Sustainable Energy Startups, Factors Influencing Fast Market Introduction and Survival of University Spin-offs in Northwest Europe

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Sustainable Energy Startups

Factors Influencing Fast Market Introduction and Survival of University Spin-offs in Northwest Europe

Dissertation

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There were many difficulties along the way that could have hindered my progress towards PhD. At the start of my study, my little daughter was born, and soon after, we moved from the Netherlands to Germany. This period coincided with the crucial phase of data collection which required me to maintain close contact with my supervisor. However, the flexibility and kind approach of my supervisor, Prof. dr. Marina van Geenhuizen, allowed me to continue and overcome the obstacles. The completion of this doctoral dissertation would not have been possible without her tremendous assistance. I will always remember her constant guidance, as well as her patience in accommodating my slower pace. Any success I achieve in my academic career is owed to her dedication and support throughout my PhD studies. For this, I would like to express my deepest gratitude to my supervisor, Prof. dr. Marina van Geenhuizen.

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Razieh Nejabat,
August 2024

Abstract

The motivation for this thesis stems from the widespread desire across various policy levels to accelerate the energy transition. While large established companies play a crucial role in this transition, owing to their substantial R&D capacity and their deep integration within socio-technical systems, this thesis focuses on young, agile companies. These emerging companies, have “little to lose”, can bear more risks and are flexible to easily penetrate specialized market niches. This thesis specifically examines innovative start-ups, with a particular emphasis on university spin-off companies.

The thesis investigates the determinants of innovative entrepreneurship and firm survival on the time required for market introduction and the longevity of spin-offs in the sustainable energy sector. The empirical analyses in this thesis draw on an original database of university spin-off companies, tracked retrospectively from 1998 to 2018. The spin-offs are founded in five countries: Denmark, Finland, and Sweden, chosen for their long-standing favourable national innovation systems (NIS), and the Netherlands and Norway, selected for their comparatively less favourable NIS and sustainable energy landscapes during part of the study period.

The data collection employed a mixed-method approach, incorporating face-to-face interviews, which, when possible, were conducted in two moments; first shortly after company formation and second interview was taken several years later. Data gathering was supplemented by telephone interviews and information from written sources such as company websites, university websites, investment consortia reports, and reports by sustainable energy organizations, and multi-level policy bodies. This time-intensive methodology ensures data reliability. The final dataset comprises 106 companies.

The data collection process was guided by the examination of four sets of potential determinants of time to market introduction and firm survival:

- Risk-taking strategy in terms of product and market (Entrepreneurial Orientation)
- Spin-off’s initial resources and skills within the start-up team
- Timing and speed of resource and skill expansion
- The role of the multilayered spatial ecosystem

The theoretical foundation for this research is presented in Chapter 1 and elaborated upon in each of the empirical Chapters 4, 5, and 6.

Prior to the main studies in Chapter 5 and 6, a pilot investigation was conducted to assess the availability of reliable data and the potential to identify influential relationships. The results, which were obtained through "rough set analysis" and presented in Chapter 2, were encouraging and motivated the design of the larger data collection and to expand the existing database, as detailed in Chapter 3.

Chapter 4 presents a descriptive analysis of the database comprising 106 spin-off companies. This analysis includes the time to market introduction and duration of survival. During the

observation period (from 2011 until 2018), 65 in the sample of 106 spin-offs (61 percent) successfully entered the market, with 45 achieving this within the first five years. The average time to market introduction was 4.4 years, with additional age patterns indicating 5 years as the boundary between early and later market entry.

Regarding survival, 70 spin-offs (66 percent) remained operational through the end of the observation period. Among the 34 percent that did not survive, 13 percent were acquired and integrated into other companies, while 21 percent closed due to bankruptcy. Using this dataset on company survival, Chapter 4 examines the influence of probable determinants comparatively, using the Log-rank test. Factors influencing the time to market introduction include the business model (services versus industry-related), the radical nature of the innovation, market novelty, master's level skills, early partnerships with large companies or organizations, and the incubation environment of the parent university. Survival determinants were fewer, primarily comprising diversification strategy (product/market) and the size of the startup team.

Chapter 5 delves deeper into the operation of the original determinants, specifically focusing on time to market. Twelve hypotheses are developed and tested, including the direction of influence. Unlike the previous analysis, this testing occurs within a single interrelated model using Cox regression analysis. Hypotheses that tested positively for early market introduction include:

- Incremental innovation
- Existing markets
- Early collaboration with large companies or organizations
- Early access to substantial funding
- A technical university as an incubation environment

Notably, the resources and skills of the startup team did not play a significant role in the speed of market introduction. Similarly, the presence or subsequent acquisition of marketing knowledge was not a significant factor. This situation may reflect comprehensive support from university and national policy programs, as well as subsequent team changes (training, personnel additions) that potentially overshadow the initial conditions at inception.

Chapter 6 follows a similar structure but focuses on long-term survival, testing an additional hypothesis regarding the positive influence of early market introduction. This hypothesis is confirmed, yielding a significant result: early market introduction and longer survival enable rapid and robust scaling of the innovation, potentially exerting stronger influence on structural situations in the energy system that require change.

The hypotheses that test positively for long-term survival include:

- Early market introduction
- Diversification strategy
- A relatively favourable national innovation system

Notably, the study in Chapter 6 identifies significant 'contrary effects' to expectations regarding: size of startup teams and technical universities as incubation environments.

Regarding startup team size, the chances of longer survival appear greater with smaller teams. A smaller team may not only make more decisive decisions due to less potential for internal friction but may also benefit from prolonged collaboration with the university, possibly through co-creation projects.

Concerning the nature of the university as an incubation environment, general universities might offer relatively more advantages for both developing innovative services and more fundamentally-oriented innovations. The last innovations can be further developed through co-creation between the spin-off company and the university.

The findings in Chapter 6 underscore the complexity of factors influencing long-term survival in university spin-offs within the sustainable energy sector. The results highlight the importance of early market entry, strategic diversification, and a supportive national innovation system. They also challenge conventional wisdom regarding team size and incubation environments, suggesting that smaller teams and general universities may offer unique advantages in certain contexts. These insights contribute valuable knowledge to the field of innovative entrepreneurship in sustainable energy, potentially informing policy decisions and strategies for fostering successful university spin-offs in this crucial sector.

Regarding the entrepreneurial ecosystem in which the spin-offs operate, the study in Chapter 6 adopted an approach that considered two additional spatial levels beyond the university as a local incubation environment. These levels include the urban character of the location and the national innovation system.

A notable overall finding is that only the national innovation system and the local incubation environment (partially) influence market introduction and survival duration, while the urban character of the location does not appear to have a significant impact. A possible explanation for this is that outside metropolitan areas, centres with strong specialization have also developed. However, in these cases, the specialization is based on the presence of natural energy resources (wind, sun, flowing water, silica sands, etc.) for new sustainable energy generation. Additionally, the absence of metropolitan advantages may be compensated internally within the spin-offs through specific organizational forms of learning and absorption. This suggests that these companies have developed strategies to overcome potential limitations of non-urban and remote locations.

This finding challenges the common assumption that urban environments are more conducive to innovation and startup success in new sectors. It highlights the importance of considering other factors, such as proximity to natural resources and the ability of companies to create their own knowledge ecosystems through specific networking and connected team-based learning, when analysing the innovation dynamics of university spin-offs in this field.

The multi-level approach to examining the entrepreneurial ecosystem provides a more nuanced understanding of the factors influencing the success of university spin-offs in sustainable energy. It emphasizes the critical roles of national innovation systems and local university incubation environments while suggesting that the urban-rural divide may be less significant than previously thought in this specific sector. Such insights could have important implications for policymakers and entrepreneurs in the sustainable energy sector, potentially informing decisions about location strategies and the development of support systems for university spin-offs.

Chapter 7, the final chapter, contextualizes the analysis results for broader discussion and reflection, and translates these findings into policy recommendations for various stakeholders. This chapter identifies numerous challenges, particularly those that could encourage spin-off companies to take more risks and mitigate disadvantages by forming collaborations earlier (sooner after establishment). These recommendations aim to better facilitate the acceleration of the energy transition.

Key points in Chapter 7 include:

- Broader context: The chapter places the findings in this thesis within the larger framework of sustainable energy innovation and entrepreneurship, discussing how these results relate to current trends and challenges in the field.
- Policy recommendations: Based on the findings in this thesis, Chapter 7 offers specific policy recommendations for different stakeholders. These suggestions likely address ways to: encourage risk-taking behaviour among spin-off companies, facilitate earlier and more effective collaborations, optimize support systems at university, local, and national levels, and enhance the overall ecosystem for sustainable energy innovation.
- Accelerating energy transition: The chapter emphasizes how implementing these recommendations could contribute to accelerating the energy transition, which is a crucial global challenge.
- Reflection on limitations: The chapter includes a critical reflection on the limitations of the studies in this thesis, providing context for interpreting the results and informing future research design. The main ones include:
    - Monitoring the performance of start-ups and particularly university spin-off companies could be seen as a valuable metric for evaluating the impact of related policies.
    - Starting explanatory research with a pilot study clarifies the landscape and helps to mitigate the future challenges.
    - Timing of events throughout the firm's the life cycle needs to receive greater attention.
    - In the absence of a direct effects of various factors, the indirect effects may still influence the outcomes, and should therefore be considered.
- Future research directions: Based on unexpected outcomes and limitations of the empirical studies, Chapter 7 proposes several directions for future research. These suggestions include areas where the current study's findings were inconclusive or contradictory to expectations and also potential new avenues of inquiry opened up by the study's results. Salient areas include:

- Considering technological readiness level (TRL) at the firm's inception.
- Accounting for the potential influence of advisory boards.
- Including more dimensions, of the entrepreneurial ecosystem, such as local policy frameworks, network strength, and the availability of mentorship and incubators for university spin-offs.
- Assessing the counterfactual effects of supportive policies for university spin-offs by using a control group of non-university spin-off start-ups in the same sector.
- Exploring possible non-linear relationships among the factors and the mediating effects that may exits.
- Incorporation of in depth-case study besides the quantitative analysis.

This final chapter serves to synthesize the thesis findings, translate them into practical recommendations, and pave the way for future research in the field of sustainable energy innovation and university spin-off companies. It underscores the importance of this work in the broader context of accelerating the global energy transition and highlights the complex interplay of factors that influence the success of innovative startups in this crucial sector.

