	0.14	0.14	0.25	1.51	-19.85
BG34	0.20	0.12	0.04	0.16	0.12	0.19	0.19	0.09	0.14	0.12	0.19	1.35	-20.88
BG41	1.73	0.14	0.04	0.17	0.21	0.29	0.26	0.18	0.41	0.32	1.05	3.07	-14.76
BG42	0.22	0.16	0.03	0.17	0.18	0.20	0.19	0.09	0.16	0.15	0.15	1.48	-20.24
CY00	3.03	0.23	0.19	0.79	0.46	0.51	2.31	0.34	0.16	0.25	1.66	6.89	-7.82
CZ01	2.96	0.51	0.46	0.38	0.67	1.23	0.50	0.47	1.08	0.96	3.10	9.35	-2.90
CZ02	0.16	0.40	0.31	0.38	0.67	0.58	0.23	0.26	1.08	0.96	0.36	5.23	-7.82
CZ03	0.22	0.48	0.40	0.30	0.26	0.47	0.21	0.23	0.43	0.40	0.17	3.34	-11.55
CZ04	0.09	0.33	0.27	0.31	0.28	0.47	0.18	0.19	0.14	0.55	0.18	2.90	-13.24
CZ05	0.18	0.51	0.43	0.62	0.23	0.47	0.19	0.27	0.34	0.50	0.19	3.76	-10.59

NUTS2 code	Crunchbase output	Formal institutions	Culture	Networks	Physical infrastructure	Finance	Leadership	Talent	Knowledge	Demand	Intermediate	EE index additive	EE index log
CZ06	0.60	0.56	0.32	0.30	0.33	0.58	0.29	0.30	1.36	0.49	0.38	4.91	-8.39
CZ07	0.14	0.55	0.35	0.50	0.24	0.47	0.19	0.22	0.33	0.49	0.16	3.49	-11.36
CZ08	0.27	0.48	0.30	0.40	0.33	0.56	0.19	0.23	0.30	0.61	0.18	3.58	-11.09
DE30	5.00	1.20	1.20	0.60	3.04	5.00	0.88	0.84	1.44	1.67	5.00	20.89	4.78
DE40	0.45	1.29	0.76	0.60	3.04	1.95	0.30	0.52	1.44	1.67	0.26	11.84	-1.08
DE11	0.60	1.54	1.54	0.39	1.02	1.39	0.27	0.64	5.00	2.64	0.33	14.76	-0.02
DE12	0.79	1.54	1.54	0.35	2.05	1.39	0.75	0.64	5.00	2.62	0.24	16.10	1.24
DE13	0.33	1.54	1.54	0.33	0.85	1.39	0.33	0.64	1.16	1.91	0.18	9.87	-2.53
DE14	0.29	1.54	1.54	0.43	0.56	1.39	0.32	0.64	5.00	2.07	0.17	13.66	-1.23
DE21	2.18	1.77	1.21	0.36	2.06	2.47	3.77	0.58	5.00	2.59	1.45	21.26	5.09
DE22	0.22	1.77	1.21	0.17	0.77	2.47	0.20	0.58	0.32	1.29	0.17	8.94	-5.22
DE23	0.27	1.77	1.21	0.23	0.82	2.47	0.26	0.58	0.64	1.18	0.19	9.35	-3.84
DE24	0.30	1.77	1.21	0.31	0.64	2.47	0.26	0.58	0.60	1.34	0.14	9.33	-4.03
DE25	0.40	1.77	1.21	0.31	1.37	2.47	0.37	0.58	3.29	1.74	0.32	13.43	-0.12
DE26	0.31	1.77	1.21	0.38	0.92	2.47	0.27	0.58	0.70	1.64	0.23	10.17	-2.56
DE27	0.45	1.77	1.21	0.48	1.13	2.47	0.21	0.58	0.43	1.81	0.20	10.30	-2.92
DE50	0.60	1.55	1.31	0.41	0.93	0.75	0.80	0.56	1.30	1.42	0.46	9.49	-1.52
DE60	3.19	1.68	0.92	0.29	2.18	2.94	0.53	0.74	0.79	2.70	2.79	15.56	1.92
DE71	0.97	1.53	1.40	0.35	2.73	1.28	0.31	0.61	1.82	2.72	1.14	13.89	1.04
DE72	0.20	1.53	1.40	0.40	1.31	1.28	0.23	0.61	1.06	1.74	0.22	9.78	-2.50
DE73	0.29	1.53	1.40	0.25	0.69	1.28	0.20	0.61	0.43	1.21	0.21	7.80	-5.07
DE80	0.27	1.61	0.87	0.37	0.49	0.93	0.26	0.48	0.57	0.52	0.18	6.28	-6.43
DE91	0.23	1.68	1.03	0.29	0.71	0.73	0.41	0.46	5.00	1.32	0.25	11.88	-2.51
DE92	0.53	1.68	1.03	0.52	1.03	0.73	0.26	0.46	0.93	1.57	0.24	8.45	-3.55
DE93	0.19	1.68	1.03	0.37	0.82	0.73	0.20	0.46	0.24	1.54	0.24	7.31	-5.77
DE94	0.24	1.68	1.03	0.34	0.72	0.73	0.21	0.46	0.24	1.25	0.20	6.85	-6.34
DEA1	0.51	1.30	1.03	0.29	2.39	1.27	0.23	0.48	0.51	3.37	0.44	11.30	-2.32
DEA2	0.88	1.30	1.03	0.50	2.19	1.27	0.56	0.48	1.34	2.92	0.67	12.24	0.25
DEA3	0.38	1.30	1.03	0.56	1.53	1.27	0.23	0.48	0.28	2.34	0.21	9.23	-3.80
DEA4	0.34	1.30	1.03	0.39	0.94	1.27	0.22	0.48	0.56	1.89	0.20	8.28	-4.25
DEA5	0.41	1.30	1.03	0.54	1.80	1.27	0.24	0.48	0.46	2.39	0.23	9.73	-3.04
DEB1	0.37	1.58	1.28	0.34	1.56	1.77	0.19	0.52	0.19	2.11	0.21	9.74	-4.18
DEB2	0.18	1.58	1.28	0.53	0.59	1.77	0.21	0.52	1.50	1.42	0.18	9.57	-3.08
DEB3	0.40	1.58	1.28	0.36	1.90	1.77	0.33	0.52	2.15	2.27	0.27	12.42	-0.61

NUTS2 code	Crunchbase output	Formal institutions	Culture	Networks	Physical infrastructure	Finance	Leadership	Talent	Knowledge	Demand	Intermediate	EE index additive	EE index log
DEC0	0.42	1.50	0.88	0.56	0.86	0.98	0.26	0.41	0.42	1.45	0.20	7.52	-4.83
DED2	0.42	1.34	1.32	0.63	0.61	1.57	0.49	0.60	3.94	0.99	0.34	11.84	-0.87
DED4	0.24	1.34	1.32	1.34	0.57	1.57	0.21	0.60	0.52	1.11	0.16	8.74	-3.73
DED5	0.92	1.34	1.32	0.93	1.18	1.57	0.37	0.60	0.66	1.10	0.60	9.68	-1.22
DEE0	0.40	1.19	0.62	0.66	0.93	0.99	0.22	0.48	0.36	0.87	0.17	6.49	-5.96
DEF0	0.27	1.56	0.90	0.44	0.96	0.90	0.26	0.47	0.39	1.41	0.33	7.62	-4.43
DEG0	0.33	1.44	0.89	0.44	0.58	1.26	0.28	0.56	0.64	0.93	0.18	7.20	-4.96
DK01	5.00	2.98	5.00	0.63	4.68	2.11	5.00	5.00	5.00	0.90	3.78	35.08	10.58
DK02	0.47	2.81	3.48	0.60	1.18	1.88	0.28	4.76	0.29	0.58	0.36	16.22	0.03
DK03	1.13	3.01	3.90	0.74	0.56	0.44	0.40	5.00	0.60	0.42	0.35	15.40	-1.01
DK04	1.73	3.50	3.89	0.58	0.58	0.99	1.90	5.00	1.10	0.42	0.45	18.40	2.19
DK05	1.06	2.99	3.75	0.50	0.55	0.91	0.73	4.05	0.40	0.29	0.37	14.54	-1.03
EE00	5.00	0.93	0.69	0.66	0.41	1.01	1.34	1.65	0.40	0.10	0.76	7.96	-4.39
EL30	0.76	0.13	0.34	0.94	0.65	0.10	0.34	0.37	0.29	0.93	1.51	5.60	-8.87
EL41	0.31	0.11	0.48	0.64	0.19	0.05	1.56	0.23	0.20	0.03	0.35	3.85	-15.07
EL42	0.34	0.11	0.79	0.33	0.17	0.05	0.19	0.17	0.12	0.09	0.32	2.35	-17.30
EL43	0.23	0.11	0.47	1.59	0.13	0.07	0.28	0.20	0.42	0.11	0.20	3.58	-14.80
EL51	0.12	0.10	0.51	0.56	0.12	0.06	4.70	0.20	0.19	0.12	0.29	6.85	-13.58
EL52	0.32	0.10	0.27	0.63	0.18	0.12	1.20	0.25	0.22	0.27	0.31	3.57	-13.03
EL53	0.01	0.10	0.13	1.14	0.11	0.05	0.19	0.22	0.15	0.15	0.12	2.37	-18.41
EL54	0.28	0.10	0.13	0.26	0.10	0.06	0.26	0.22	0.31	0.11	0.23	1.78	-18.53
EL61	0.22	0.13	0.45	0.58	0.11	0.06	0.23	0.24	0.19	0.17	0.23	2.39	-16.18
EL62	0.30	0.13	0.14	0.43	0.17	0.05	0.20	0.17	0.16	0.09	0.21	1.75	-18.76
EL63	0.19	0.13	0.28	0.58	0.10	0.05	0.32	0.21	0.34	0.14	0.13	2.27	-16.96
EL64	0.21	0.13	0.26	0.41	0.12	0.07	0.19	0.17	0.17	0.31	0.25	2.09	-16.77
EL65	0.12	0.13	0.21	0.32	0.15	0.06	0.18	0.18	0.15	0.17	0.21	1.75	-18.16
ES11	0.53	0.33	0.29	0.40	0.35	0.77	0.29	0.68	0.23	0.35	0.43	4.13	-9.54
ES12	0.61	0.46	0.16	0.36	0.41	0.71	0.55	0.77	0.20	0.35	0.38	4.37	-9.29
ES13	0.28	0.52	0.80	0.24	0.44	0.41	0.35	0.76	0.22	0.38	0.26	4.38	-9.17
ES21	0.85	0.58	0.44	0.70	0.58	1.03	4.63	1.19	0.59	1.06	0.57	11.37	-1.56
ES22	0.70	0.54	0.45	0.35	0.42	1.67	1.90	0.99	0.45	0.64	0.53	7.94	-4.06
ES23	0.73	0.47	0.86	0.29	0.32	0.44	1.25	0.80	0.23	0.37	0.15	5.18	-8.45
ES24	0.46	0.44	0.26	0.25	1.08	0.49	0.95	0.77	0.23	0.28	0.29	5.04	-8.47
ES30	2.18	0.37	0.92	0.26	3.21	1.90	2.11	1.19	0.49	2.05	1.97	14.45	0.97