Samenvatting

De achtergrond van dit proefschrift is de wens om op diverse beleidsniveaus de energie transitie te versnellen. Hoewel grote gevestigde bedrijven in deze transitie een belangwekkende rol spelen, niet in het minst vanwege hun relatief grote R&D capaciteit, maar ook hun behoudende greep op de betreffende socio-technische systemen, staan in dit proefschrift jonge, flexibele bedrijven centraal. Dit segment van bedrijven kan een risicovolle rol op zich nemen omdat zij met groter gemak via specialistische niches kunnen bijdragen aan marktintroductie. In dit proefschrift staan deze innovatieve start-ups centraal, in het bijzonder de universitaire spin-off bedrijven.

In dit proefschrift wordt de invloed van bedrijfsspecifieke en omgevingsfactoren op de markttoetreding en het overleven van spin-offs in de duurzame energie sector geschat. De focus ligt hierbij op de tijd die deze nodig hebben voor marktintroductie en de kans dat de betreffende bedrijven een bepaalde periode overleven. De empirische analyses stoelen hierbij op een origineel databestand van universitaire spin-off bedrijven die retrospectief zijn gevolgd in de tijd, over de jaren 1998-2018. De landenkeuze is hierbij gebaseerd op het merendeel van Scandinavische landen die al vele jaren een gunstig nationaal innovatie systeem (NIS) hebben, te weten Denemarken, Finland en Zweden, en twee landen die een deel van de periode, een minder gunstig beeld wat betreft NIS en duurzame energie vertonen, namelijk Nederland en Noorwegen.

De betreffende data zijn verzameld kort na de bedrijfsoprichting en vervolgens is de dataverzameling enkele jaren later opnieuw herhaald. Data zijn gebaseerd op persoonlijke en telefonische interviews met de ondernemers, en bestaan hiernaast uit informatie die is verkregen uit geschreven bronnen zoals bedrijf websites en websites van universiteiten, investeringsconsortia, duurzame energie organisaties (tijdschriften) en beleidsorganen op verschillende niveaus. Deze zogenaamde 'mixed-method' aanpak is tijdsintensief, maar maakt checks op data betrouwbaarheid mogelijk. In totaal bevat het databestand informatie van 106 spin-off bedrijven.

Leidend in de dataverzameling is het in beeld brengen van de ontwikkeling van vier sets van vermoedelijke determinanten van succesvolle innovatie en overleven:

- de risico-nemende strategie qua product en markt ('entrepreneurial orientation');
- de hulpbronnen en vaardigheden die het spin-off startersteam bezit;
- het tijdstip/snelheid van het uitbreiden van hulpbronnen en vaardigheden via netwerken,
- en de rol van het meer-lagen ruimtelijke ecosysteem.

Hiernaast zijn twee controle factoren onderscheiden, periode van bedrijfsoprichting, in relatie tot macro-economische crisis, en het gekozen business model van de spin-offs. De theoretische grondslag hiervoor wordt gepresenteerd in Hoofdstuk 1 en in elk van de empirische Hoofdstukken 4, 5 en 6.

Voorafgaand hieraan is een pilot studie gehouden om te beoordelen of voldoende betrouwbare data beschikbaar zouden zijn en of beïnvloedende relaties konden worden geïdentificeerd. De betreffende uitkomsten zijn verkregen met 'rough set analysis' en gepresenteerd in Hoofdstuk 2. De resultaten waren positief zodat de opzet van de grotere studie en uitbreiding van het databestand ter hand kon worden genomen, gemotiveerd in Hoofdstuk 3.

Hoofdstuk 4 is het eerste empirische hoofdstuk uit de grotere studie en hierin wordt een beschrijvende analyse gepresenteerd van de database met 106 spin-off bedrijven. Het gaat hierbij om de tijdspanne tussen bedrijfsoprichting en markt introductie, en kans van overleven gedurende een bepaalde periode. In de observatie periode slagen 65 spin-offs (61 procent) erin om de markt te bereiken waarvan 45 binnen de eerste vijf jaar. De gemiddelde duur om tot market introductie te komen is 4,4 jaar en aanvullende de leeftijdspatronen wijzen op 5 jaar als grens tussen vroege en latere marktintroductie.

Wat betreft overleven, zijn 70 spin-offs (66 procent) in staat om te overleven tot en met einde van de observatieperiode. De 34 procent die niet overleeft, valt uiteen in 13 procent acquisitie en integratie en 21 procent sluiting (faillissement). Vervolgens wordt in Hoofdstuk 4 de invloed van de vermoedelijk invloedrijke factoren vergelijkenderwijs onderzocht en getest met Log-rank test. Qua *markt introductie* leidt dit tot een beeld van invloed van het business model (services versus industrie gerelateerd), radicaal karakter van de innovatie, nieuwheid van de markt, vaardigheden samenhangend met een master niveau, een vroegtijdig samenwerken met een groot bedrijf (organisatie) en het incubatiemilieu van de moeder universiteit. Qua *overleven*, komt duidelijk een geringer aantal factoren naar voren als invloedrijk, namelijk, alleen strategie van diversificatie (product/markt) en omvang van het startersteam.

Hoofdstuk 5 vervolgt met een meer diepgaande analyse van de werking van de oorspronkelijke factoren, specifiek op tijd tot marktintroductie. Hier worden een 12-tal hypothesen ontwikkeld en getest met de richting van de werking. Het verschil met de voorgaande analyse is ook dat de toetsing in onderlinge samenhang in één model plaats vindt (Cox regressie analyse). De hypothesen die positief testen op een gemiddeld *snellere* marktintroductie zijn die betreffende:

- incrementele innovatie,
- bestaande markten,
- vroege samenwerking met een groot bedrijf (organisatie),
- vroege toegang tot substantiële financiering, en
- een technische universiteit als incubatie omgeving.

Opmerkelijk in dit deel van het proefschrift is dat oorspronkelijke hulpbronnen en vaardigheden van het startersteam geen rol van betekenis spelen in een vroege marktintroductie. Dat geldt ook voor aanwezigheid van of latere verwerving van marketing kennis. Deze situatie zou kunnen wijzen op veelomvattende steun van universiteit en nationale beleid programma's, maar ook latere team veranderingen (training, personele aanvulling op het startersteam) die de uitgangssituatie bij oprichting kunnen overschaduwen.

Hoofdstuk 6 is identiek in opzet maar heeft langer overleven als onderwerp, en toetst hierbij een extra hypothese, namelijk betreffende de positieve invloed van vroege marktintroductie. Deze hypothese kan worden bevestigd. Dit is een belangwekkend resultaat, want vroege marktintroductie en een langer overleven, maken een snelle en solide opschaling van de betreffende innovatie mogelijk zodat deze een sterkere invloed kan hebben op structurele vernieuwing in de energie sector. De hypothesen die positief testen op langdurig overleven, zijn naast vroegtijdige marktintroductie, een diversificatie strategie en een relatief gunstig nationaal innovatiesysteem. Opmerkelijk is het constateren van significante 'tegengestelde effecten' ten opzichte van de hypothesen, namelijk wat betreft de omvang van starterteams en technische universiteit als incubatiemilieu. Wat betreft omvang van starterteams lijkt de kans op langer overleven groter te zijn bij kleine teams. Een kleiner team zou niet alleen vanwege minder kans op frictie binnen het team meer slagvaardig besluiten kunnen nemen, maar ook het voordeel hebben van langer samenwerken met de universiteit, eventueel in co-creatie projecten. Wat betreft de aard van de universiteit als incubatiemilieu, zou de algemene universiteit relatief veel voordeel kunnen bieden zowel voor ontwikkelen van innovatieve services als voor meer fundamenteel gerichte innovaties die in co-creatie van het spin-off bedrijf met de universiteit doorontwikkeld kunnen worden.

Ten aanzien van het bedrijven ecosysteem waarin de spin-offs opereren, is een benadering gevolgd op nog twee andere ruimtelijke niveaus, naast de universiteit als lokaal incubatiemilieu. Het gaat hierbij om het stedelijk karakter van de vestigingsplaats en het nationale innovatiesysteem. Over het geheel is opmerkelijk dat alleen het nationale innovatie systeem en het lokale incubatiemilieu (deels) doorwerken op marktintroductie en de duur van overleven, en dat het stedelijk karakter van de vestigingsplaats hier buiten valt. Een mogelijke verklaring is dat buiten de metropoolgebieden zich ook centra hebben ontwikkeld met sterke specialisatie, maar in deze gevallen sterker gebaseerd op aanwezige natuurlijke energie- en hulpbronnen (wind, zon, bossen, stromend water, silicium zanden, etc.) voor nieuwe duurzame energie winning. Hiernaast kan het missen van metropoolvoordelen ook intern binnen de spin-offs worden opgevangen door specifieke organisatievormen van leren en absorptie.

In Hoofdstuk 7, als laatste hoofdstuk, worden de uitkomsten van de analyses in een bredere context geplaatst voor discussie en reflectie, en worden deze vertaald naar beleidsaanbevelingen voor verschillende stakeholders. Op dit vlak liggen vele uitdagingen, met name die waardoor spin-off bedrijven eerder geneigd zijn om *risico's* te nemen en nadelen te beperken door eerder (sneller na oprichting) samenwerkingsverbanden aan te gaan. Dit om versnelling van de energie transitie beter mogelijk te maken. Hoofdstuk 7 presenteert hiernaast op basis van onverwachte uitkomsten en beperkingen van de onderhavige uitkomsten van analyse, enkele richtingen voor toekomstig onderzoek.

De belangrijkste punten in hoofdstuk 7 zijn onder meer:

- Bredere context: Het hoofdstuk plaatst de bevindingen in dit proefschrift binnen het bredere kader van duurzame energie-innovatie en ondernemerschap en bespreekt hoe deze resultaten zich verhouden tot de huidige trends en uitdagingen in het veld.

- Beleidsaanbevelingen: Op basis van de bevindingen in dit proefschrift biedt hoofdstuk 7 specifieke beleidsaanbevelingen voor verschillende stakeholders. Deze suggesties hebben waarschijnlijk betrekking op manieren om: het nemen van risico's bij spin-offbedrijven aan te moedigen, eerdere en effectievere samenwerkingen te vergemakkelijken, ondersteuningssystemen op universitair, lokaal en nationaal niveau te optimaliseren en het algehele ecosysteem voor duurzame energie-innovatie te verbeteren.
- Versnellen van de energietransitie: Het hoofdstuk benadrukt hoe de implementatie van deze aanbevelingen kan bijdragen aan het versnellen van de energietransitie, een cruciale wereldwijde uitdaging.
- Reflectie op beperkingen: Het hoofdstuk bevat een kritische reflectie op de beperkingen van de studies in dit proefschrift, waarbij context wordt geboden voor het interpreteren van de resultaten en het informeren van toekomstige onderzoeksopzet. De belangrijkste zijn:

    - Het monitoren van de prestaties van startups en met name spin-offbedrijven van universiteiten kan worden gezien als een waardevolle maatstaf voor het evalueren van de impact van gerelateerd beleid.
    - Het starten van verklarend onderzoek met een pilotstudie verheldert het landschap en helpt de toekomstige uitdagingen te mitigeren.
    - Er moet meer aandacht worden besteed aan de timing van gebeurtenissen gedurende de levenscyclus van het bedrijf.
    - Bij gebrek aan directe effecten van verschillende factoren, kunnen de indirecte effecten nog steeds van invloed zijn op de uitkomsten en moeten ze daarom in overweging worden genomen.
- Toekomstige onderzoeksrichtingen: Op basis van onverwachte uitkomsten en beperkingen van de empirische studies worden in hoofdstuk zeven verschillende richtingen voor toekomstig onderzoek voorgesteld. Deze suggesties omvatten gebieden waar de bevindingen van de huidige studie niet doorslaggevend waren of in tegenspraak waren met de verwachtingen, en ook mogelijke nieuw onderzoek die door de resultaten van de studie werden geopend. Opvallende onderwerpen zijn:

    - Wat is het Technology Readiness Level (TRL) bij de oprichting van het bedrijf?
    - Rekening houden met de mogelijke invloed van een advisory board.
    - Het controleren voor andere dimensies van het ondernemersecosysteem, zoals lokale beleidskaders, netwerksterkte en de beschikbaarheid van mentorschap en incubators voor universitaire spin-offs.
    - Beoordeling van de tegenovergestelde effecten van ondersteunend beleid voor universitaire spin-offs door gebruik te maken van een controlegroep van niet-universitaire spin-off startups in dezelfde sector.

- Het verkennen van mogelijke niet-lineaire relaties tussen de factoren en de mediërende effecten die kunnen optreden.
- Integratie van diepgaande casestudy's naast de kwantitatieve analyse.

Dit laatste hoofdstuk dient om de bevindingen van het proefschrift samen te vatten, te vertalen naar praktische aanbevelingen en de weg vrij te maken voor toekomstig onderzoek op het gebied van duurzame energie-innovatie en universitaire spin-off bedrijven. Het onderstreept het belang van dit werk in de bredere context van het versnellen van de wereldwijde energietransitie en benadrukt het complexe samenspel van factoren die van invloed zijn op het succes van innovatieve startups in deze cruciale sector.

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Chapter 1. Introduction

1.1 Global Challenges in Energy Sustainability and the Role of Startups

Nowadays, climate change is taken more seriously worldwide, with many environmental changes and disasters being labelled as unprecedented over decades or even millennia. The global average temperature has risen by about 2°C compared to pre-industrial levels (Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, 2021), leading to the phenomenon known as global warming. Consequently, more frequent droughts and wildfires are being observed globally, rainfall patterns are shifting, glaciers and snow are diminishing, and the global mean sea level is rising. These changes collectively pose a significant threat to human life. The primary driver of global warming is the increase in greenhouse gas emissions, with the largest source of these emissions coming from burning fossil fuels for electricity, heat, and transportation, particularly in recent decades. Therefore, there is an urgent need for a transition to sustainability in the existing energy system that involves the participation of all stakeholders. This need has been formalized in various agreements, such as the Kyoto Protocol in 2007, the Paris Agreement in 2015, and is reiterated in the IPCC report on Climate Change 2022, while it puts more stress on acceleration in the more recent report in 2023 (IPCC, 2022, 2023).

As an indication of the seriousness of concerns, many national and local governments offer incentives to firms to make a transition to sustainability. For entrepreneurs, this transition is an opportunity to develop radically and incrementally innovative solutions for sustainable energy, introduce them to the market, and eventually scale them up. In particular, in recent decades, the advantage of startups over incumbent firms in technological changes has been popularized (e.g., Weiblen and Chesbrough, 2015; Horne et al., 2020; Johnson and Schaltegger, 2020; Tiba et al., 2021; Horne and Fichter, 2022), and many startups, especially university spin-off firms, have stepped into the sustainability transition. The question remains how university spin-off firms can successfully contribute to transitional change.

The important role of high-tech small startups in innovation development and economic growth has been recognized in recent studies (e.g., Weiblen and Chesbrough, 2015; Saunila, 2020). However, the role that small firms play in transformational change in technology has remained a subject of debate (Burch et al., 2016; van Mossel et al., 2018). Some scholars emphasize that large firms are important given their monopoly power, whereas others emphasize the exceptional creative drive of independent entrepreneurs. Likewise, large firms have the advantage of access to resources, but small firms benefit from flexibility and adaptability (Brown et al., 2007; Hockerts and Wüstenhagen, 2010; Weiblen and Chesbrough, 2015; Troise et al., 2022). Further, young entrepreneurs endeavour risky innovative developments, leading to the launch of radically new products and new industry sectors and eventually making changes in existing market structures (Rothwell, 1989; Hill and Rothaermel, 2003; Cohen and Winn, 2007; Saunila, 2020). It has also been argued that strong entrepreneurial ecosystems where young firms operate, could compensate for their shortages of resources by providing access to supportive facilities in the cities and regions concerned (Hockerts and Wüstenhagen, 2010; Acs et al., 2017; Stam and Van de Ven, 2021; Audretsch et al., 2024).

Considering the energy transition as a transformative change that necessitates adaptations at various levels and within different system components, such as infrastructure, regulations, standards, and technology, the role of small firms in the sustainable energy transition remains ambiguous. Finding new solutions for the energy transition requires a vast amount of investment. Therefore, given the liability of newness and the smallness of young startups (Stinchcombe, 1965), it is questionable whether they could play a substantial role in making changes in the energy market. However, the flexibility and agility of young and small firms, coupled with their freedom from path dependency and lock-in to the current system, give them an advantage in finding innovative solutions and actively participating in the new and emerging fields of the sustainability transition (Christensen, 1997; Freeman and Engel, 2007; Moore and Manring, 2009; Burch et al., 2016; Horne and Fichter, 2022). If small startups in the sustainable energy market successfully bring their innovative technology to the market, survive, and, most importantly, scale it up, it means the innovative product —eventually after having crossed the chasm— can be produced for larger customer markets (segments) (Mohr et al., 2013; Naber et al., 2018; EC, 2021), enabling a quicker and stronger contribution to the transition of the energy system.

Building upon the idea of the Triple-Helix model of innovation (Leydesdorff, 2006; Zhou and Etzkowitz, 2021), which describes the growth of the knowledge economy through interactions between universities, industry, and government, an important role for universities in the energy transition could be envisioned. University spin-off firms (USOs), the subject of this thesis, are specific startups independently established by university graduates and/or staff with the mission to bring novel university knowledge to market (Pirnay et al., 2003; Shane, 2004). While such young startups are not the only channel of knowledge transfer from universities, they attract wide attention due to their role in creating of high-level employment and spill-overs in the regional knowledge economy (Walter et al., 2011; Mathisen and Rasmussen, 2019; Wagner et al., 2021).

Preferred conditions and circumstances for university spin-offs or, in a wider view, for startups to empower them in high-tech markets are widely under discussion (e.g., Samsom and Gurdon, 1993; Walter et al., 2006; Boh et al., 2016; Mathisen and Rasmussen, 2019; Audretsch and Belitski, 2022). However, it is important to focus on sustainable energy markets separately because the energy market is surrounded by its own specific characteristics and restrictions, particularly uncertainty regarding adoption in the market. The present study, both theoretically and empirically, contributes to this part of the literature.

The Knowledge Gaps

As mentioned earlier, a consensus regarding the role of technology startups (including USOs), in the market introduction and scaling-up of sustainable energy innovations during a transitional phase, is currently lacking. Empirical analysis may shed light on this debated topic. Specifically, there is a limited understanding of the extent to which risk-taking strategies employed by university spin-off firms contribute to achieving rapid market introduction. The influence of the university spin-off firm resources and the resources they have access to within the ecosystem remains unclear. In general, there is a lack of knowledge regarding conditions leading to the long-term survival of sustainable energy startups. Governments and universities have offered support infrastructures as part of National Innovation Systems to focus on energy transition, which justifies a need for evaluation. This is crucial, particularly for policymakers, to fine-tune policies based on empirical results and for entrepreneurs, to strategically align their businesses with the evolving dynamics of sustainable energy markets.

The analysis of sustainable energy transitions typically departs from the Multi-Level Perspective Model (MLP) (Geels, 2002; Markard et al., 2012). However, more recent and repeated criticisms call for a focus on empirical work on the role of actors and agencies in the energy transition, particularly firms (Hekkert et al., 2007; Alkemade et al., 2011; van Mossel et al., 2018; De Haan and Rotmans, 2018; Upham et al., 2020). Responding to this call, the current study seeks to empirically assess to what extent university spin-offs have capitalized on recent encouraging policies, overcome barriers, and successfully participated in the energy transition.

Despite the large body of literature on energy transition, there is little empirical research that focuses on firms' activities in the sustainable energy market from a retrospective perspective at the micro level (e.g., Horne and Fichter, 2022). The current study aims to contribute to this area of analysis.

1.2 Scope of the Study; Perspective of University Spin-offs

The consolidation of the 'third mission' of universities in Europe and North America, both in theory and practice in recent decades, increased the interaction of universities with the business world and civil society, thereby more focusing on societal problems and needs (Van Geenhuizen et al., 2016; Gabrielsson et al., 2019; Cai and Amaral, 2021). University spin-offs (USOs), by definition, are one of the channels through which universities transfer novel knowledge to the market (Samsom and Gurdon, 1993; Steffensen et al., 1999; Shane, 2004; Walter et al., 2006; Van Geenhuizen and Soetanto, 2009; Mathisen and Rasmussen, 2019; Sciarelli et al., 2021). Considering the knowledge spill-over theory of entrepreneurship (Acs et al., 2013), university spin-off firms are seen as the natural result of spill-over knowledge from the rich, dense, and knowledge-based context of universities (Audretsch et al., 2005; Wennberg et al., 2011; Rodríguez-Gulías et al., 2018), which might eventually lead to the creation of transformational technologies.

The focus on university spin-off firms in this dissertation is motivated by their close relationship with research universities that fuel them with up-to-date technologies, which are promising for sustainable transition, and also by their relatively large chance to survive the first years due to specific incubation support (Van Geenhuizen and Soetanto, 2009; Soetanto and Jack, 2016). Combining the importance of accelerating sustainable energy transition and the capacity of university spin-off firms in commercializing university knowledge, a crucial role for university spin-off firms in sustainable energy transition emerges (Etzkowitz, 2003; Zhou and Etzkowitz, 2021). University spin-off firms are mostly run by innovative, risk-taking individuals who are motivated by personal or social gain through opportunity identification and resource mobilization (Lumpkin and Dess, 1996). They also leverage the facilities available in entrepreneurial ecosystems to mitigate risks and uncertainties, resulting in quicker market introductions and prolonged survival. However, like many young and small firms, university spin-off firms face challenges such as a lack of investment capital, networks, and reputation.