NUTS2 code	Crunchbase output	Formal institutions	Culture	Networks	Physical infrastructure	Finance	Leadership	Talent	Knowledge	Demand	Intermediate	EE index additive	EE index log
ES41	0.40	0.35	0.45	0.24	0.44	0.92	0.32	0.74	0.25	0.28	0.22	4.21	-9.77
ES42	0.18	0.35	0.41	0.25	0.75	0.67	0.20	0.57	0.17	0.31	0.18	3.85	-10.90
ES43	0.26	0.42	0.32	0.24	0.27	0.70	0.25	0.53	0.19	0.13	0.16	3.20	-12.65
ES51	2.06	0.34	0.64	0.26	1.30	2.01	2.46	0.71	0.41	0.87	1.20	10.21	-2.22
ES52	0.86	0.33	0.38	0.24	0.60	0.69	0.48	0.70	0.26	0.53	0.43	4.64	-8.30
ES53	0.65	0.31	0.37	0.13	0.62	1.43	0.23	0.52	0.14	0.32	0.38	4.45	-10.53
ES61	0.45	0.28	0.39	0.23	0.38	0.44	0.30	0.54	0.26	0.31	0.25	3.38	-11.21
ES62	0.40	0.39	0.28	0.21	0.56	0.63	0.35	0.56	0.22	0.40	0.31	3.91	-10.04
ES70	0.41	0.29	0.33	0.17	0.49	0.37	0.25	0.54	0.16	0.21	0.26	3.07	-12.55
FI19	1.20	1.88	2.86	0.95	0.41	1.27	0.52	3.13	1.42	0.17	0.33	12.94	-1.09
FI1B	5.00	2.05	3.05	0.89	1.55	3.13	5.00	5.00	2.76	0.75	5.00	29.18	8.85
FI1C	1.18	1.95	2.28	1.23	0.64	1.23	0.37	2.98	0.64	0.27	0.65	12.24	-0.62
FI1D	1.08	1.99	2.41	0.78	0.30	1.33	0.59	2.92	1.04	0.05	0.40	11.81	-2.87
FI20	0.72	3.16	2.43	NA	NA	NA	0.18	3.06	0.13	0.07	4.83	NA	NA
FR10	3.05	0.64	0.68	0.77	5.00	2.96	2.64	1.95	1.48	3.58	3.32	23.03	6.12
FRB0	0.36	0.61	0.87	0.47	0.71	0.72	0.21	1.13	0.46	0.74	0.18	6.10	-6.30
FRC1	0.37	0.57	0.66	0.47	0.41	0.54	0.21	1.10	0.25	0.49	0.20	4.90	-8.40
FRC2	0.31	0.54	1.03	0.47	0.26	0.55	0.22	1.19	1.25	0.63	0.22	6.38	-6.32
FRD1	0.26	0.61	0.84	0.47	0.33	0.62	0.22	0.87	0.33	0.52	0.22	5.01	-7.99
FRD2	0.30	0.63	0.68	0.47	0.85	0.73	0.19	1.09	0.38	1.01	0.29	6.31	-5.87
FRE1	0.46	0.58	0.75	0.54	0.98	1.00	0.21	1.22	0.23	1.02	0.25	6.79	-5.64
FRE2	0.25	0.61	0.58	0.54	1.24	0.67	0.21	0.77	0.37	1.25	0.39	6.63	-5.36
FRF1	0.45	0.60	0.48	0.48	0.72	1.03	0.33	1.32	0.49	1.20	0.20	6.84	-5.28
FRF2	0.32	0.59	1.19	0.48	0.97	0.75	0.19	0.84	0.20	0.47	0.19	5.87	-7.28
FRF3	0.37	0.56	0.85	0.48	0.47	0.83	0.18	1.08	0.32	0.76	0.16	5.68	-7.32
FRG0	0.46	0.72	0.89	0.64	0.50	0.85	0.22	1.44	0.31	0.68	0.32	6.56	-5.62
FRH0	0.44	0.74	0.57	0.64	0.36	1.19	0.25	1.65	0.64	0.57	0.25	6.86	-5.42
FRI1	0.59	0.71	0.80	0.68	0.52	0.93	0.26	1.42	0.44	0.53	0.29	6.59	-5.35
FRI2	0.27	0.68	0.73	0.68	0.17	0.54	0.22	1.39	0.25	0.37	0.19	5.24	-8.66
FRI3	0.28	0.58	0.48	0.68	0.35	0.44	0.19	1.03	0.24	0.51	0.21	4.71	-8.83
FRJ1	0.53	0.53	0.76	0.57	0.53	1.08	0.22	1.26	0.92	0.51	0.30	6.67	-5.30
FRJ2	0.58	0.62	0.63	0.57	0.46	1.55	0.35	2.45	5.00	0.51	0.82	12.96	-1.26
FRK1	0.44	0.62	0.87	0.77	0.34	0.91	0.21	1.06	0.80	0.49	0.13	6.21	-6.51
FRK2	0.68	0.67	0.81	0.77	0.60	1.57	0.31	2.09	1.31	0.95	0.32	9.39	-2.31

NUTS2 code	Crunchbase output	Formal institutions	Culture	Networks	Physical infrastructure	Finance	Leadership	Talent	Knowledge	Demand	Intermediate	EE index additive	EE index log
FRL0	0.71	0.55	0.83	0.45	0.75	1.24	0.25	1.40	1.01	0.75	0.51	7.74	-3.68
FRM0	0.50	0.51	1.00	0.45	0.24	1.56	0.18	0.80	0.13	0.14	0.53	5.55	-9.00
HR03	0.47	0.16	0.07	0.22	0.22	0.12	0.21	0.15	0.14	0.12	0.42	1.82	-18.09
HR04	0.47	0.16	0.10	0.29	0.22	0.15	0.22	0.14	0.27	0.24	0.28	2.08	-16.23
HU11	2.00	0.14	0.24	0.32	0.69	0.82	0.69	0.46	0.57	0.73	3.86	8.52	-5.78
HU12	0.27	0.14	0.24	0.32	0.69	0.82	0.20	0.46	0.57	0.73	0.25	4.41	-9.78
HU21	0.36	0.18	0.16	0.22	0.34	0.50	0.22	0.24	0.24	0.46	0.14	2.71	-13.92
HU22	0.25	0.18	0.18	0.26	0.31	0.48	0.21	0.25	0.17	0.38	0.13	2.55	-14.41
HU23	0.24	0.18	0.35	0.21	0.15	0.52	0.18	0.25	0.15	0.22	0.13	2.34	-15.45
HU31	0.21	0.17	0.15	0.25	0.16	0.44	0.20	0.24	0.16	0.33	0.14	2.24	-15.65
HU32	0.36	0.16	0.16	0.18	0.14	0.60	0.20	0.26	0.28	0.26	0.12	2.35	-15.61
HU33	0.30	0.21	0.14	0.25	0.17	0.50	0.22	0.25	0.46	0.25	0.14	2.57	-14.49
IE04	1.46	1.67	1.06	0.63	0.18	1.27	1.43	0.62	0.57	0.20	0.32	7.96	-4.76
IE05	1.43	1.60	1.08	0.69	0.29	0.70	0.97	0.89	0.28	0.37	0.65	7.52	-4.26
IE06	5.00	1.60	0.79	0.68	0.88	1.95	3.97	0.89	0.30	0.66	3.58	15.28	1.28
ITC1	0.49	0.17	0.34	0.39	0.80	0.37	0.38	0.18	0.74	1.25	0.54	5.15	-8.38
ITC2	0.01	0.23	0.37	0.20	0.24	0.28	0.25	0.18	0.19	0.77	0.32	3.02	-12.96
ITC3	0.38	0.17	0.17	0.22	0.66	0.34	0.83	0.21	0.38	0.86	0.77	4.62	-9.65
ITC4	0.89	0.25	0.40	0.27	0.76	0.78	0.48	0.20	0.32	2.07	1.14	6.67	-6.74
ITF1	0.29	0.12	0.27	0.28	0.27	0.46	0.22	0.19	0.24	0.58	0.47	3.10	-12.71
ITF2	0.24	0.17	0.14	0.27	0.13	0.28	0.21	0.18	0.19	0.50	0.32	2.39	-15.17
ITF3	0.22	0.12	0.41	0.17	0.38	0.41	0.23	0.16	0.32	0.68	0.49	3.37	-12.19
ITF4	0.22	0.14	0.57	0.29	0.30	0.43	0.21	0.16	0.25	0.42	0.36	3.14	-12.45
ITF5	0.38	0.14	0.70	0.16	0.18	0.30	0.21	0.17	0.18	0.34	0.36	2.73	-14.26
ITF6	0.20	0.10	0.60	0.26	0.21	0.30	0.21	0.17	0.19	0.27	0.32	2.64	-14.32
ITG1	0.15	0.14	0.20	0.22	0.27	0.29	0.19	0.15	0.25	0.38	0.34	2.42	-14.65
ITG2	0.43	0.17	0.19	0.60	0.30	0.71	0.21	0.18	0.21	0.23	0.35	3.15	-12.83
ITH1	0.33	0.27	0.67	0.28	0.17	0.28	0.44	0.22	0.20	0.77	0.19	3.49	-11.88
ITH2	1.17	0.27	1.91	0.45	0.21	0.28	5.00	0.24	0.53	1.02	0.42	10.33	-5.59
ITH3	0.40	0.26	0.49	0.24	0.51	0.34	0.37	0.18	0.28	1.25	0.42	4.34	-9.86
ITH4	0.50	0.25	0.44	0.30	0.37	0.61	0.41	0.22	0.42	0.82	0.32	4.19	-9.45
ITH5	0.46	0.26	0.43	0.22	0.53	0.45	0.58	0.21	0.53	1.41	0.37	4.99	-8.53
ITI1	0.40	0.21	0.40	0.26	0.39	0.53	0.43	0.20	0.34	0.87	0.47	4.11	-9.82
ITI2	0.35	0.15	0.25	0.27	0.25	0.37	0.33	0.23	0.25	0.68	0.39	3.17	-12.31

NUTS2 code	Crunchbase output	Formal institutions	Culture	Networks	Physical infrastructure	Finance	Leadership	Talent	Knowledge	Demand	Intermediate	EE index additive	EE index log
ITI3	0.28	0.16	0.40	0.28	0.41	0.51	0.25	0.21	0.22	0.68	0.35	3.47	-11.49
ITI4	0.65	0.15	0.50	0.42	0.89	0.40	0.85	0.24	0.44	1.16	0.66	5.72	-7.17
LT01	3.87	0.55	0.28	1.71	0.28	0.10	0.54	1.09	0.26	0.28	4.99	10.09	-6.41
LT02	0.39	0.55	0.28	0.87	0.19	0.10	0.22	1.09	0.26	0.19	0.18	3.95	-12.02
LU00	4.47	0.54	1.26	0.50	0.70	2.26	1.16	2.69	0.33	1.91	1.73	13.08	0.60
LV00	1.33	0.61	0.52	0.15	0.23	0.10	0.27	0.83	0.18	0.11	0.41	3.41	-13.16
MT00	4.59	0.19	0.04	0.20	0.42	0.39	0.58	0.19	0.21	0.25	2.23	4.69	-12.60
NL23	1.22	1.18	3.90	0.99	2.81	1.07	0.23	1.22	0.48	1.81	1.09	14.79	1.30
NL32	5.00	1.05	5.00	0.99	2.81	3.02	3.08	1.92	0.48	1.81	5.00	25.16	7.03
NL11	1.20	1.19	4.68	1.41	0.87	1.39	4.47	1.38	0.69	0.73	0.73	17.53	3.06
NL12	0.54	1.19	3.92	0.89	1.13	0.99	0.23	1.01	0.22	0.73	0.56	10.86	-2.34
NL13	0.38	1.19	3.67	1.45	0.79	1.43	0.20	1.06	0.21	0.89	0.69	11.59	-1.63
NL21	1.16	1.18	4.29	1.03	1.57	1.66	0.65	1.24	0.56	1.16	0.51	13.86	1.30
NL22	0.73	1.18	5.00	1.10	2.83	1.62	1.24	1.41	0.74	1.69	0.85	17.67	4.02
NL31	2.33	1.05	4.19	1.37	3.58	2.84	5.00	2.29	0.79	2.32	1.77	25.18	7.72
NL33	1.80	1.05	4.50	1.15	3.02	2.09	2.62	1.43	0.75	2.03	2.78	21.43	6.30
NL34	0.36	1.05	4.35	1.21	1.03	1.45	0.19	0.98	0.17	1.56	0.53	12.52	-1.51
NL41	1.17	1.12	4.80	1.08	3.13	1.69	0.65	1.33	1.26	1.93	1.48	18.46	4.55
NL42	0.69	1.12	5.00	1.05	2.07	1.59	0.72	1.01	0.56	1.81	0.86	15.80	2.51
PL21	0.67	0.44	0.28	0.17	0.22	0.25	0.21	0.22	0.40	0.59	0.21	3.01	-12.79
PL22	0.19	0.43	0.33	0.20	0.29	0.19	0.19	0.20	0.18	0.88	0.22	3.11	-13.09
PL41	0.40	0.43	0.21	0.16	0.25	0.19	0.20	0.20	0.20	0.45	0.17	2.46	-14.71
PL42	0.31	0.45	0.38	0.17	0.29	0.20	0.20	0.19	0.14	0.26	0.22	2.50	-14.49
PL43	0.10	0.44	0.30	0.15	0.23	0.16	0.18	0.18	0.12	0.31	0.16	2.23	-15.75
PL51	0.54	0.43	0.35	0.17	0.23	0.19	0.21	0.23	0.22	0.51	0.24	2.77	-13.46
PL52	0.13	0.47	0.49	0.19	0.21	0.15	0.19	0.18	0.14	0.48	0.18	2.67	-14.39
PL61	0.17	0.46	0.33	0.18	0.25	0.16	0.19	0.17	0.15	0.37	0.18	2.45	-14.81
PL62	0.20	0.46	0.16	0.17	0.22	0.22	0.19	0.18	0.14	0.21	0.13	2.07	-16.43
PL63	0.50	0.51	0.41	0.17	0.39	0.19	0.20	0.23	0.28	0.34	0.40	3.13	-12.27
PL71	0.21	0.39	0.18	0.15	0.28	0.19	0.19	0.20	0.19	0.52	0.24	2.52	-14.53
PL72	0.14	0.42	0.44	0.18	0.14	0.15	0.20	0.20	0.18	0.38	0.12	2.41	-15.32
PL81	0.19	0.39	0.28	0.18	0.17	0.16	0.20	0.23	0.27	0.27	0.14	2.28	-15.24
PL82	0.20	0.40	0.35	0.20	0.18	0.15	0.19	0.18	0.33	0.29	0.16	2.43	-14.73
PL84	0.21	0.43	0.42	0.18	0.20	0.16	0.19	0.22	0.20	0.19	0.13	2.31	-15.39

NUTS2 code	Crunchbase output	Formal institutions	Culture	Networks	Physical infrastructure	Finance	Leadership	Talent	Knowledge	Demand	Intermediate	EE index additive	EE index log
PL91	1.89	0.42	0.38	0.18	0.63	0.35	0.35	0.35	0.50	0.99	1.88	6.05	-7.18
PL92	0.16	0.42	0.38	0.18	0.28	0.35	0.18	0.35	0.50	0.59	0.16	3.40	-11.68
PT11	0.51	0.52	0.24	0.26	0.32	0.41	0.38	0.66	0.35	0.40	0.21	3.75	-10.36
PT15	0.64	0.46	0.24	0.14	0.38	0.21	0.27	0.69	0.14	0.21	0.23	2.96	-13.41
PT16	1.22	0.55	0.22	0.42	0.26	0.41	0.42	0.73	0.31	0.33	0.22	3.86	-10.22
PT17	2.00	0.56	0.43	0.34	1.29	0.62	0.80	1.17	0.41	1.05	3.74	10.41	-2.30
PT18	0.40	0.61	0.28	0.30	0.17	0.25	0.34	0.63	0.16	0.25	0.14	3.13	-12.84
PT20	0.27	0.54	0.59	0.16	0.39	0.28	0.18	0.50	0.14	0.04	0.23	3.05	-14.18
PT30	0.67	0.58	0.59	0.21	0.36	0.33	0.29	0.64	0.14	0.13	0.18	3.45	-12.16
RO11	0.60	0.13	0.46	0.14	0.15	0.10	0.20	0.08	0.15	0.22	0.17	1.80	-18.35
RO12	0.28	0.16	0.27	0.14	0.10	0.10	0.18	0.08	0.14	0.22	0.13	1.52	-19.49
RO21	0.27	0.14	0.23	0.12	0.10	0.10	0.19	0.07	0.15	0.17	0.08	1.36	-20.60
RO22	0.12	0.12	0.30	0.15	0.10	0.10	0.19	0.07	0.11	0.19	0.19	1.51	-19.69
RO31	0.13	0.19	0.28	0.14	0.15	0.14	0.19	0.07	0.14	0.35	0.21	1.84	-17.74
RO32	1.22	0.14	0.27	0.16	0.55	0.14	0.26	0.15	0.23	1.91	1.71	5.53	-11.14
RO41	0.12	0.14	0.37	0.12	0.12	0.13	0.18	0.08	0.12	0.18	0.10	1.54	-19.62
RO42	0.33	0.16	0.54	0.13	0.16	0.10	0.19	0.07	0.15	0.21	0.15	1.87	-18.22
SE11	5.00	2.34	3.88	0.46	1.66	4.59	2.22	4.33	3.34	1.26	5.00	29.08	8.78
SE12	0.82	2.34	2.50	0.80	0.62	1.77	0.96	2.69	3.77	0.42	1.13	17.01	3.17
SE21	0.47	2.37	3.35	0.72	0.36	1.03	0.23	1.92	0.41	0.20	0.54	11.13	-3.16
SE22	1.73	2.37	3.04	0.38	1.07	2.44	1.13	2.99	2.04	0.63	3.03	19.11	4.53
SE23	1.15	2.37	2.80	0.39	0.61	1.83	0.89	3.14	3.43	0.43	1.51	17.40	2.89
SE31	0.40	2.18	2.65	1.32	0.32	0.97	0.24	1.50	0.34	0.12	0.44	10.07	-4.18
SE32	0.82	2.18	2.41	0.74	0.32	1.21	0.18	1.80	0.20	0.05	0.37	9.47	-6.34
SE33	0.83	2.18	3.73	0.68	0.29	1.54	0.66	2.19	1.22	0.03	0.32	12.84	-3.13
SI03	0.37	0.31	0.31	0.52	0.29	0.32	0.26	0.35	0.45	0.47	0.18	3.47	-11.00
SI04	1.52	0.31	0.37	0.71	0.47	0.51	2.09	0.53	1.17	0.51	0.67	7.34	-4.75
SK01	2.43	0.24	0.67	0.51	0.72	1.06	0.62	0.77	0.55	1.25	1.32	7.70	-3.62
SK02	0.15	0.23	0.25	0.23	0.19	0.40	0.20	0.29	0.23	0.52	0.16	2.69	-13.73
SK03	0.16	0.28	0.33	0.35	0.11	0.32	0.19	0.31	0.29	0.39	0.14	2.71	-13.75
SK04	0.23	0.28	0.26	0.33	0.12	0.36	0.19	0.31	0.20	0.30	0.14	2.51	-14.41
UKH2	1.15	2.26	1.23	2.27	5.00	2.03	0.27	1.65	0.34	4.76	0.76	20.57	3.55
UKH3	0.56	2.26	1.23	2.27	5.00	2.03	0.23	1.65	0.34	4.76	0.63	20.40	3.21
UKI3&4	5.00	2.18	1.74	2.27	5.00	3.66	5.00	3.18	0.34	4.76	5.00	33.13	9.92

NUTS2 code	Crunchbase output	Formal institutions	Culture	Networks	Physical infrastructure	Finance	Leadership	Talent	Knowledge	Demand	Intermediate	EE index additive	EE index log
UKI5	0.29	2.18	1.74	2.27	5.00	3.66	0.21	3.18	0.34	4.76	1.49	24.83	5.55
UKI6	0.47	2.18	1.74	2.27	5.00	3.66	0.20	3.18	0.34	4.76	2.86	26.20	6.15
UKI7	0.72	2.18	1.74	2.27	5.00	3.66	0.24	3.18	0.34	4.76	2.35	25.72	6.11
UKC1	0.64	2.33	1.07	3.56	0.57	0.87	0.38	1.21	0.25	0.83	0.30	11.36	-2.09
UKC2	1.23	2.33	1.07	3.56	0.64	0.87	0.50	1.21	0.32	0.62	0.43	11.54	-1.39
UKD1	0.75	1.91	1.13	1.90	0.38	0.93	0.18	1.53	0.31	0.59	0.49	9.36	-3.31
UKD3	1.85	1.91	1.13	1.90	1.42	0.93	0.46	1.53	0.24	1.91	0.97	12.40	0.54
UKD4	0.69	1.91	1.13	1.90	1.01	0.93	0.29	1.53	0.23	1.50	0.25	10.68	-1.89
UKD6	1.38	1.91	1.13	1.90	1.35	0.93	0.24	1.53	4.19	2.29	1.15	16.63	3.06
UKD7	0.75	1.91	1.13	1.90	1.59	0.93	0.39	1.53	0.43	1.64	0.33	11.79	-0.16
UKE1	0.51	2.09	0.71	4.75	0.62	0.76	0.22	1.40	0.21	0.87	0.22	11.85	-3.21
UKE2	1.17	2.09	0.71	4.75	0.70	0.76	0.66	1.40	0.45	1.30	0.46	13.28	-0.08
UKE3	0.79	2.09	0.71	4.75	1.16	0.76	0.69	1.40	0.32	1.59	0.29	13.77	-0.11
UKE4	0.93	2.09	0.71	4.75	1.22	0.76	0.55	1.40	0.26	1.67	0.47	13.88	0.03
UKF1	0.75	2.06	1.01	3.81	0.97	0.66	0.48	1.47	1.25	1.67	0.37	13.77	1.04
UKF2	0.92	2.06	1.01	3.81	1.47	0.66	0.29	1.47	0.30	1.66	0.55	13.28	-0.13
UKF3	0.71	2.06	1.01	3.81	0.39	0.66	0.26	1.47	0.14	0.97	0.26	11.04	-3.58
UKG1	0.85	2.33	0.93	2.94	1.47	1.09	0.24	1.29	2.04	1.73	0.69	14.72	2.00
UKG2	0.68	2.33	0.93	2.94	1.17	1.09	0.21	1.29	0.18	1.54	0.29	11.96	-1.72
UKG3	1.07	2.33	0.93	2.94	2.37	1.09	2.20	1.29	0.57	1.54	0.82	16.07	3.51
UKH1	1.99	2.26	1.23	1.97	0.69	2.03	5.00	1.65	5.00	1.08	0.70	21.62	5.49
UKJ1	2.53	2.21	1.25	3.66	3.55	1.37	4.80	2.24	2.81	3.14	1.64	26.68	8.95
UKJ2	1.49	2.21	1.25	3.66	4.66	1.37	0.37	2.24	0.43	3.51	1.18	20.88	4.55
UKJ3	1.10	2.21	1.25	3.66	2.33	1.37	0.41	2.24	0.73	1.95	0.71	16.87	3.42
UKJ4	0.83	2.21	1.25	3.66	4.96	1.37	0.26	2.24	0.32	2.34	0.53	19.15	2.77
UKK1	1.87	2.32	0.90	1.45	1.18	1.30	1.00	1.96	0.69	1.53	0.73	13.05	1.94
UKK2	0.99	2.32	0.90	1.45	0.56	1.30	0.27	1.96	0.22	1.10	0.46	10.54	-2.03
UKK3	0.84	2.32	0.90	1.45	0.54	1.30	0.18	1.96	0.15	0.37	0.58	9.74	-3.75
UKK4	0.91	2.32	0.90	1.45	0.58	1.30	1.11	1.96	0.28	0.63	0.40	10.92	-1.04
UKL1	0.48	2.23	1.20	2.50	0.55	0.95	0.26	1.65	0.21	0.51	0.27	10.34	-3.11
UKL2	1.55	2.23	1.20	2.50	0.77	0.95	0.48	1.65	0.30	0.87	0.57	11.53	-0.54
UKM5	1.26	2.15	1.17	3.29	0.47	0.79	0.39	2.11	0.37	0.49	1.83	13.04	-0.20
UKM6	0.61	2.15	1.17	3.29	0.26	0.79	0.25	2.11	0.16	0.14	0.13	10.45	-5.94
UKM7	1.78	2.15	1.17	3.29	1.13	0.79	2.68	2.11	0.71	0.78	0.60	15.40	2.63

NUTS2 code	Crunchbase output	Formal institutions	Culture	Networks	Physical infrastructure	Finance	Leadership	Talent	Knowledge	Demand	Intermediate	EE index additive	EE index log	index
UKM8	1.33	2.15	1.17	3.29	3.84	0.79	0.96	2.11	0.28	1.02	0.61	16.21	2.18	
UKM9	0.36	2.15	1.17	3.29	1.16	0.79	0.19	2.11	0.32	0.60	0.20	11.97	-2.17	
UKN0	0.87	1.72	0.96	2.93	0.68	0.74	0.32	1.21	0.45	0.47	0.45	9.94	-2.40	

Annex Chapter 4

Appendix A

Table A1. Operationalisation of the indicators of ten entrepreneurial ecosystem elements from (Leendertse et al., 2022).