Young university spin-off firms exhibit distinct characteristics for two primary reasons. Firstly, the process of spin-off preparation and establishment varies among universities, depending on their differing approaches to business and the level of departmental (faculty) support they provide (Rasmussen et al., 2014; Bathelt et al., 2010). Secondly, founders of university spin-off firms may develop different entrepreneurial orientations and strategies (Covin and Lumpkin, 2011). In this context, the formation of founding teams among university spin-off firms is often not a rational process and may result from factors such as pre-existing friendships among graduates or shared preferences and specific knowledge gained during master's studies (Clough and Vissa, 2022). While this may lead to a lack of business experience and acumen, strong entrepreneurial ecosystems can facilitate the establishment of necessary linkages and networks.

Furthermore, it needs to be mentioned that urban or regional entrepreneurial ecosystems are influenced by factors at the national level, primarily national innovation systems (Acs et al., 2014). Such influence may include subsidies and investment programs for specific energy R&D at universities or research institutes, participation in internationally established research programs (like Horizon 2020 in the EU context), a strong entrepreneurial spirit, and generic SME support programs (Stam and Van de Ven, 2021). In addition to city-specific agglomeration advantages, which include knowledge spillovers, a skilled labour pool, and non-traded local inputs (McCann and Shefer, 2004), factors like the presence of experimentation places and launching customers (Nejabat and Van Geenhuizen, 2022) are integral to local entrepreneurial ecosystems.

The aim of the present study is to bridge the gap between research and development (R&D) and entrepreneurship at universities and the energy transition in society by exploring the development of high-tech university spin-off firms in the sustainable energy market. This empirical study draws on data derived from Dutch and Scandinavian university spin-offs. It investigates the factors that influence the time needed to develop new energy solutions and bring them to the market, as well as the factors that affect the survival of these young high-tech firms in sustainable energy markets.

1.3 Research Aim and Objectives

Building upon previous studies aimed at understanding the role of startups in sustainable energy transition, this study tries to deepen our understanding of the factors influencing market introduction and the survival of university spin-off firms in energy transition. The underlying assumption of this study is that if university spin-off firms bring their new energy solutions to the market faster or survive longer as startups, they will advance energy solutions perceived as valuable, thereby contributing to the transition of the energy sector to a more sustainable one.

Given the knowledge gaps highlighted in Section 1.1, particularly the absence of empirical studies evaluating the potential of startups in successfully bringing sustainable energy innovations to the market and surviving, this thesis aims to shed light on potential pathways for university spin-off firms in the sustainable energy market. It considers entrepreneurs and their conditions, as well as the entrepreneurial ecosystem. The following objectives have been established with the aim of addressing the existing knowledge gaps:

a. To picture the characteristics of energy spin-off activities in bringing sustainable energy innovations to market over a period of 20 years between 1998 and 2018 and to assess the extent of their success in terms of survival and time to market introduction.

b. To assess the impact of risk-taking and risk-avoidance strategies, as well as the timing of resource access, on early market introduction and firm survival.

c. To evaluate the influence of the supportive entrepreneurial ecosystem in the sustainable energy market in the Netherlands and four Scandinavian countries from 1998 to 2018 on the success of firms in terms of early market introduction and survival.

d. To propose policies that can enhance the effectiveness of university spin-off firms in bringing sustainable energy solutions to the market.

1.4 Research Questions

The overarching research question addressed in this dissertation is phrased as follows:

> *Which conditions influence the speed of university spin-off firms in bringing new products and services to the sustainable energy market, and what influences their survival?*

Giving due consideration to the specific features of small, innovative university spin-offs and high-tech sustainable energy market, three bundles of sub-questions examine different aspects of university spin-offs in the sustainable energy sector, each addressed in different chapters.

Sub-questions I:

The first bundle of sub-questions aligns with recent calls to expedite sustainability transition through the involvement of firms and agencies (e.g., Burch et al., 2016; Gliedt et al., 2018). To achieve this objective, the conditions and circumstances that cause shorter product development time and speedy market introduction, as well as firms' survival dynamics, must be investigated. The first bundle of sub-questions is discussed in Chapter 4, exploring previous and existing patterns among sustainable energy spin-offs in terms of type of energy technology, their strategic risk-taking or avoiding choices, having competences at the start or gaining them later, and their distribution in different entrepreneurial eco-systems relating to diversity in character of National Innovation Systems and diversity in location and size of cities (municipalities). This chapter provides extensive descriptive insights based on the available representative database (for details about the database, see Chapter 3, Section 3.2). The sub-questions are formulated to be addressed in Chapter 4:

1) What are the characteristics of the university spin-off firms regarding sustainable energy technology and assumed influencing factors like period of establishment, entrepreneurial orientation (risks), resources and capabilities of the founding team and early networking, and quality of the entrepreneurial ecosystem?

2) What are the dynamics of the market introduction of sustainable energy technologies among different categories of university spin-offs, regarding the time needed, given these influencing factors?

3) What are the dynamics of firm survival among different categories of university spin-offs with regard to time of survival, given the influencing factors?

Sub-questions II:

As the energy system is considered a socio-technical system, its transformation involves various dynamics, including resistance to change (e.g., Geels 2005, 2014; Smith et al. 2010; Markard et al. 2016). In this context, the 'regime' acts as a stable framework within the energy system, governed by rules that guide and coordinate social and economic activities to maintain system stability. From a firm's perspective, the sustainable energy business environment is surrounded by risks and uncertainties that can lead to delays in R&D and market introduction. To explore the time-to-market introduction of sustainable energy innovations, the second bundle of sub-questions, addressed in Chapter 5, is formulated:

1) To what extent do university spin-off firms successfully bring sustainable energy innovations to the market, and what is the time frame involved?

2) What factors influence the time patterns of market introduction, particularly in terms of risk-taking and -avoiding and risk-mitigation strategies, and the availability of resources and capabilities?

3) For highly innovative university spin-off firms, to what extent do entrepreneurial ecosystems affect the time patterns of market introduction?

Sub-questions III:

From an entrepreneurial perspective, the survival of innovative high-tech startups is a significant concern. In recent years, a remarkable increase in the number of startups has been observed, which is also followed by fairly high rates of exit from the market (Soto-Simeone et al., 2020). In this vein, some literature has pointed out that entry into markets is relatively easy, but surviving is not (Geroski, 1995). According to the liability of newness, the early years of a firm's life are the riskiest, as new ventures lack specific resources and capabilities that more established organizations have already accumulated (Steffensen et al., 1999).

The situation is even more pressing for innovative startups, and two competing arguments explain the relationship between a firm survival and its innovativeness. On the one hand, innovativeness is argued to enhance survival through attributes like market power and cost efficiency and capabilities such as absorptive capacity. On the other hand, an innovative startup faces liabilities of newness and smallness to a greater extent than their non-innovative counterparts (Hyytinen et al., 2015). This brings the study to the following research questions on firms' survival, addressed in Chapter 6:

1) What are the dynamics of firm survival among the sample of university spin-offs with regard to time of survival and influencing factors?

2) In what ways do factors related to entrepreneurial orientation and firm strategies regarding risk-taking and -avoiding and risk mitigation influence the survival of university spin-off firms?

3) How do firm-owned competencies influence the survival of university spin-off firms? What is the impact of the timing of resource access and capability acquisition on the survival of university spin-off firms? What is the impact of early market introduction on firm survival?

4) How does a supportive entrepreneurial ecosystem affect the survival of university spin-off firms in the sustainable energy sector?

1.5 Theoretical Perspectives

The framework of this thesis is anchored in four distinct theoretical streams: transition theories, entrepreneurial orientation of firms, resource-based theory and capabilities, and entrepreneurial ecosystem theory. Transition theories and their link to entrepreneurship may uncover how these theories can elucidate the dynamics of sustainability in the context of startup ventures. For university spin-offs operating in the high-stakes arena of sustainable energy, the entrepreneurial orientation of firms becomes particularly critical. Meanwhile, the resource-based theory and capabilities will underscore the pivotal role of competitive advantages and the challenges that university spin-offs encounter within the sustainable energy landscape. Entrepreneurial ecosystem theory considers the environmental factors that shape and influence the trajectory of sustainable energy startups.

Together, these theories lay the foundation for our comprehensive investigation into university spin-offs and the factors that advance the sustainable energy transition through academic spin-offs. The following sections will provide a concise overview of the current state of art on these theories, setting the stage for our in-depth study.

1.5.1 Transition Theory and Entrepreneurship

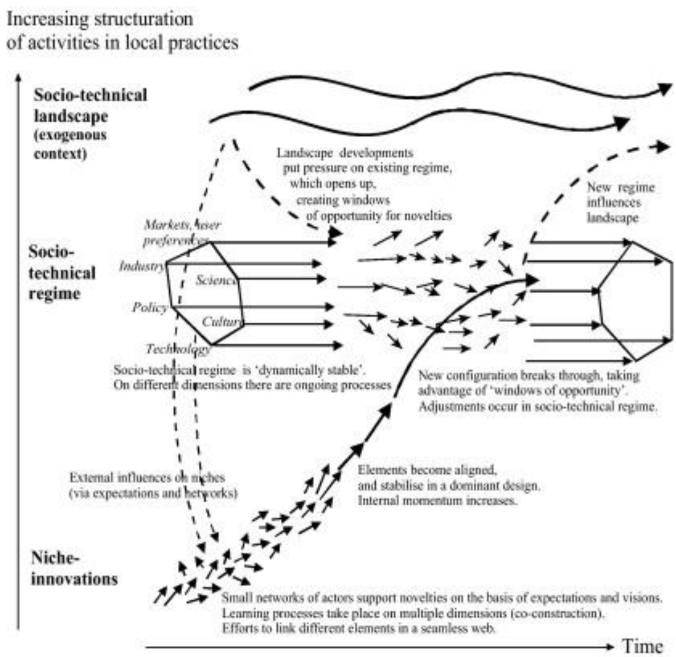
Multi-level Perspective of Transition

According to the Multi-level Perspective model (MLP) (Geels, 2002, 2014), transition refers to a significant change in a socio-technical system resulting from interactions across three interconnected levels: niches, regimes, and the landscape. The MLP model helps explain the patterns of event chains in sustainability transition processes, offering new insights. Radical innovations often face significant risks but can develop within 'niches', where rules, institutions, and motivations differ from the dominant regime, providing a protected environment. Niche-level activities involve nurturing and experimentation in the co-evolution of technology, user practices, and regulatory structures (Raven et al., 2010; Schot and Geels, 2008; Stiles, 2020; Schöpper et al., 2024).