Elements	Description	Empirical indicators	Data source	Years
Formal institutions	The rules of the game in society	Two composite indicators measuring the overall quality of government (consisting of scores for corruption, accountability, and impartiality) and the ease of doing business	Quality of Government Survey (QOG) and the World Bank Doing Business Report	2015-2017
Entrepreneurship culture	The degree to which entrepreneurship is valued in a region	A composite measure capturing the regional entrepreneurial culture, consisting of entrepreneurial motivation, cultural and social norms, importance to be innovative, and trust in others	European Social Survey (ESS), Global Entrepreneurship Monitor (GEM), and OECD, Eurostat, and national statistics offices	2008-2016
Networks	The connectedness of businesses for new value creation	Percentage of SMEs that engage in innovative collaborations as a percentage of all SMEs in the business population	Regional Innovation Scoreboard (RIS)	2016
Physical Infrastructure	Transportation infrastructure and digital infrastructure	Four components in which the transportation infrastructure is measured as the accessibility by road, accessibility by railway and number of	Regional Competitiveness Index (RCI)	2014-2018

		passenger flights and digital infrastructure is measured by the percentage of households with access to internet		
Finance	The availability of venture capital and access to finance	Two components: The average amount of venture capital per capita and the percentage of SMEs that is credit constrained	Invest Europe and European Investment Bank (EIB)	2014-2019
Leadership	The presence of actors taking a leadership role in the ecosystem	The number of coordinators on H2020 innovation projects per capita	Community Research and Development Information Service (CORDIS)	2014-2019
Talent	The prevalence of individuals with high levels of human capital, both in terms of formal education and skills	Four components: The percentage of the population with tertiary education, the percentage of the working population engaged in lifelong learning, the percentage of the population with an entrepreneurship education, the percentage of the population with e-skills	Eurostat and the Global Entrepreneurship Monitor (GEM)	2013-2014
New Knowledge	Investments in new knowledge	Intramural R&D expenditure as a percentage of Gross Regional Product	Eurostat	2015
Demand	Potential market demand	Three components: disposable income per capita, potential market size expressed in GRP, potential market size in population. All relative to EU average.	Regional Competitiveness Index (RCI)	2014-2018
Intermediate services	The supply and accessibility of intermediate business services	Two components: the percentage of employment in knowledge-intensive market services and the number of incubators/accelerators per capita	Eurostat and Crunchbase	2018-2019

Index construction

To determine the quality of EEs Leendertse et al. (2022) combine the measures of the ten elements of the EE into an index. To calculate this index they first standardize the empirical indicators for each element. This ensures that all elements get similar weights in the creation of the index. They then take the inverse natural log of the standardized values. This is necessary because the mean is 0 after standardization and the next step, normalizing the data, requires division by the mean. The element values are normalized by setting the European average of each element to 1 and letting all other regional values deviate from this. After exploring various alternatives way of calculating such index they settle on reporting an index that is created in an additive way (E1 + E2 +…+E10) where regions with an average value on each element will thus score an index value of 10.

Appendix B

Table B2. Included questions from the European Social Survey wave 8.

How worried are you about [country] being too dependent on using energy generated by fossil fuels such as oil, gas and coal?
You may have heard the idea that the world's climate is changing due to increases in temperature over the past 100 years. What is your personal opinion on this? Do you think the world's climate is changing?
To what extent do you feel a personal responsibility to try to reduce climate change?
How worried are you about climate change?
How good or bad do you think the impact of climate change will be on people across the world? Please choose a number from 0 to 10, where 0 is extremely bad and 10 is extremely good.

Appendix C

Table C1. Full model for the presence of SSUs without informal institutions

	Dependent variable:
	Sustainable start-up presence
Entrepreneurial Ecosystem index	1.347***
	(0.431)
Fellow start-ups	5.056***
	(1.921)
Actors & resources	6.293***
	(1.352)
Formal institutions	1.468
	(1.029)
Population	0.000
	(0.000)
GRP	-0.111*
	(0.067)
Constant	-21.970**
	(11.153)

Observations	272
Adjusted R^2	0.373
Residual Std. Error	26.150
F Statistic	27.890***
Note:	*p<0.1; **p<0.05; ***p<0.01

Annex Chapter 5

Appendix A: A comprehensive overview of the EE of Rotterdam

Rotterdam is a young dynamic world city which is rapidly innovating. Unique at home, internationally renowned for our innovative drive and unpolished charm. Whether it is the constantly changing skyline with its bold architecture, our port which is the smartest in the world or the can-do mentality of our residents. Rotterdam is a city with a distinct character, energetic and always in motion. A city of forerunners, pioneers and people with the courage and will to drive change (Rotterdam Partners, 2020).

For the case of Rotterdam, interviewees provided insights and formulated strengths, weaknesses, and regional factors of the Rotterdam EE. Fig.I shows the characteristics of the interviewee sample of Rotterdam.

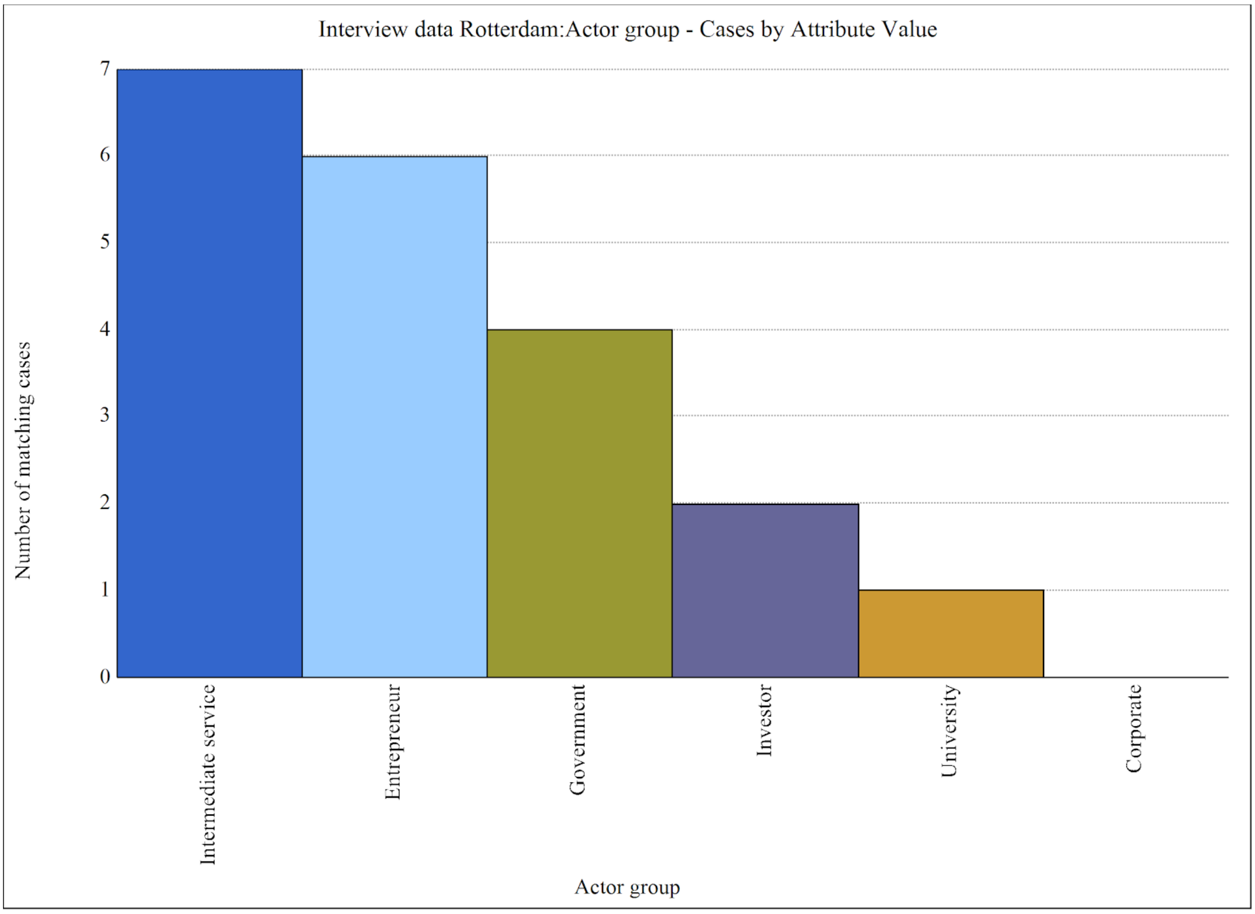

Fig.I. Characteristics of interviewee sample Rotterdam

Table I. Strengths of Rotterdam's EE, based on interview data

EE strengths	Mentioned by interviewees
Municipality active and aware	18/20
Highly collaborative	16/20
Harbor-industrial-complex	14/20
Good incubators and facilitators	14/20
Regional public funding	14/20
Many and good start- and scale-ups	12/20
High quality and volume of research institutes in the region	12/20
Rotterdam mentality	11/20

With regard to the framework condition 'formal institutions', the active and constructive role of the city of Rotterdam was highlighted as a strength: *"And you see with us in Rotterdam, for example, that it was only about five or six years ago that the button was pushed and that is very much encouraged by the municipality."* [R11]. The municipality of Rotterdam is therefore named the 'entrepreneurial government'. This is for a large part due to the fact that Rotterdam has some very capable counsellors this term and became particularly clear with the establishment of UP!Rotterdam which is a four year programme that serves as a public private entity and through a process of co-creation connects the different actors in the EE. Also, the fact that Rotterdam municipality actively acquired expertise outside its own organization to improve the EE, thereby acknowledging that they are themselves not the experts regarding their EE, stands out. [V11]: *"We had the luxury that we could see a party that has done well elsewhere in the past: we're not going to do it all ourselves again, we're just taking it in".* Regarding the international branding of the city of Rotterdam, public-private organization Rotterdam Partners takes a central role. In addition, the role of InnovationQuarter as the regional development agency of Zuid-Holland is positively stressed.

Secondly it was stressed by the interviewees that Rotterdam contains high quality intermediate services such as incubators, facilitators, and accelerators[58]. As one interviewee simply said: *"You have a lot of cool places like incubators and accelerators"* [R16]. The intermediate services in Rotterdam are also complementary in a sense that they are specialized in various fields. Also, in terms of shared office space, Rotterdam hosts an abundance of those possibilities. However, because of this high volume of intermediate services, the accessibility is a point of improvement: "*One thing which is difficult for the start-ups is to also get in contact with the network"* [V15]. It is stressed that some entrepreneurs are overwhelmed by the amount of options available.

Thirdly it was argued by the interviewees that the Rotterdam EE (same as the Vaasa EE) is highly collaborative: *"Yes. How much I do not know myself, I am not involved, but I have the feeling that they do work together, pick things up together and coordinate events and not all organize an event on the same day*" [R10]. Rotterdam findings furthermore show that the actors propagate that there are many (network) events. An important player hosting those events and connecting the EE is VentureCafe in

[58] ECE, Yes!Delft/Yes!Rotterdam, PortXL, CIC, Erasmus Tech Community, Van Nelle Fabriek, Rotterdam Partners, InnovationQuarter, VentureCafe, BlueCity, Get in the Ring, RDM, Buccaneer Delft, Deltalinqs, Keilewerf, Steurgebouw, VoorGoed, iTanks, UP!Rotterdam, Erasmus MC incubator, Thrive Institute, We Are Builders

Rotterdam. Next, the harbor-industrial-complex (HIC) has an interesting and prominent role in the Rotterdam TEE. A great source of economic activity but also a tremendous challenge in the urban sustainability transition: "*And I would say that Rotterdam is, we are a city with a huge petrochemical cluster logistics. So, you mentioned clean tech (in Vaasa) we did not, we were not a representative of the cleanest industry. So, if a city like Rotterdam is changing to, for instance renewable energy, energy, or more sustainable companies. The impact is tremendous"* [R17].

Additional EE strengths that were highlighted is the high level of regional public funding. Rotterdam is characterized by a high level of public funding instruments as well. Most regional funds are administered by InnovationQuarter. The municipality of Rotterdam distinguishes itself by funding not only start-ups directly through grants and competitions but also indirectly by funding the EE: "*Sometimes you just have to do something to speed things up. And it also took the city money and time to get it all done. But I think it is definitely invested on the right side"* [R18]. Other strength is the amount and quality of entrepreneurs, Rotterdam's EE creates a potent volume and quality of start- and scale-ups.

Next quality and volume of research institutes in the region is perceived as a strength. Interviewees from Rotterdam stress that the Erasmus University and the TU Delft are complementary. Interviewee [R18]: *"That combination and that is also a good thing that you do not find everywhere in the Netherlands or in Europe. It is precisely the combination between the Delft University of Technology and the Erasmus University and even the Erasmus Medical Center*". Additionally, on a national level in the Netherlands, there is high investment in education and a lot of research into start- and scale-ups. Finally, the Rotterdam mentality is celebrated for being bold and forward: "*Exactly, the Rotterdam mentality that is one thing that makes a difference, you see that people are fighting really hard to make their company a success"* [R1]. As such creating the right mindset to do business.

Table II. Weaknesses of the EE of Rotterdam, based on interview data

EE weaknesses	Mentioned by interviewees
Lack of ecosystem level collaboration	14/20
Talent scarce	10/20
Lack of ambition	6/20
Access to capital	5/20
City of opposites	5/20
Ecosystem leadership not optimal with municipality because of bureaucracy	5/20

In the previous subparagraph, the finding was presented that the EE of Rotterdam is highly collaborative, however this insight was also one of the most heavily debated, as on the opposite side, the majority of the interviewees underlined that there is a lack of ecosystem collaboration. In fact, this insight means that some interviewees discussed that the Rotterdam EE is highly collaborative, whilst they mentioned in the same interview that there is a lack of ecosystem collaboration. This interviewee accentuates it as such: "*What I have heard, is that there was only very limited cooperation a few years ago. Not only within the ecosystem, but also to a very important extent between public parties. Parties found each other insufficient"*. But, A positive element is that improvements in Rotterdam are triggered: "*In the ecosystem in Rotterdam, a lot of things are happening, but quite fragmented, but that is getting better and better. And the government plays a very important role in this"* [R11]. This important role of the local government in ecosystem level collaboration is, again, observed by the establishment of UP!Rotterdam: "*The objective of UP!Rotterdam is to support and strengthen the ecosystem and is therefore an initiative organized by the Rotterdam innovation team (city of Rotterdam). But not only with the municipality, also with other (private) partners*" [R12].

Next weakness of the Rotterdam EE is the scarcity of talent: *"If you look at the statistics, you will see that ... human capital, I believe that one in four South Holland companies now see limited supply of human capital as an obstacle to growth, which is really a big thing"* [R14]. This lack of talent is especially witnessed for software developers and programmers. Also, the drain of talent to Asia is emphasized as a threat. Specially to capture talent for sustainability is perceived as difficult because of fierce talent competition with large corporates: *"You have to be quite special (as a start-up), to prevent those kids from just walking straight to the big money-making consultancy bureau x..."* [R5]. An additional barrier is access to capital. This access to capital is a bottleneck. Also, the lack of ambition in the Netherlands, has a causal connection with the fact that Dutch investors display lack of courage. The former leading to the latter and vice-versa.

Rotterdam being a city of opposites is also perceived as a weakness. Especially when witnessing that the Rotterdam-Zuid area suffers from a large concentration of socio-economic problems compared to Rotterdam-Noord (Bastiaanssen et al., 2013). Also, the fact that the 'top' sectors of Rotterdam are widely spread both in terms of geography and in terms of interfaces: the harbor cluster on one side and the life-science and health cluster on the other side: "*The range of ideas is good, but it is very difficult because the port and medical sector are so far apart"* [R11]. Lastly a dichotomy was found that has to do with the size of companies in Rotterdam: "*We have no intermediate size companies in Rotterdam. Some very large companies, those in an industry are among the largest in the world. And we actually have SMEs, but in between it is very limited"* [R11].

Finally, interviewees warn that ecosystem leadership is not optimal with the municipality because of its bureaucracy. The solution that is suggested is public-private leadership or governance to pave the way for ecosystem level collaboration: *"It only has a good chance of success if you pull the organization out of the bureaucracy. But with some sort of accountability"* [V6]. In accordance with this public-private governance, interviewees from Rotterdam stress the strategic coordination provided by public private actors like UP!Rotterdam and Rotterdam Partners and the (informal) Economic Board of Zuid-Holland: "*It is not only avoiding that they (the actors) reinvent the wheel but also connecting these initiatives, this makes the ecosystem bigger and the impact bigger*" [R17]. These organizations function as a spider in the web and guide collective action.

Findings on strengths and weaknesses of the EE of Rotterdam are combined and visualized in Fig.I, which gives an illustrative overview of the current EE of Rotterdam.

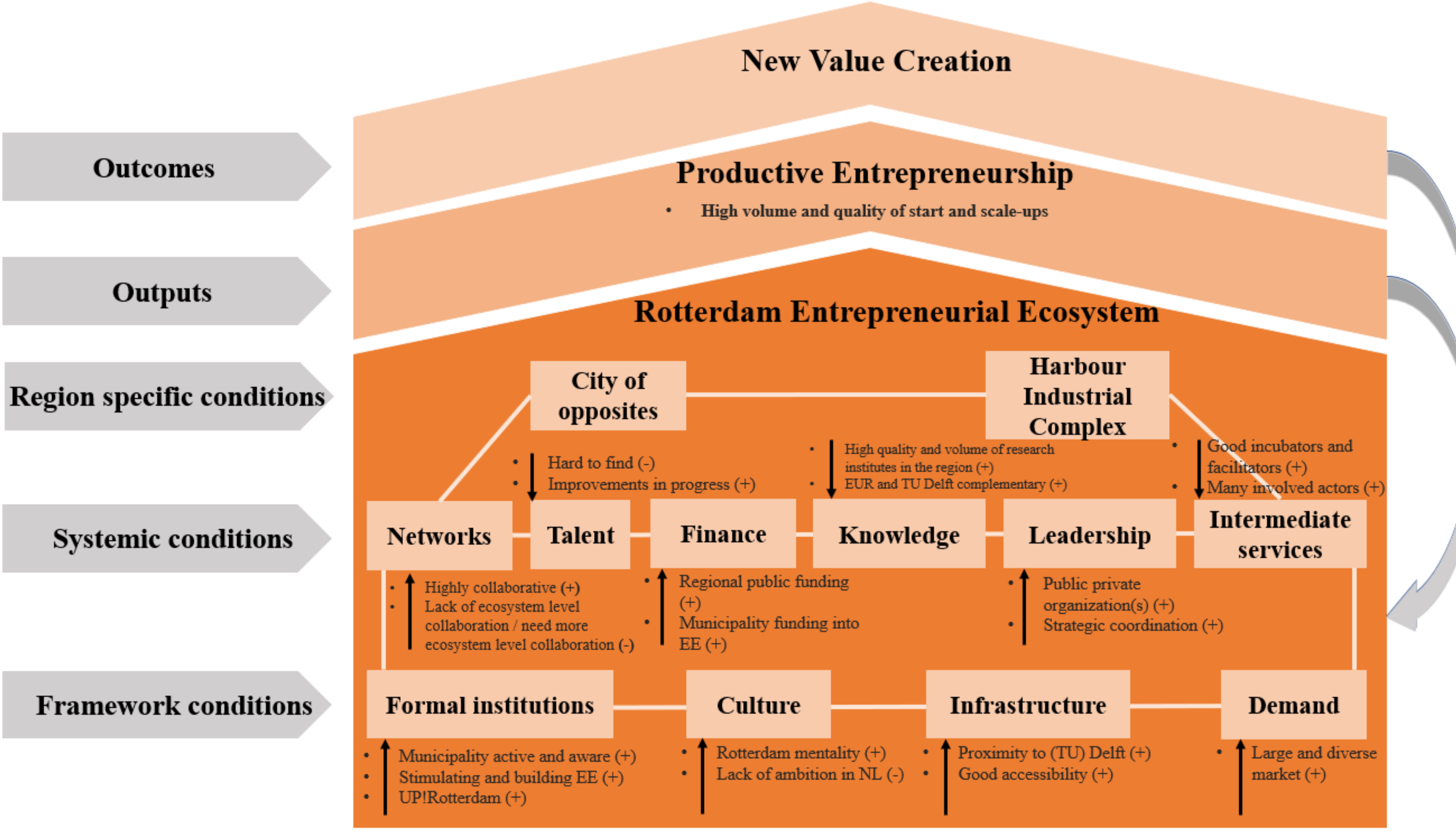

Fig.II. The EE of Rotterdam, based on Stam (2015)

Next to Fig.II, Fig.III additionally depicts a comprehensive overview of the current actors and their role in the EE of Rotterdam.

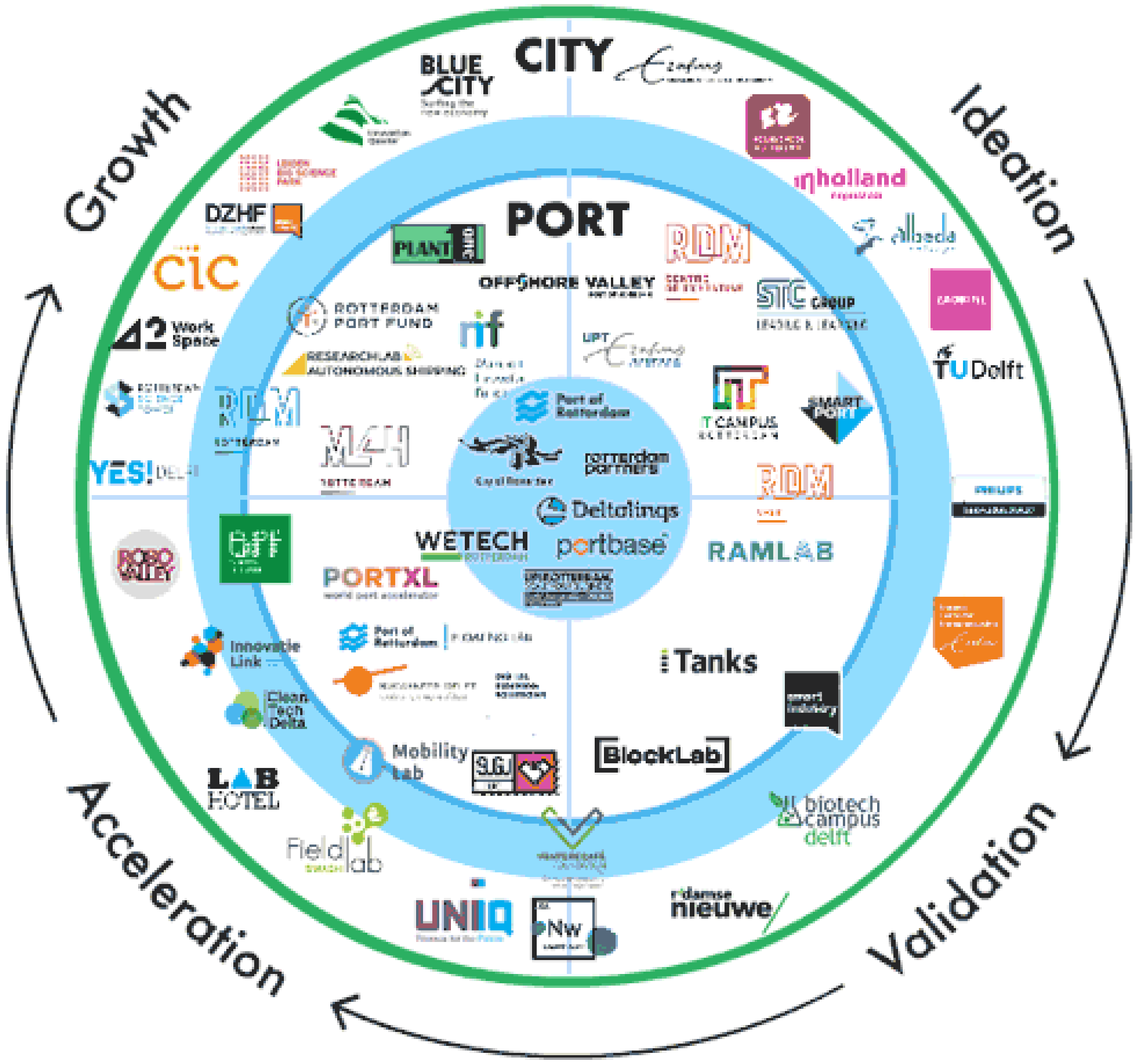

Fig.III. Overview of EE actors and initiatives in Rotterdam, retrieved from Haven van Rotterdam (2020)

Appendix B: A comprehensive overview of the EE of Vaasa

In Vaasa, energy is a positive force that is not only visible in business, but also in people's everyday lives and the development of the city. The Nordic Energy Capital is a unique combination of modern internationalism, young enthusiasm, innovative know-how as well as peace and tranquility (City of Vaasa, 2020).