Experimentation across various projects, which happens in niches, can lead to shared visions and practices that often organize activities at the local level. While most transitional innovations remain within the niche, some manage to transition to the dominant regime, which is a central focus of transitional research. These developments within and between niches and regimes occur against the backdrop of broader social, economic, political, and cultural changes at the landscape level. Landscape-level processes can significantly impact the success of a niche innovation. Changes in landscape dynamics, such as new global climate policies, can create opportunities by destabilizing the regime and its established norms and rules (Schot and Geels, 2013). Figure 1.1 illustrates Geels' MLP model, encompassing three levels: landscape, regime, and niche.

The three levels of socio-technical transition mutually affect each other. For example, dynamics at the landscape level would affect the regime and niche, while these also receive substantial influences from them. At the regime level, actors are being influenced by pressure from the landscape and niche levels. The regime level is where resistance to transition originates, as a result of vested interests, consumer preferences, stiff regulations, etc. As shown in Figure 1.1, the transition is supposed to reconfigure the stable regime through the creation of new trajectories. The alignment of new trajectories creates a window of opportunity for desired changes that eventually re-stabilize a new regime.

Figure 1.1 Multi Level Perspective model of transition (MLP).



Source: Geels 2011

Transitions are essentially changes in the existing socio-technical regime, leading to the development of stability in a new regime. This concept forms the core narrative of the transition towards sustainability within the Multi-Level Perspective model (MLP) and has gained widespread acceptance among scholars (Wang et al., 2022). The MLP provides a valuable framework for categorizing and understanding socio-technical change with its three analytical levels: niches, regimes, and landscapes. These levels are not considered distinct, tangible entities in the real world but are instrumental for analytical purposes (Raven et al., 2010).

Sustainability Entrepreneurship

Large firms, which play the roles of developers and producers, are integral parts of the socio-technical regime, reinforcing its dynamic stability (Burch et al., 2016; Bidmon and Knab, 2018). In contrast, small and vulnerable firms, especially startups, often nurture new products at the niche level, offering protection from the mainstream market, before potentially transitioning to the regime level. This study focuses on the specific role of small high-tech university spin-off firms in the energy transition, emphasizing their potential in sustainable entrepreneurship.

Sustainability entrepreneurship has emerged as a research area in response to growing concerns about both entrepreneurship and sustainable development (Horne et al., 2020). It recognizes enterprises as fundamental drivers of societal and economic progress (Cohen and Winn, 2007; Muñoz and Cohen, 2018). Sustainability entrepreneurship involves identifying and creating opportunities in the sustainability domain, considering social, technological, and environmental factors, as well as entrepreneurial self-interests (Hockerts and Wüstenhagen, 2010; Pacheco et al., 2010; Shepherd and Patzelt, 2011; Gast et al., 2017; Haldar, 2019).

While entrepreneurs typically seek opportunities by addressing unmet needs, they may not always prioritize environmental or societal concerns. Therefore, sustainable entrepreneurs are expected to actively seek innovative solutions to emerging environmental problems. Compared to conventional entrepreneurship, sustainable entrepreneurs face additional challenges, including the potential mismatch between self-value and social value creation (Hoogendoorn et al., 2019). Characteristics of sustainable entrepreneurship, such as market imperfections, institutional gaps, technological complexity, and social acceptance ambiguity, further increase uncertainty and business risks.

Given the assumed social responsibility of universities and their diverse array of stakeholders, including students, institutions, government, employees, companies, and local communities, universities are expected to play a pivotal role in the transition towards sustainability (Vasilescu et al., 2010; Etzkowitz and Zhou, 2017; Soini et al., 2018). This study posits that business activities in the sustainable energy market can foster the energy transition by establishing successful startups and developing sustainable energy innovations. As such, the study aims to explore the influential factors affecting the market introduction and survival of university spin-offs in the sustainable energy sector.

1.5.2 Entrepreneurial Orientation of the Firm

Entrepreneurial Orientation in General

Entrepreneurial orientation theory primarily focuses on how firms achieve growth through the identification and exploitation of market opportunities (Baker and Sinkula, 2009). This attention to entrepreneurial orientation (EO) has its roots in the strategy-making literature, as it pertains to the organizational processes, methods, practices, and decision-making activities that firms employ to act entrepreneurially (Lumpkin and Dess, 1996; Covin and Lumpkin, 2011). According to Lumpkin and Dess (1996), entrepreneurial orientation encompasses five dimensions: autonomy, innovativeness, risk-taking, proactiveness, and competitive aggressiveness. Firms may adopt differing strategies, with some taking more risks and pioneering while others proceed cautiously as followers (Mohr et al., 2013). This study focuses on understanding how these strategies impact the market introduction and survival of university spin-off firms, with a specific emphasis on their innovativeness and risk-taking.

Entrepreneurial orientation theory suggests that in competitive and dynamic environments, entrepreneurial behaviour is essential for the survival and growth of firms, irrespective of their size or age (Lumpkin and Dess, 1996; Rauch et al., 2009). Nevertheless, empirical studies indicate that the relationship between a firm's entrepreneurial orientation and performance, as evident in metrics like sales growth and profitability, is more complex than initially assumed (e.g., Covin and Slevin, 1991; Dess et al., 1997; Walter et al., 2006). Wiklund and Shepherd (2005) highlight the complexity of the relationship between entrepreneurial orientation and a firm's performance in their model and show that a small firm’s performance could be explained by the configurations of entrepreneurial orientation, access to capital, and environmental dynamics. According to these results, relying merely on the entrepreneurial orientation of firms may lead to an incomplete understanding of the firm's performance in the market. The current study follows this line of thinking and not only considers the entrepreneurial orientation of the firm but also the firm's access to resources and capabilities as well as networks in the environmental eco-system.

High-tech innovative firms operate in dynamic and competitive environments, which emphasize the significance of time (Lynn and Akgün, 1998; Shan et al., 2016). This has led to a shift in the traditional approach to gaining a competitive advantage, focusing on 'the most value for the lowest cost' to 'the most value for the lowest cost in the least amount of time' (Chen et al., 2010; Shan et al., 2016). Many studies from various perspectives have explored how firms' strategies and characteristics influence their speed to market (e.g., Schoonhoven et al., 1990; Kessler and Chakrabarti, 1996; Atuahene-Gima, 2003; Fang, 2008).

Given the emphasis on risk in sustainable energy markets and transitions, this study particularly focuses on the firm's risk-taking and risk-avoiding strategies. The following subsection delves into the fine-tuning of entrepreneurial risk strategies within the context of sustainable energy technology and markets in this study.

Risk Taking and Risk Avoiding Strategies

Anderson et al. (2015) defined firms’ entrepreneurial orientation in two levels: entrepreneurial behaviour (encompassing innovativeness and pro-activeness) and entrepreneurial managerial attitude (risk-taking), and the latter stresses the entrepreneurial orientation of managers for either taking risk and working in uncertainty or avoiding it. Since many uncertainties, such as uncertainty in the efficiency of new technologies, shortages in infrastructure, and customer acceptance, are still around in sustainable energy technologies and markets, the degree of risk taking and avoiding/mitigating could be counted as an important strategic choice for firms, which might affect the firms’ performance and success. Producing radical or incremental innovation differs in the degree of risks involved in the product technology or design, and in this study, it has been taken into account as an indicator of risk strategy. For example, firms that are dealing with the development of technologies to produce electricity from wave energy or those that produce new types of fuels are evidently different in terms of product radicality from those that improve energy efficiency in industries or households. Consequently, different behaviour in the market and different outcomes of firm survival may be expected. If a radically new product is launched, startups are facing more uncertainty, but they may benefit from a first mover advantage through creating a new technology, which makes them the initial leaders in the market. Similarly, it could be argued that the newness of the market is another risk-related factor. While the playground and players in established markets are relatively clear, in new and emerging markets, the structure of the market has not been set yet, potentially causing unclear and risky situations. There are different levels of newness in the market for sustainable energy over time, given the retrospective view in the study. For example, offshore wind technology started its small-scale demonstration phase in the late 1990s and early 2000s; in about 2010, the take-off phase started, and the international offshore wind market has turned from an immature niche into a large industry. Numerous 400–500 MW projects were developed annually, leading to a new phase of technological diffusion (van der Loos et al., 2021).

Building on the theory of entrepreneurial orientation within firms and recognizing the imperative for accelerating significant changes in the energy system to attain transition goals, this study posits that adopting risk-taking strategies, such as developing radical inventions and entering new or emerging markets, is likely to lead to a slower market introduction but prolonged firm survival.

Another risk-related strategy —to be precise, a risk-avoiding strategy— is to adopt a certain diversification (Chang and Thomas, 1987; Miller, 2006; Mohr et al., 2013). Accordingly, firms may expand their product or market with a less risky or traditional product or service or an established market. An often-observed example is adding services to the novel equipment that has already been developed. In this way, the firm would secure the business through some self-investment —particularly in avoiding the 'valley of death' if some essential R&D is still needed (Auerswald and Branscomp, 2003; Mohr et al., 2013; Bocken et al., 2015)— and more confidently spend on the risky product or market. However, the strategy of diversification may also reduce the concentration of the firm on the core invention and take the firm's time and effort, leading to delays in product development or market introduction. As a result of this reasoning, it is difficult to forward a clear proposition on diversification, as a precondition needs to be taken into account, namely narrow diversification. Given this situation, narrow diversification would lead to faster market introduction and longer firm survival. This will be studied in detail in the coming chapters.

In addition to risk-taking and risk-mitigating strategies, having access to resources by owning or gaining them, like competence to better perceive opportunities and use resources, may increase a firm's competitiveness, and enhance its success in the market. The following section addresses resource-based theories and their application in this study.

1.5.3 Resource Based Theory and Theory on Capabilities

Resource-based Theory and Capabilities in General

The theoretical perspective of the liability of newness (Freeman et al., 1983; Yang and Aldrich, 2017) argues that the smallness and newness of startups make them more vulnerable compared to incumbent firms. In more detail, it states that when starting a new firm, the risk of dying is highest. The vulnerability stems, for example, from low capabilities (in response to needs to adapt), shortages in resources, and a lack of reputation. Further, building upon resource-based theory (Barney, 1991), which suggests that valuable, rare, difficult to imitate, and non-substitutable resources give a firm the best position for long-term competitiveness, it is vital for young firms to compensate for their shortage of owned resources by a smart selection of external resources and capabilities.