Vaasa is considering its size a thriving region with many opportunities. Located on the west coast of Finland at the Gulf of Bothnia, Vaasa has had (since the 17th century) strong sea connections and therefore a long history of ship building and trade. 24 interviews were conducted resulting in more than 24 hours of transcription. This appendix describes the current EE of Vaasa. Interviewees provided insights in these conditions and formulated strengths, weaknesses and unique regional factors of the Vaasa EE. Fig.I shows the characteristics of the interviewee sample of Vaasa.

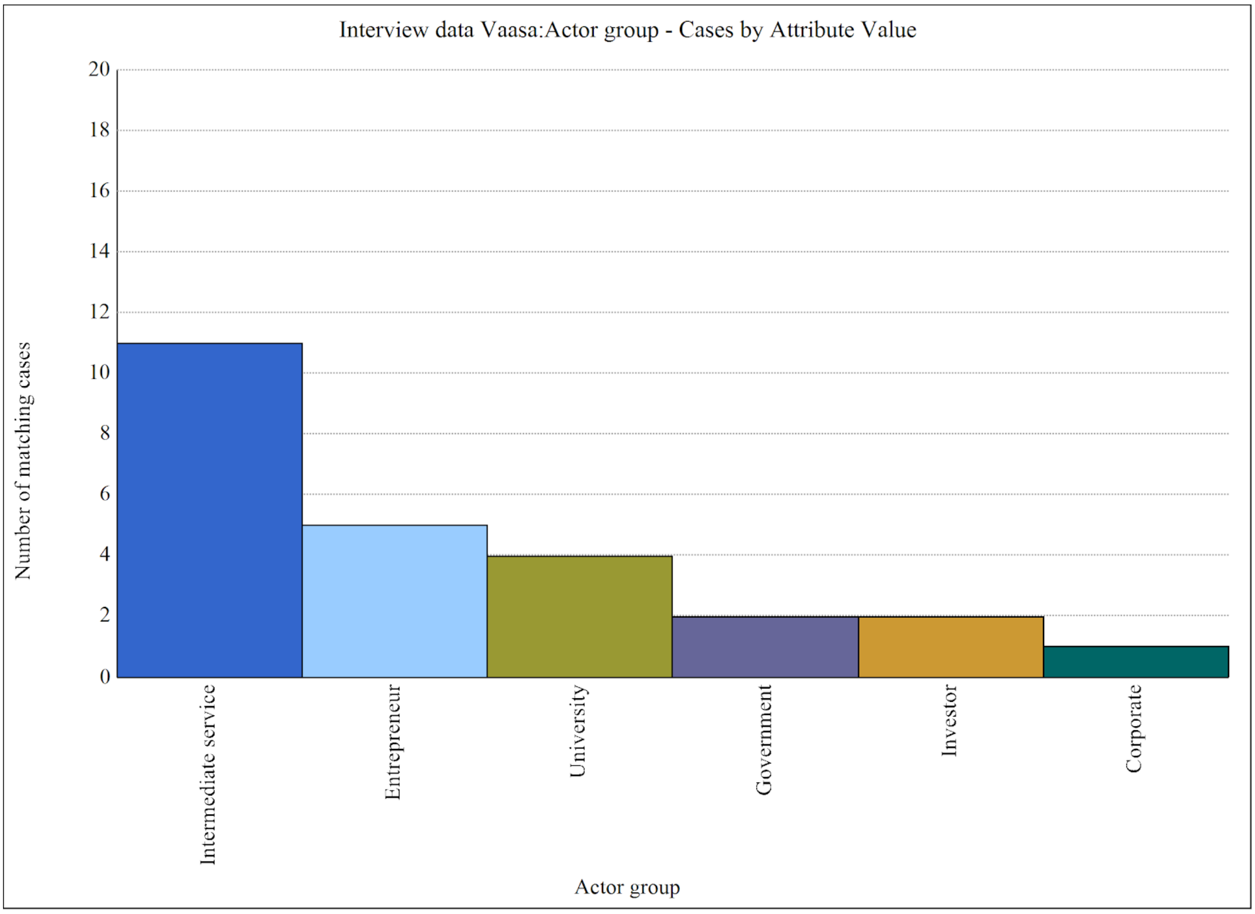

Fig.II. Characteristics of interviewee sample Vaasa

Table I. Strengths of the EE of Vaasa, based on interview data

EE strengths	Mentioned by interviewees
Energy cluster	22/24
Collaboration	21/24
High volume of intermediate services	20/24
International	19/24
Culture	18/24
Small size	13/24
Bilingual	11/24
Strong surrounding region	10/24

First and foremost, the energy cluster is highlighted almost unanimously by the interviewee sample as a major strong point of the Vaasa region and its EE. [Interviewee V16] highlights: "*I would say because this region, they embark on being the energy cluster hub".* This is not surprising as the Vaasa energy cluster comprises more than 160 businesses of which several are global market leaders in their field and has a total business turnover of some 5 billion euros annually with an export rate of over 80%. To put things in perspective: 2% of Finland's population in Vaasa generates 5.5% of its export, 12% of its tech export and 30% of its energy tech export (EnergyVaasa, 2020). Within the theme 'energy cluster', interviewees identified multiple interesting concepts. Firstly, the existence of the big companies within the energy cluster was emphasized as a positive influence (17/24 interviewees): "*But then we have these big companies. So, of course they have not always been big, but they grew big. And it means that they have quite a big influence on a city this small*" [V12]. The big companies mentioned most often are ABB, Wärtsilä and Danfoss. Reasons for their positive influence are that they boost the economy and EE by giving subcontracting possibilities, that they enable start-ups and invest in start-ups. As [V14] argues: "*And thanks to them it has also been possible to build up a quite great number of suppliers. Let in different kinds of activities and subcontractors in the whole area*". Secondly, the energy cluster's long history is underscored (11/24 interviewees). Especially the prevalent coevolution of the energy sector with the city of Vaasa and its universities is stressed (9/24 interviewees): "*I think what's good also: very and extremely strong connections between the universities and industry and also with the city*" [V23]. This insight is also interesting considering the MLP and will be discussed later on. Finally, to a lesser extent remarks were made about the positive influence of transformative knowledge, generating spin offs, being a source of innovation, being high tech and the existence of the accelerator EnergySpin as contributing to the strength of the Vaasa energy cluster.

Next, it was pointed out by the interviewee sample that collaboration is a major strong point of the Vaasa EE. [V1] highlights: "*Which is our strength from that collaboration. It is very unique, ... Even though they are competitors in some form, they might be cooperating in some other, so that is very unique*". Within the theme collaboration concepts as interdisciplinary collaboration are deemed important, especially between the universities and the (big energy) companies. Also, the Nordic cross border collaboration is underlined. Interviewees even speak of a collaborative culture, "*We have this mindset of co-creation and open innovation and I think that kind of culture is very beneficial*" [V11] and further accentuate the concept of co-creation.

Another important strength of the Vaasa EE is the high volume of intermediate services, "*Well, what comes to the spectrum of it, I see that there are quite many services available"* [V2]. Other significant strengths of the Vaasa EE that arose from the data are its international character, its small size, its bilingualism, its culture and the strong surrounding region. Regarding the international strength of Vaasa, the following reasons surfaced: close to Sweden, export oriented, inherent to large international companies, international history and international image. "*And then we have quite an international environment here. People in Vaasa are, if I remember right so we are talking 104 languages now. So, this is quite an international place"* [V22].

The small size was mentioned as a strong point because it results in short lines and tight networks, loyalty and easy access to intermediate services. [V11] argues: "*Because the city of Vaasa is quite small, all the actors are close to each other so there's benefits in proximity to say that if I want to call someone I can do it and I do not have to really be worried about it because people know each other*". Next the strength of bilingualism was stressed, as Vaasa has a large Swedish speaking minority: "*It develops the brain and I think that is also a big strength*" [V10]. For the highlighted cultural EE strength, interviewees mostly celebrated the entrepreneurial spirit and history in the region and the high level of trust. Finally, the strong surrounding region was mentioned often. This makes sense as Vaasa is surrounded by the affluent Finnish Ostrobothnia region and with Sweden only 40 kilometers away also falls within the scope of the economically strong Kvarken region. [V5] underscores: "*Getting more and more and more here in this Vaasa area and beyond in Sweden in the Kvarken region*".

Table II. Weaknesses of the EE of Vaasa, based interview data

EE weaknesses	**Mentioned by interviewees**
Difficulties in finding talent	20/24
Small size	16/24
Culture	12/24
Strategic coordination	12/24
Homogenous economy	11/24
Geography	11/24
Shortage of startup supply	9/24
Bilingual	7/24

What is most widely recognized as a weakness of the Vaasa EE is the difficulty of finding talent. [V10] contemplates: "*And of course, big weakness for our region as well. We need more people here to come to work. Yes, I think so we will have a big problem with, with the labor force. because people do not want to live, to move to our regions, for some reason*". Multiple reasons cause this phenomenon. One of them being that the earlier mentioned big companies take a large chunk from the talent pool. Also, there is a lack of interest from people outside the Vaasa region to come and stay, which is caused by a lack of cooperation and a large outflow of talent. Finally, the size and thus the little amount of job options is emphasized as a reason for the lack of talent. These 'size-issues' will further be discussed in the next paragraph.

The next EE weakness that is affirmed by the interviewees is the size of the city. "*There's not many people here*" states [V6] when asked about the weaknesses of the Vaasa EE. As reasons and consequences of its small size, interviewees indicate a small customer base, little amount of options, little number of investors, little funding opportunities for investors, a stagnating population growth and that the city is too small for some EU projects. An example of this is the fact that Vaasa is an IRIS follower city, because of its size.

In addition, cultural aspects are recognized as weaknesses of the EE. Interviewees mostly argue that this entails a lack of promoting and marketing of the region. [V24] explains: "*Marketing is really important and there's one thing, cultural thing in Finland, the Fins have been really bad at marketing*". An interesting insight as this probably is a cause of the weaknesses mentioned in the previous paragraphs. A lack of promoting and marketing can cause a lack of talent in a region, leading to difficulties in finding talent in that region. Some interviewees suggest that this lack of promoting and marketing of the region is due to the fact that the people of the Vaasa region are too proud. Other cultural EE weaknesses are affirmed as the Fins being too risk averse and introvert with regard to entrepreneurship.

Other weaknesses of the Vaasa EE worth mentioning are a lack of strategic coordination, a too homogenous economy, its geography, an overall shortage of start-up supply and its bilingualism. The lack of strategic coordination becomes clear from [V11]: "*I think it also raises the question like how we coordinate resources, effectively so that same thing is not done twice in two places*". With regard to the homogeneity of the Vaasa economy [V15] explains: "*I have not seen that the government or the Vaasa city are doing anything for other businesses than energy, that is basically it*". Geography wise, Vaasa is far away from the Finnish capital, Helsinki (4+ hours by train), leading to little political power in the capital which in turn results in difficulties to get national (infrastructure) investments causing poor public transit and logistics. [V23] acknowledges: "*We are also, let us say used to doing things by ourselves, and we have never counted on any help from Helsinki because Helsinki is very far away*". The shortage of start-up supply is again a size-issue, *"I mean, one really big challenge here in Vaasa is the volume of prospects*" [V14]. The bilingual character is described as a weakness by interviewees who mostly have in mind the language barrier for non-bilingual Fins from other parts of Finland. Hampering them from coming to Vaasa. [V21] expresses it as follows: "*Most speak Swedish, which is a bit problematic for Finnish speakers because they do not feel comfortable here*".