Resource-based theory is the starting point of many entrepreneurial studies to determine which resources may play a crucial role in different types of firms and technologies (Alexy et al., 2018; Collins, 2021). The current study explores three distinct types of resources and capabilities pertinent to small and young university spin-off firms, and hypotheses are formulated to investigate the impact of possessing or acquiring these resources and capabilities on market introduction and firm survival. The three categories are marketing resources and capabilities, technical resources and capabilities, and financial resources and capabilities.

Marketing Resources and Capabilities

In the literature, marketing resources and capabilities are viewed as those capabilities that are associated with several market knowledge and marketing functions, i.e., market segmentation, advertisement, sales, pricing, distribution management, and particularly the use of customer networks (Morgan et al., 2009; Mohr et al., 2013; Kozlenkova et al., 2014). To be more specific, for young innovative spin-off firms, they often lack marketing education and market experience among the founding team (Clarysse and Moray, 2004; van Geenhuizen and Soetanto, 2009). Previous studies show that a match between entrepreneurial ambitions and marketing abilities leads to successful spin-off firms (Pérez and Sánchez, 2003). In addition to hiring marketing staff as a direct solution, missing market knowledge and abilities can be compensated by connecting with a large company that not only provides knowledge of markets and market segments but also access to an existing sales organization and eventually financial resources. Large companies (or other large organizations) may also act as launching customers.

Technological Resources and Capabilities

When it comes to technological resources, it is important to consider several factors as follows. Given that the university spin-off firms in the present study are focused on technology innovations related to sustainable energy, the richness of knowledge and skills available among the founding team can be perceived as technology resources of the firm (Fern et al., 2012; Visintin and Pittino, 2014). While university spin-off firms are expected to be led by knowledgeable individuals, there might be differences in the depth of technical knowledge they own (as reflected in pre-start technology experience in business and having achieved a PhD). The practical implications of this are not always straightforward, as possessing extensive technology knowledge can sometimes be accompanied by a relatively weak focus on business and market orientation during the early stages of growth. Another strategy to gain access to technology resources is that the starting team remains closely related to R&D at the university for a couple of years after the start. For example, through the sharing of staff and the use of advanced equipment.

Financial Resources and Capabilities

Small and new startups often face challenges when it comes to financing their innovation efforts (Katila and Shane, 2005). As a result, they typically rely on external sources of funding to sustain themselves during their initial stages, especially when they lack profitability or have limited income (Schoonhoven et al., 1990). However, from an investor's perspective, investing in innovative firms is considered high-risk due to the uncertainties surrounding market introduction and product acceptance. This is particularly true for radical innovations, which entail increased uncertainty and risk. Although the financial requirements may vary among university spin-off firms, depending on factors such as product readiness and expected benefits, it's generally argued that access to financial capital can enhance a firm's ability to take risks and foster creativity (e.g., Katila and Shane, 2005). It also opens opportunities for firms to enhance their reputation, recruit professional management teams, identify customers and suppliers, expand research and development activities, and engage in strategic and operational planning (Sapienza and Gupta, 1994; Ou and Haynes, 2006; Markham et al., 2010; Hussain et al., 2018). Therefore, gaining venture capital can be considered as a significant competitive advantage for startups in their early stages.

Despite the apparent advantages of securing financial investments, it's worth noting the potential drawbacks, such as the accumulation of debt and the need for short-term repayments, which could ultimately hinder a firm's market introduction and growth (scaling up). These contrasting ideas will be empirically tested in our analysis to examine the impact of access to financial resources on small university spin-offs in the sustainable energy market.

Resources/Competences Owned by the Firm and Gained Later on

Making a distinction between resources initially possessed by the firm and those acquired later through networking, the latter can significantly contribute to the firm's competences. Competences, as defined, are indeed a subset of capabilities, denoting specific, distinctive strengths or advantages within the firm's broader capabilities (Teece et al., 1997; Helfat and Winter, 2011). Consequently, this study examines two distinct categories of resources that enhance its competences: those capabilities inherent to the founding team from the outset, and those acquired by the firm through networking efforts. The subsequent section provides a detailed exploration of the resources and capabilities investigated in this study.

Founding Team Experience

Generally, the founder's competences have been known as one of the entrepreneurial firm's competitive advantages (Alvarez et al., 2001). Because entrepreneurial firms are often built around the founding entrepreneur (or founding teams) who identifies the opportunity and attempts to exploit it commercially, the knowledge and skills of founders in entrepreneurial firms count as intangible soft resources, which are inimitable and more useful than tangible resources in the creation of competitive advantage (Alvarez et al., 2001). Young USOs, which originate from universities with a strong technical background, often lack competences related to market and business knowledge and market experience among their founders (Van Geenhuizen and Soetanto, 2009; Rasmussen et al., 2014). This deficiency becomes particularly critical when seeking financial investment, as previous research has indicated that early-stage capital funds are more inclined to support startups with founders possessing pre-business experience (Clarysse and Moray, 2004).

The newly founded university spin-off firms face a unique set of challenges during their development, from a scientific environment to a business context. This challenge is more highlighted when they have to cope with conditions of high-tech markets and technological uncertainty, given that the commercialization process involves various phases, from research and opportunity screening to the proof of viability and maturity of the innovation (Nikiforou et al., 2018). Academic entrepreneurs come from a historically non-commercial environment; therefore, they often lack commercial skills and prior professional experience in the private sector. University incubators and Technology Transfer Offices (TTOs) within universities attempt to address this gap by offering consultations and providing access to the relevant networks, thus enhancing the entrepreneurial capabilities of founders and managers (Clarysse and Moray, 2004; Van Geenhuizen and Soetanto, 2009). Another suggested solution involves expanding the founding team and promoting diversity to form a larger and more diversified team. This strategy aims to acquire both high-tech knowledge and business- and market-related competencies in the founding team (Taheri and Van Geenhuizen, 2016). However, academic entrepreneurs have a strong science identity that is often incompatible with an entrepreneurial mindset (Huynh et al. 2017). They may experience conflicts of interest as they are torn between their research and venture endeavours (Nikiforou et al., 2018) and may face tensions between remaining an academic or becoming an entrepreneur, or alternatively working part time at both (Wright et al., 2004). Consequently, increased conflicts and tensions within the founding team may impact the firm's overall performance. However, the university spin-off founding team needs to undoubtedly identify and address this shortage, expanding their resources to enhance capabilities for gaining competitive advantages in the market. As a result, this founding team's relatively strong resources would lead to faster market introductions and longer firm survival.

Collaboration with Large Firms

Lack of resources and capabilities often urges young high-tech startups to seek collaboration with large firms. But not all of them do this as early as possible. Collaboration with large firms has been forwarded as an extension of the resource-based view (e.g., Lavie, 2006). Accordingly, large firms may provide investment capital, market knowledge, use of R&D facilities, use of market channels (sales organization), and overall, an improved reputation. Following the perspective of the liability of newness, however, it can be assumed that such collaboration is not easy to establish from scratch, for example, due to potential imbalances and concerns about intellectual ownership (IO) and the managerial challenges involved for the young team.

Access to Financial Investment

Small and new firms often lack sufficient capital to finance R&D in innovation (Katila and Shane, 2005). Therefore, they expect to gain finance from external sources to survive in their early years when they have none or limited turnover and profitability (Schoonhoven et al., 1990; Beck et al., 2005; Malhotra, 2007). For investors, however, investment in innovative firms is high-risk because of their unclear future in market introduction and acceptance of the novel product. In fact, the more radical the innovation, the more uncertainty and risks are involved. Although the financial needs may vary among university spin-off firms based on level of product readiness and amount of self-investment, for some of them, debt accumulation may be threatening (Di Gregorio and Shane, 2003; Gaddy et al., 2016). Overall, it has been argued that access to financial capital would increase a firm's risk-taking ability and boost its creativity (e.g., Katila and Shane, 2005). It also creates possibilities for young firms to increase their reputation, recruit professional managers, identify customers and suppliers, extend R&D, and engage in strategic and operational planning (Sapienza and Gupta, 1994; Ou and Haynes, 2006; Markham et al., 2010; Hussain et al., 2018). Accordingly, all-in-all, having gained substantial venture capital could be seen as an important competitive advantage for startups in the early stages.

Despite the obvious benefits that access to financial investment provides, it is worth noting the danger of a quick accumulation of debt and paying it back in the short term, which at the end may work as an obstacle for firm market introduction and growth (scaling up). These controversial ideas will be empirically investigated in the study, with the aim of identifying the influence of early access to substantial financial resources on young university spin-offs in the sustainable energy market.

Recruitment of Marketing Staff

As highlighted in the preceding section, university spin-off firms represent a distinctive category of startups, characterized not only by their roots in university science but also by the intricacies of their team formation process (Clarysse and Moray, 2004). As a startup advances from product development to marketing and commercialization the necessity arises for individuals with advanced business and market knowledge to the team, especially if such expertise has not been integrated into the founding team from the beginning. It becomes increasingly apparent that equipping the team with experienced marketing professionals is vital, particularly when faced with pivotal decisions concerning target market segments, competitive positioning, marketing communication, pricing, and more (Mohr et al., 2013). The strategic inclusion of marketing expertise not only serves to compensate for any deficiencies in the founding team's business knowledge but also empowers the startup to make informed and bold decisions vital for market success and sustained growth.

All in all, most of the of the above theoretical perspectives point to the advantages of early networking to a greater a greater extent. Hence, the strategy of acquiring resources earlier, including collaborations, investments, and having a marketing expert in the team, would lead to a shorter time to market and a longer survival of the firm.

1.5.4 Entrepreneurial Ecosystem

University spin-off firms are established in or close to a university in an area that can be considered an entrepreneurial ecosystem (EES). Entrepreneurial ecosystems consist of a set of interdependent actors and factors that are governed in such a way that they enable productive entrepreneurship in a particular territory (Stam, 2015). The entrepreneurial ecosystem concept emphasizes that entrepreneurship takes place in a community of interdependent actors and focuses on the role of the environmental context in encouraging or restricting (risk-taking) entrepreneurship.

The entrepreneurial ecosystem approach offers a systemic and broad view of entrepreneurship in which, rather than focusing merely on the characteristics and behaviours of individuals or firms—a main concern of entrepreneurship studies—it understands the context of entrepreneurship at the level of an organizational community supported by a set of positive institutions in a particular territory, such as countries, regions, or cities (Acs et al., 2014; Cavallo et al., 2019).

Borrowing from biology, the 'ecosystem' metaphor gains popularity in entrepreneurship studies, highlighting the reciprocal impact of the environment on entrepreneurship. Entrepreneurial ecosystems, akin to living ecosystems, exhibit co-evolution and mutualistic interdependence among various organizations and actors (Stam and Van der Ven, 2021). Similar to biological ecosystems, entrepreneurial ecosystems comprise interconnected organizations and institutions playing distinct but complementary roles, fostering emergence, growth, and survival within a broader community evolution. This mutualistic interdependence involves both cooperative and competitive relationships, influencing the system's trajectory. The entrepreneurial ecosystem approach views entrepreneurship not only as an outcome of the system but also recognizes the central role of key players in its creation and maintenance. Entrepreneurs, deemed the heart of a successful ecosystem, collaborate with entities like professional service providers, financial infrastructure, and governments to shape the ecosystem over time.

Stam and Van der Ven (2021) introduced an integrative entrepreneurial ecosystem model, comprising ten observable elements (institutions, networks of entrepreneurs, infrastructure, access to financing, leadership, talent, knowledge, supporting services, culture, and demand). This model posits mutual interdependence and co-evolution among these elements, with upward and downward causation influencing entrepreneurial ecosystem outputs. Essentially, the ten observable elements explain entrepreneurial activity levels, and simultaneously, positive feedback from entrepreneurs' impact on these elements. Literature examples include successful entrepreneurs evolving into venture capitalists, role models, leaders, and network developers, contributing to the knowledge worker pool (Stam and Van der Ven, 2021).

National Innovation System

At a higher regime level, a strong National Innovation System (NIS) (Nelson, 1993; Lundvall, 2007; Wirkierman et al., 2018) indicates relatively good entrepreneurial conditions for innovative firms to be nurtured and grow. The set of conditions includes, among others, subsidies for specific R&D, participation in European research programs (Horizon 2020), and benefits from a strong entrepreneurial spirit and a rich circulation of knowledge and information. In some particular countries, such as in Scandinavia, there has been strong activity from national venture capital and investment consortia, providing several rounds of investment in an easy-going way. By contrast, the idea has also developed that strong financing and subsidies stimulate university spin-off firms to aim at high-level risk inventions, which may eventually cause delay due to longer development time and late or no market introduction, and accordingly, sometimes difficulty in payback and bankruptcy. The reasoning on the influence of strong National Innovation Systems on the whole has developed a positive view. This could lead to the observation that stronger National Innovation Systems contribute to fast market introduction and longer survival among university spin-off firms.

Metropolitan Area

In the current study, the above theoretical perspective on entrepreneurial ecosystems (Stam, 2015; Stam and Van der Ven, 2021) is adopted and merged with agglomeration theory (e.g., Anselin et al., 1997; McCann, 2006; Florida et al., 2017). Entrepreneurial ecosystem theory is in line with the older theory of Marshall agglomeration (1890), which pointed out the effect of a firm's location and environment on its access to resources and eventually its growth and success. This mainly refers to benefits from the local pool of skilled labour, local supplier linkages, and local knowledge spillovers, all at a high level of diversity and specialization in large cities (Bathelt et al., 2010). Hence, larger metropolitan areas and their cities may offer better potential for a thriving entrepreneurial ecosystem compared to smaller cities at a distance from these areas, coming with a fast market introduction and longer survival. It is worth noting that the idea has also grown that after exceeding a certain population size and economic activity, advantages of large cities may give way to disadvantages, namely of increasing prices (land, business accommodation, housing) and increasing congestion (Richardson, 1995; Zengh, 2001). The cities taken into account in the current study, however, may not yet have reached such size, certainly compared with their counterparts elsewhere in the world.

Type of University

The first direct environment that may impact university spin-off firms is the university itself. Previous studies have highlighted variations among universities in their policies regarding the creation of opportunities for commercializing knowledge and technology, as well as in fostering the development of new businesses (Di Gregorio and Shane, 2003; Audretsch et al., 2005; Bathelt et al., 2010). Some universities are more purely research-oriented, while others might focus their research more closely on the needs of industry, perhaps influenced by their state affiliations or historical collaborations with industry.

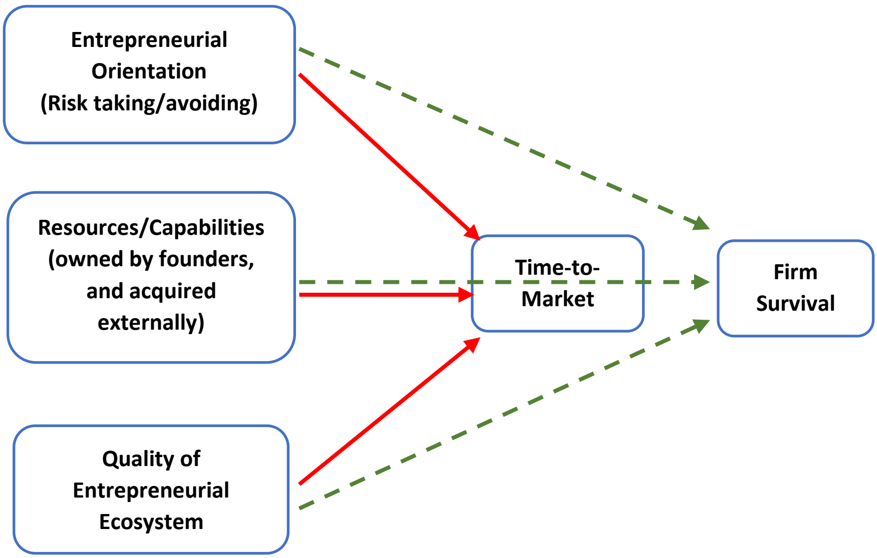
Given that technical universities are more involved in industry projects and frequently collaborate with the industry, facilitated by having more technically oriented professors and students, it can be argued that technical universities create a more conducive environment for the creation and success of university spin-off firms (Martínez-Ardila et al., 2023). This study distinguishes between two types of universities: technical universities and general universities. Technical universities may provide better support for university spin-offs as compared to general universities, to foster faster market introduction and longer survival.

The discussions outlined above constitute the foundational framework of this study, elaborated in the subsequent section.

1.6 Conceptual Framework

Figure 1.2 is a simplified conceptual framework underlying the empirical studies of this dissertation. It consists of two separate models which are distinguished by arrows with different outlines in different colours (green, red) which are separately addressed in different chapters (Chapters 2, 5 and 6) focussing on time to market introduction and firm survival, respectively. As Figure 1.2 demonstrates this study aims to investigate the effect of three blocks of entrepreneurial orientation, resources and capabilities and entrepreneurial ecosystem on the time to market introduction and firm survival. It should be noted, though, that the factors listed in the blocks of the model are categories of factors that are explained in detail in the next chapters.

Figure 1.2 The Conceptual framework of the study



The model with the solid red line pertains to modelling the speed of market introduction (Chapters 2 and 5), and the model with dashed green line illustrates firm survival modelling (Chapter 6).

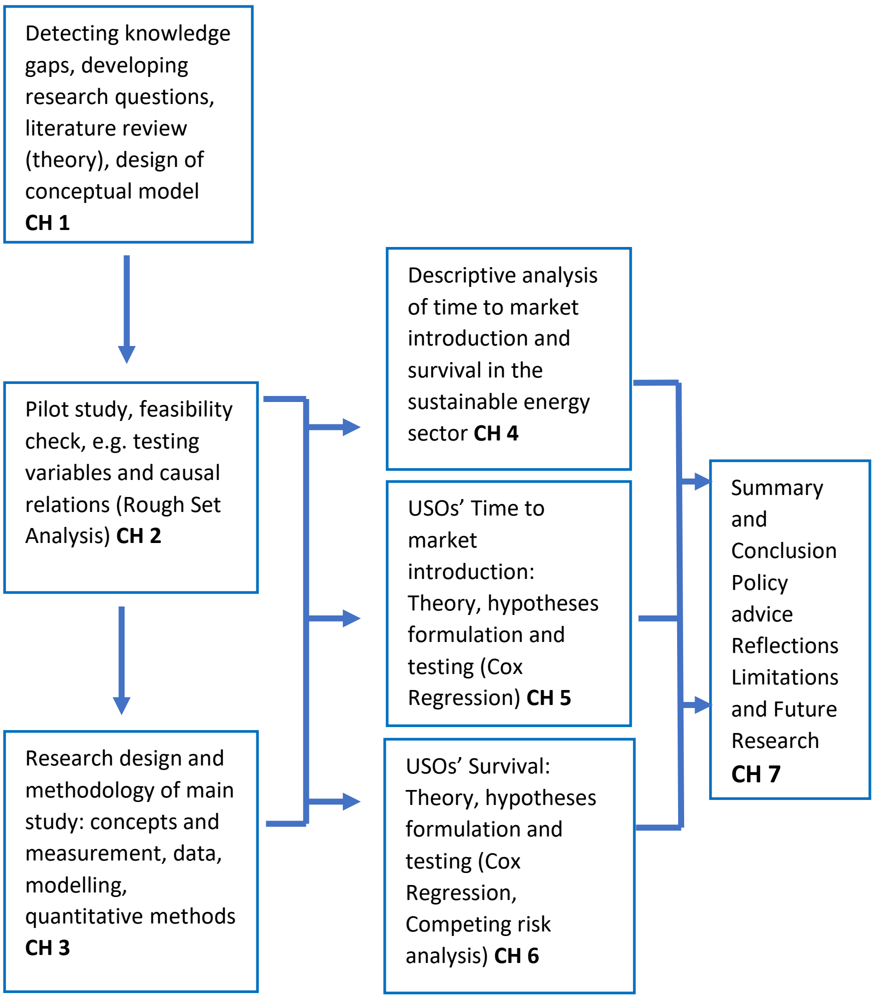
1.7 Research Structure and Outline of the Dissertation

The structure of this thesis, shown in Figure 1.3, reflects a sequential progression through its chapters. Comprising seven chapters in total, the first three chapters represent the initial phase, focusing on research development, feasibility check, and database preparation. This phase consumed a significant amount of time due to the inherent complexity of the theoretical aspects and challenges in data collection, stemming from the novelty of the study. The subsequent two chapters constitute the empirical phase which could be counted as second phase of the study benefitted from the groundwork laid in the initial phase (pilot study), involving two distinct modelling approaches. Finally, the seventh chapter encapsulates the study's outcome, presenting conclusions and suggested policies.

Key findings from this study have been shared in various conferences and two journals, with feedback encouraging an extension of the study’s focus on firm survival to enable scaling-up of innovations in the market. The overall content of each chapter will be discussed below.