Vaasa has certain characteristics that are both a blessing and a curse. These characteristics deserve some further scrutiny. The first one being that the small size of Vaasa is mentioned both as a strength and a weakness by the interviewees. While on the one hand its small size leads to strong lines and tight networks, it on the other hand leads to difficulties in finding talent, options, funding etc. The crux is to maximize the positive aspect and minimize the negative aspect of the same characteristic. This is easier said than done and also has to do with the next aspect of the Vaasa EE that is both a strength and a weakness, the culture. Interviewees positively highlight the entrepreneurial spirit present in the Vaasa region, but also criticize the culture for its insufficient promotion and marketing of the region possibly due to pride on the one hand and being risk averse on the other hand. This lack of promotion and marketing in turn hampers the city and EE to grow. Related to this cultural dilemma is the fact that the bilingualism of the region is both identified as a strength and a weakness. A strong background in both Swedish and Finnish adds to the skill set of Vaasa inhabitants, while people from different areas see it as a barrier to come to the region, as they feel not at ease because they sometimes do not understand the language. It also makes it more difficult: "*There's a risk for this language, of course also. It makes* *everything a little bit more difficult. Yes, there always have to be two languages. Yeah, so you have to provide everything in two*" [V5].

Next factor that has both an upside and a downside is the presence of the energy cluster, although broadly appreciated and celebrated, interviewees do voice their concern on the dependence of Vaasa on the energy sector. There is a call not to have all the eggs in the same basket and to strive to a more heterogeneous playing field. "*But this is a strong energy cluster, I think it can be like a strength, or at the same time it can be a weakness if you are focusing too much on one sector*" [V9]. "*That is of course a risk*" argues [V20], but "*The good thing about energy is that that will always be needed in everything*". Which is a valid argument.

Finally, there is a discrepancy between the insight that a major strength of the Vaasa EE is the collaboration, while it also became clear that a weakness of the EE is its strategic coordination. An important remark here is, again, the fact that in such a small city, different dynamics are in play. What is happening in Vaasa is that highly collaborative small networks prevent ecosystem level collaboration decreasing the EE's efficiency and effectiveness. As [V18] identifies: "*And how do we distribute the work so that we are, we're not like doing the same thing. Double work, triple, quadruple work which we are doing now. And there is no, not the pyramid is not, there is nobody in charge. Yeah, there is just all these small actors, but so like small, small kings on every hill, instead of having a common vision".*

These findings about strengths and weaknesses result in the Fig.III, which provides a customization of Stam's (2015) framework for the status quo of the Vaasa region EE. It depicts the various framework and systemic conditions of Stam (2015) and adds distinct Vaasa characteristics to those framework and systemic conditions. It also adds the two major region-specific conditions that cannot be integrated in the conditions in Stam's authentic framework as they have a dynamic influence on all these different initial conditions. For that reason, they are added as extra 'boxes' in the Figure.

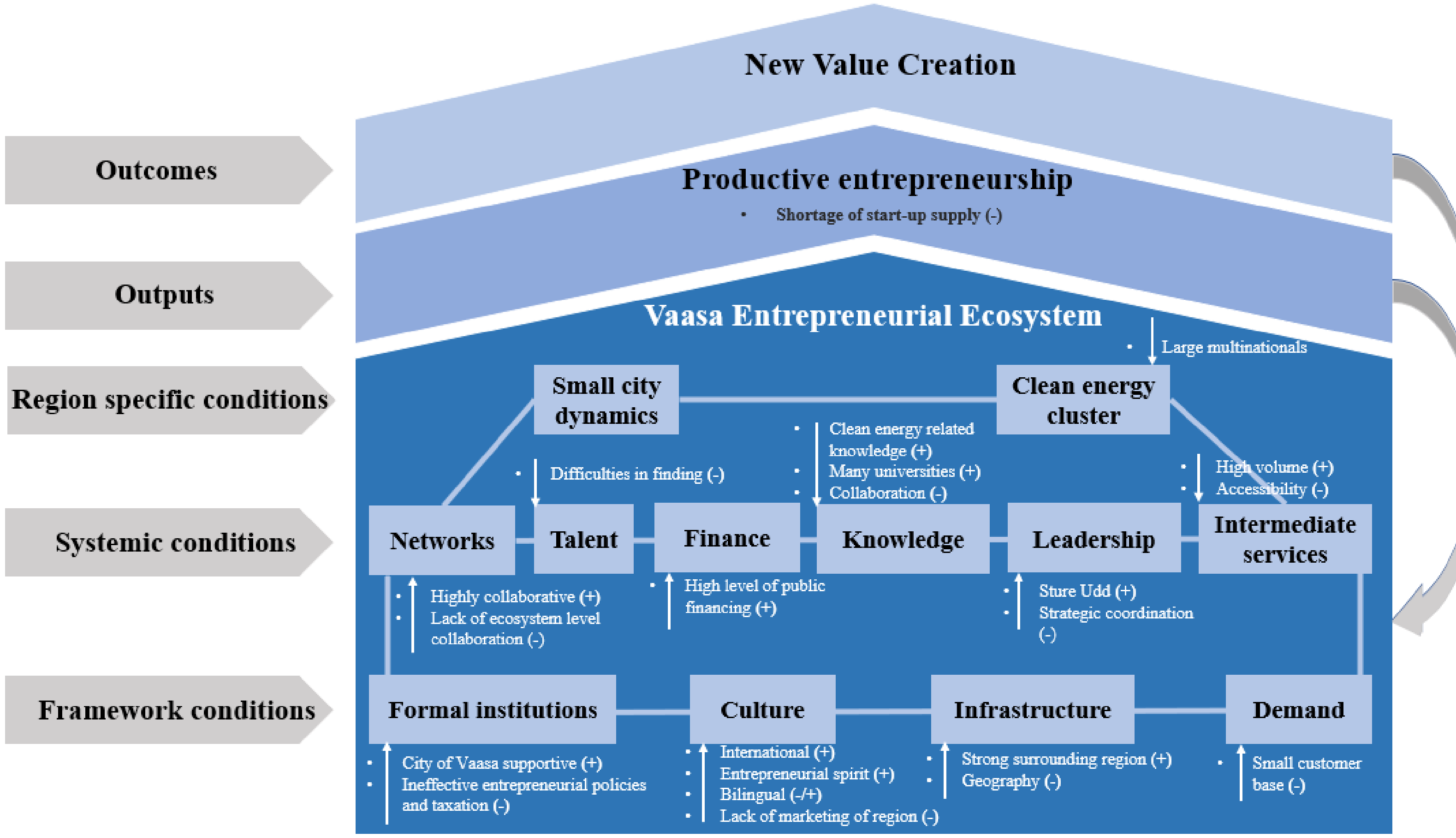

Fig.III. The EE of Vaasa, based on Stam (2015)

Next to Fig.II, Fig.III additionally depicts a comprehensive overview of the current actors and initiatives in the EE of Vaasa.

Fig.IV. Actors and initiatives in Vaasa, retrieved from EnergyVaasa (2020)

Appendix C: Transition pathways of Rotterdam and Vaasa

This Appendix translates the generalizable TEE findings from the results chapter back to the unique case specific situations and subsequent transition paths in Rotterdam and Vaasa.

I propose that the TEE and incumbent system of Rotterdam are currently on a transformational transition pathway. Landscape developments from European (European Green Deal) and national level ('Klimaatakkoord') exert pressure on the incumbent system. The developments lead thus to a substantial change in institutions (Geels et al., 2016). But especially in Rotterdam with its HIC, TEE outputs are not impactful enough to break through the incumbent system but are rather gradually adjusted in collaboration with the incumbent multinationals after which the system adjusts more slowly than in Vaasa.

The energy transition is even more a difficult task in Rotterdam because of the petrochemical industry in the harbor that will still need oil for the coming 30 to 40 years: *"In the end we will just continue to use oil for the next thirty or forty year, for transport it will become less and less, but you just cannot stop with oil in chemistry"* [R8]. Additionally, the HIC is dominated by conservative corporates that still earn vast amounts of money. Also the fact that the harbor is part of the culture in Rotterdam, inhabitants are historically proud of their harbor. Next, the Rotterdam harbor is far away from the city center, so negative externalities like fossil industry air pollution are perceived as less negative because it does not directly affect the inhabitants. These factors amplify the current lock-in: *"Unfortunately there still are too many powerful players in the market who are also stopping things"* [R18].

Also positive elements are witnessed. Namely that the Port of Rotterdam as an organization takes a central role, strategizing their ambition of a sustainable port. Example is the fact that even though the corona crisis occurred they are still investing in the energy transition. Another positive element is the announcement of the build of a hydrogen plant on the '2e Maasvlakte' by Shell and partners to become the hydrogen hub of northwestern Europe (Shell, 2020). This announcement shows a partial but substantial incumbent reorientation in line with the transformation pathway. Moreover, the open innovation process between incumbents and start-ups coordinated by PortXL adds to this partial incumbent reorientation and in co-creative way develops old and new technologies.

9.3.2. The reconfiguration transition pathway of Vaasa

The Vaasa TEE is symbiotic to the clean energy incumbent system. Innovations from TEE outputs such as start-ups, scale-ups and spin-offs from incumbent actors are adopted (again) by these incumbent actors. Triggering possible further incumbent adjustments and 'innovation cascades[59]' through co-creation in Wärtsilä's newly built Smart Technology Hub (Berkers & Geels, 2011; Geels et al., 2016). Vaasa's incumbent energy system is a frontrunner: *"The difference is that in Vaasa most of the people have already been working over 10 years in this (clean energy) business. When somewhere else they have started and got an idea that we have to go into it, so the starting point is different"* [V17]. Which has the consequence that the incumbent system also does not have to be overthrown because it is already on a sustainable trajectory. Therefore, I argue that Vaasa is on a reconfiguration trajectory where alliances are established between incumbents and transformative entrepreneurs (Geels et al., 2016). The initial add-ons from transformative entrepreneurs lead to new combinations between new and existing clean energy technologies. The locus of these new combinations will likely take place in the Smart Technology Hub. Next, the coevolution of the energy cluster, the city of Vaasa and the

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universities has led to limited institutional change in the past but changed recently to a more ongoing substantial institutional change, specifically observed by Vaasa's ambition to become carbon neutral before 2030. Interviewee V23 underscores: "*Vaasa has extremely strong connections between the universities, industry and the city*".

Appendix D: Interview guide

Interview Guide Thesis Beyer

Introduction

Firstly, thank you for your time, and this opportunity to conduct an interview with you. As became clear from our earlier contact, I am a master student in the master sustainable business and innovation. (I am conducting an internship at Merinova for my thesis at Utrecht University. Merinova is an important and neutral background actor, whose mission is to make the energy cluster in the Vaasa region even more successful). I am looking into the Vaasa/Rotterdam entrepreneurial ecosystem and how it relates to transition challenges towards a sustainable future.

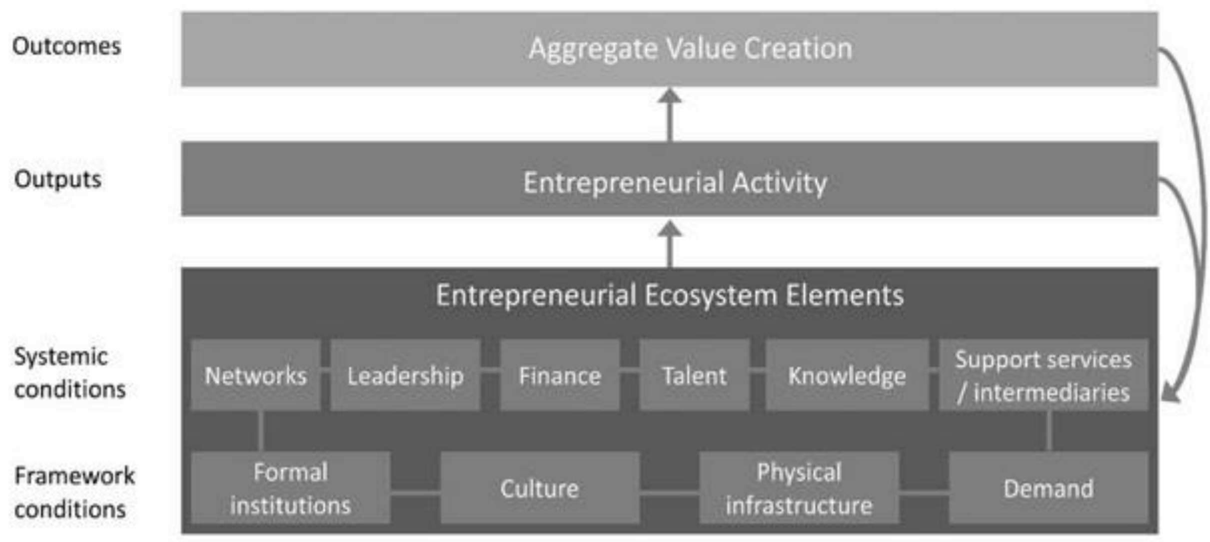
Confidentiality + Introduction

I. Do you agree with this interview being recorded for transcribing purposes?
II. Could you give a short description of what you do and how you ended up doing this?

General questions

1. Can you tell me about your organization?
    a. *What does your organization do?*

A way to map entrepreneurship in a region is by looking at it as an entrepreneurial ecosystem, with multiple interconnected actors. Your organization is (of course) part of this. See Fig.below.



2. How does this EE look here?
    a. *If not answered: what role do you/your organization play in this?*

i. *How do you influence the ecosystem?*

b. *Reversing it, how are you influenced by the ecosystem?*

3. What are the strengths of the EE here?
    a. *And what are the weaknesses?*
4. In your experience, how did entrepreneurial activity or entrepreneurship develop in your city?
    a. *From a historical perspective: how did it evolve?*
    b. ***Which (unique) regional factors influence the rate and content of this entrepreneurship?***
        i. *Did these factors change over the years?*
        ii. *Which are the most important?*

Now we move to sustainability, for entrepreneurship to be transformative it is important to get a grasp of the state of sustainability in your region.

5. To what extent are there initiatives for a more sustainable future society in your city?
    a. *Can you tell me more about them?*
    b. *What do you miss?*
        i. *What can be improved?*
            1. *How?*
6. How did (thinking about) sustainability develop in your city?
    a. *What role does sustainability play in your city now?*
    b. *If not answered: what role does your organization play in this?*

Mapping the unique EEs of the different cities

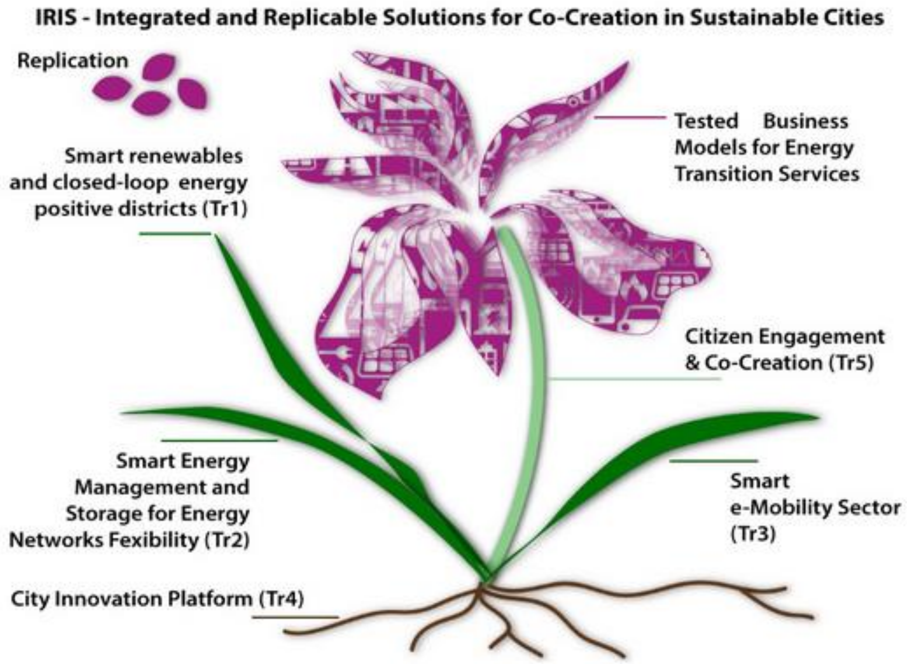
(The following questions are optional and complementary to what has already been answered in the general questions to get the most complete overview of the unique EE of the city/region. They are based on the empirical work of Stam (2018))

The following questions aim to get a more detailed overview of your EE and is also specifically looking into transformative entrepreneurship. With transformative entrepreneurship I mean start-ups looking for transition solution and into sustainability

Formal institutions

7. How would you describe the regulatory environment for entrepreneurs in general? (employee scheme, regulation of patents, accessibility domestic and foreign markets etc.)
    a. *What are current barriers/impediments?*
    b. *How can this be improved?*
    c. *What about the regulatory environment for transformative entrepreneurs?*
8. To what extent does the municipality/local government contribute to a favorable system for start-ups?
    a. *What do you miss?*
    b. *What measures could the municipality implement to stimulate start-ups?*
    c. *Does the municipality also stimulate transformative start-ups?*
    d. ***(For Vaasa and Merinova) Do you know about the IRIS project?***

i. *" Each city will draw upon a mix of universities and research organizations, local authorities, innovation agencies and private expertise to accelerate entire communities to adopt ambitious energy, mobility and ICT initiatives."*



Finance

9. What are the financing opportunities in your city for start-ups in general?
    i. *What are your experiences with this?*
    ii. *What do you miss?*
    iii. *How can this be improved?*
  b. *And what about financing opportunities for transformative start-ups specifically?*

Demand & Culture

10. How is the demand/appetite from Vaasa society for start-up's services and products?
    a. *What about transformative/sustainable start-ups?*
    b. *What are your experiences with this?*
    c. *What can be improved?*
        i. *How?*
11. How is entrepreneurship valued in your region/city by society?
    a. *What are your experiences?*
        i. *If entrepreneur: how do people react to you?*
    b. *What can be improved?*

Interacting actors/networks

12. To what extent are you collaborating in your region/city?
    a. *With whom do you collaborate?*
        i. *Other start-ups?*
        ii. *Municipality/government?*
        iii. *Research institutes?*

b. *What are your experiences with the overall rate of collaboration between actors in your city/region?*
    i. *What can be improved?*
c. *What about your connections with other actors?*
    i. *Do you work together intensively?*
d. *Wherefore do you collaborate? (i.e. for innovation and sustainable new value creation)*

Leadership

13. In your city, are there organizations or persons that provide leadership regarding sustainability? Persons that help you achieve your goals.
    a. *How did they come about?*
    b. *Can you tell me something about the process?*
    c. ***What about leadership for entrepreneurship?***

Talent

14. Do you find sufficient talent in your city?
    a. *What is missing or not?*

(New) knowledge plays a key role in every system.

15. What can you say about the creation and maintaining of knowledge in Vaasa?

Local vs non-local influences

16. To what extent are there local initiatives in the start-up ecosystem development in your region/city (for instance: knowledge creation)
    a. *What about nonlocal (external) initiatives?*

17. What about external/non-local influences and initiatives to develop your ecosystem?
    a. *To what extent do you look beyond your own system for guidance (for instance by looking at silicon valley)?*
        i. *What about other actors, what do they do in general?*

18. What is the balance between these local influences and external influences in your city? (with regards to the EE development?)
    a. *Did this balance change over the years?*
    b. *Is this the right balance according to you?*

Intermediate services

19. How is the supply and accessibility of intermediate business services in your city/region (i.e. incubators, accelerators, facilitators for start-ups)?
    a. *What is your experience with intermediates?*
    b. *What can be improved?*

Relating the EE to the MLP

Now it is time to relate the topics of entrepreneurship to sustainability and transition thinking

EE and (MLP on) transition

20. To summarize everything we talked about, what role does entrepreneurship play in the sustainability transition here?
    a. *How can it help?*
    b. *What can be done to improve this role of entrepreneurship?*
21. Taking it one step further: **what are conditions for entrepreneurship to play an important role in the sustainability transition in your city**?
    a. ***How can the EE be configured/used to support the sustainability transition here?***
    b. *How can this be improved, to make even more use of entrepreneurs in this transition?*
22. What is your vision for a sustainable Vaasa?

Conclusion

23. Do you recommend other people/colleagues within your network for me to speak to?
24. Do you agree with the use of your own name in the results of my thesis, or would you prefer to stay anonymous?

Annex Chapter 6

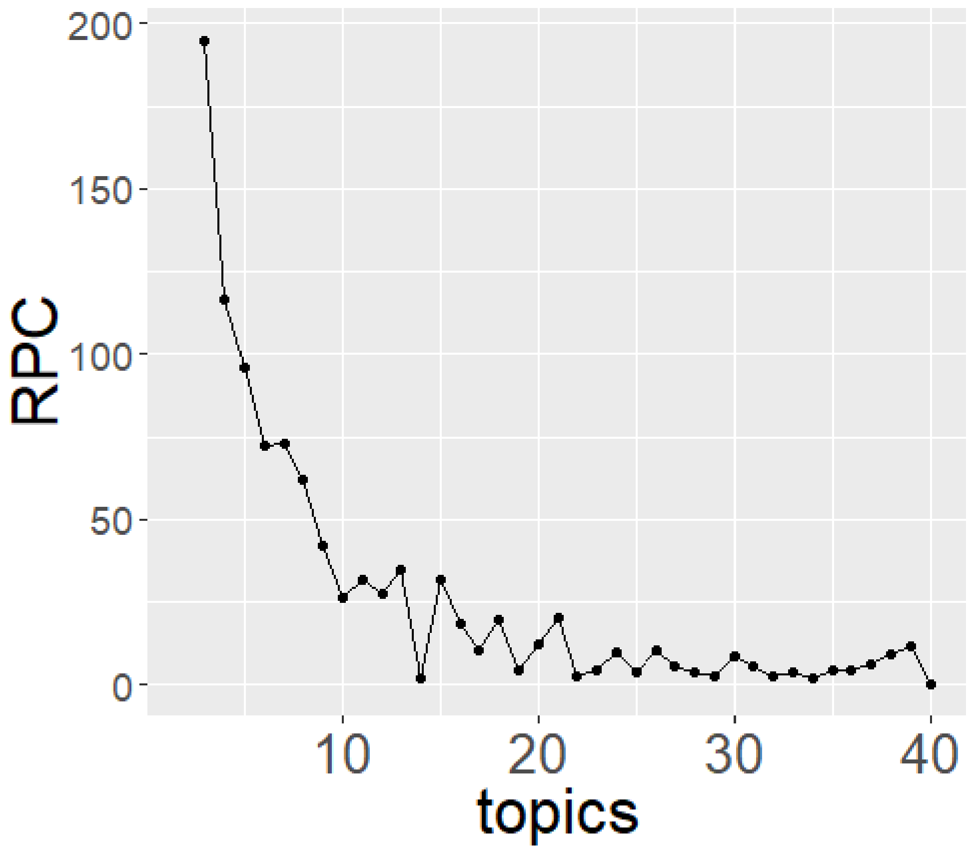


Fig.A.1: The rate of perplexity change of the LDA model which is used to determine the most appropriate amount of topics.

Table A.1: The ten most frequent (stemmed) terms for the fourteen topics resulting from the technologies of 920 sustainable start-ups.

Topic 1	*Topic 2*	*Topic 3*	*Topic 4*	*Topic 5*	*Topic 6*	*Topic 7*	*Topic 8*	*Topic 9*	*Topic 10*	*Topic 11*	*Topic 12*	*Topic 13*	*Topic 14*
green	wind	water	heat	people	transport	waste	solar	bike	sensor	vehicle	project	chemic	plant
flexible	storage	treatment	engine	carbon	app	recycle	smart	share	measure	charge	renew	fibre	food
layer	module	filter	cool	online	clean	organ	home	city	machine	battery	database	composite	soil
box	turbine	pump	fuel	climate	smart-phone	contain	panel	plastic	intelligent	car	risk	structure	farm
space	tank	flow	gas	find	europe	pallet	house	delivery	predict	light	client	extract	farmer
concrete	air	drink	thermal	social	park	wood	hardware	package	cloud	station	rate	receive	fertile
print	ship	region	air	shop	match	fruit	grid	digit	detect	drive	financi	atmosphere	agriculture
trade	scalable	reus	hydrogen	footprint	rout	dry	household	urban	health	electron	finance	renew	organ
call	compress	shower	exchange	market place	driver	biomass	meter	bicycle	compute	weight	startup	coffee	nutrient
side	pollute	human	oil	engage	travel	raw	roof	bag	day	public	solve	hand	crop