Chapter 1 is the current introduction chapter providing a roadmap of the steps in the thesis. It attempts to give an overview of the motivations for the study, such as urgency and knowledge gaps, and of the aims and questions addressed in the study. This is followed by a review of theoretical perspectives on sustainable energy transition and entrepreneurship, leading to the development of the conceptual model of the study. The conceptual model consists of three main blocks, namely, entrepreneurial orientation (risk-taking/avoiding strategies), resources and capabilities of founding teams and interaction with national and local entrepreneurial ecosystem on one side, and their influence on firms' time to market and survival on the other side. Identifying connections between these important conditions and behaviours in the context of sustainable energy technologies and transition, makes the study one of the first of its kind.

Figure 1.3 Structure of the study



Chapter 2 presents the results of a pilot study using a small sample. The aim of pilot study was to check the feasibility of the study, particularly measurements of concepts (proxies) and identification of causal patterns. A detailed report on the methodology and results of the pilot study is presented in this chapter which was also published as a Journal paper (Nejabat and Van Geenhuizen, 2019). The lessons learned from the pilot study, underpins some modification of measurement of data (indicators) and also proved that identification of causal relations is possible and that such relations can be extended in the main study that follows. For example, the importance of local/regional entrepreneurial ecosystem is more strongly highlighted in the main study, thus new variables related to the type of location (metropolitan area) and the type of university as a breeding ground are added.

Chapter 3 encompasses research design and methodology of the main study, and deals with demarcation of the population of university spin-off firms, data collection and formation of the panel of sampled firms. Emphasis is put on translation of key concepts into measurable variables, among others given lessons from the pilot study. A distinction is made between observed dependent variables and latent variables. For the latent variables, in an attempt to operationalize and measure them, several sets of indicators have been designed, mainly derived from literature.

Chapter 4 leverages the advantages of having a unique and valuable database of university spin-off firms in the field of sustainable energy. It provides important insights by conducting a descriptive analysis, among others, of sustainable energy technologies in which the spin-offs are involved, and spin-offs' different dynamic patterns of market introduction and survival in detail. The latter can be illustrated with the following trends on time to market introduction. A higher likelihood of early market introduction is observed for spin-offs that are services-oriented, engage in more incremental innovation, enter established markets, have a founding team with mainly Master's-level education, originate from technical universities, and initiate collaboration with a large firm early on.

Chapter 5 provides a theoretical and empirical modelling approach to time to market introduction, examining factors that influence this strategy on the basis of formulation and testing of hypotheses. The main outcome underscores the impact of innovation strategies on the speed to market with risk-avoidance strategies leading to quicker market introductions. It reveals that radicalness of product and newness of market, as well as the business model (manufacturing or service), all play crucial role in time to market. Additionally, the significant support received from technical universities is highlighted as a contributing factor.

Chapter 6, similar to the previous chapter, provides a theoretical and an empirical modelling approach, but now to survival of the firms, including formulation and testing of hypotheses concerned. The analysis primarily employs survival analysis, distinguishing between acquired and closed firms, utilizing competing risk analysis. Beyond examining firm's resources and strategies, the analysis also explores the impact of various events in a firm's life cycle—such as market introduction, receiving investment, making formal collaborations, and hiring marketing personnel— on firm survival. The analysis indicates that while a firm's innovation strategies may not directly influence its survival, diversification in products and/or markets emerges as a crucial factor for ensuring long-lasting viability. Furthermore, the entrepreneurial ecosystem tends to be significant for the firm survival, with regard to quality of NIS and type of incubating university.

Chapter 7 discusses the concluding remarks of the partial studies conducted in this dissertation. By combining the outcomes of quantitative analyses of time to market introduction and survival of university spin-offs in sustainable energy markets in Chapter 5 and Chapter 6 with the informative results obtained from qualitative descriptive analyses of the sample in Chapter 4, a strong foundation for summarizing key findings, providing policy advice, is established in Chapter 7. The limitations of the study are also addressed in this chapter, along with suggestions for future research.

1.8 Contribution of the Study

The main contributions of the thesis can be divided into three categories: 1. contribution to theory and the literature, 2. contribution to measurement and methodology and 3. contribution to practice in using results in policy evaluation and design.

1. This dissertation contributes to the theory and literature by looking at sustainable energy transition on the micro level of firms' activities. Despite much attention to sustainable energy transition in recent years, study at the micro level of firm's characteristics and behaviour in sustainable energy market is still missing in the literature (Alkemade et al., 2011; Greco and de Jong, 2017). The firms are seen as still developing the invention (in R&D), being active either in niche level where they are protected from the market (price) and regulations while involved in experimentation and learning, or already entered the so-called regime level and are competing in the normal market structure. Either way, their activities in the market contribute to the sustainable energy transition and will potentially push it further.

   Given that sustainability transition goals, as established in Paris agreement (the UN Climate Change Conference), in many countries have yet to be achieved, the study underscores the importance of evaluating sustainable energy markets concerning the impact of policies and support on firms' behaviour. The study posits that young high-tech firms can leverage their flexibility and relative freedom from lock-in and path dependency mechanisms while compensating their vulnerability due to the liability of smallness and newness, through enhanced resource access and competence gained via collaboration with large firms and/or financial capital investment. Consequently, the study constructs a detailed database of university spin-off firms active in the sustainable energy market across four Nordic countries and the Netherlands, providing an updated and novel portrayal of the dynamics of these university spin-offs with regard to the market. This portrayal enriches the literature of university spin-offs, and in broader view also that of startups, helping university researchers to understand how policies at the university and local (municipal) levels impact university spin-offs, particularly in the field of sustainable energy. Above all, the novel results and valuable empirical insights derived from the modelling, discussed in Chapter 5 and 6, constitute the primary contribution of this thesis to the literature.

2. In terms of measurement issues, the study has experimented with measurement of several concepts in the pilot study in Chapter 2. Main examples are market introduction and time involved, entrepreneurial risk-taking, and radical innovation. One of them turns out to be *ambiguous*, and that is time to market. The intention has been to picture the years from start of R&D on the invention up to market introduction, but it turns out difficult for respondents to reconstruct this part of recent history coming with severe memory bias. This situation is also due to interpretation differences of start of R&D (could have been somewhere else at university, or in large firms; could have been a patent externally achieved, or basic research from start like in chemical engineering). Such circumstances have urged the adoption of a new measurement approach, which considers the age of the university spin-off firms from their establishment to the first sale of the associated innovative product in the market, rather than the age of the product from R&D to market launch.

   Furthermore, the originality of this dissertation lies in the use of the *Multi-stage Method* in survival analysis within the context of business studies (applied in Chapter 5 and 6). This method has been developed and wildly utilized in some medical studies (e.g. Andersen and Keiding, 2002; Meira-Machado et al., 2009) to assess the impact of timing and occurrence of one event on the timing and occurrence of the second event or survival of patients. However, to the best of our knowledge, this method has not been applied in business studies. When examining the lifespans of firms, various scenarios can naturally be envisioned where the occurrence of certain events might influence the survival of the firm. This study has investigated, among others, the impact of four distinct events on firms' survival: time to product's market launch, access to initial large investment capital, the first formal collaboration with large firms, and the hiring of the first marketing staff. Regardless of the outcomes, the application of this method stands out as a novel aspect of the study, with potential applicability in future research endeavours.

3. The practical contribution of this research encompasses detailed insights from quantitative analysis. Entrepreneurs can draw valuable lessons from findings of two empirical studies in this research: first, it was learned from the results that factors promoting faster market introduction do not necessarily translate to prolonged firm

survival. While a risk-averse approach tend to expedites market entry, highly innovative firms in the sustainable energy market demonstrate longer survival. This paradox may stem from the imperative need for promising radical innovations to achieve energy transition goals, garnering increased support from national and local authorities for prolonged survival. Strikingly, a more innovative strategy correlates with longer survival but simultaneous slower market introduction, whereas faster market introduction aligns with longer survival. Thus, firms seeking survival must strike a balance between innovative product-market strategies and faster market entry.

Furthermore, the study reaffirms the pivotal role of a supportive entrepreneurial ecosystem for young high-tech firms. While the National Innovation System (NIS) level does not accelerate time-to-market, it remains a critical factor for a firm’s survival. Contrary to expectations, being located in a metropolitan area does not have a positive effect on faster market introduction or longer survival of small energy university spin-offs. Conversely, the influence of incubating universities was confirmed to be beneficial for both faster market introduction and longer survival of university spin-offs. Policymakers can glean insights from these findings, understanding that local entrepreneurial ecosystems are influenced by the quality of the NIS and/or the quality of incubation.

Chapter 2. A Pilot Study
University Spin-Offs and Market Introduction in Northwest Europe

2.1 Introduction

This chapter reports the results of a pilot conducted as a pre-study to the main study. The aim was twofold: first, to assess the feasibility of operationalization and measurement of several key concepts (e.g. attention to accuracy and validity); and second, to determine whether several expected (causal) relationships (as derived from theory in Chapter 1) could be identified. The outcome of this pilot study includes a measurement table in which some of the initial concepts and existing indicators (proxies) have been modified and new indicators designed. Additionally, (new) understandings or assumptions regarding causal relations have been summarized.

The pilot study uses a small sample of 37 university spin-offs selected systematically from a larger data base in order to cover contrasting theoretical positions of spin-offs regarding entrepreneurial orientation, competences and interaction in entrepreneurial ecosystems. The pilot study made use of Rough Set Analysis, a non-parametric classification technique that supports in identifying causal relations (Pawlak et al., 1998; Bonikowski et al., 1998; Yao, 2015). The pilot study is published as a journal paper. (Entrepreneurial Risk-Taking in Sustainable Energy: University Spin-Off Firms and Market Introduction in Northwest Europe, Nejabat and Van Geenhuizen) The current chapter draws for large parts on the journal paper.

To explore anticipated (causal) relationships within the context of longitudinal data, the pilot study addresses several key questions. These include examining patterns of market introduction, specifically focusing on the time required for market entry. Additionally, the role of entrepreneurial orientation, firm capabilities, and interactions within entrepreneurial ecosystems, is investigated along with associated risk factors during the market introduction phase.

The chapter is structured as follows. In Section 2.2, the theoretical background of the study is briefly presented, laying the preliminary and simplified framework in Section 2.3. Subsequently, the methodology of the study is explained, encompassing data collection and the principles of rough-set analysis in Section 2.4. The results of rough-set analysis and their interpretation are discussed in Section 2.5, presenting the patterns of influence on market introduction, which include age (time) and energy technology, as well as sets of firms' behaviour and risks in market introduction. Finally, what has been learned from this feasibility study is summarized in Section 2.6, including measurement reflections, and concomitant suggestions for the main study.

2.2 Context and Theoretical Approaches

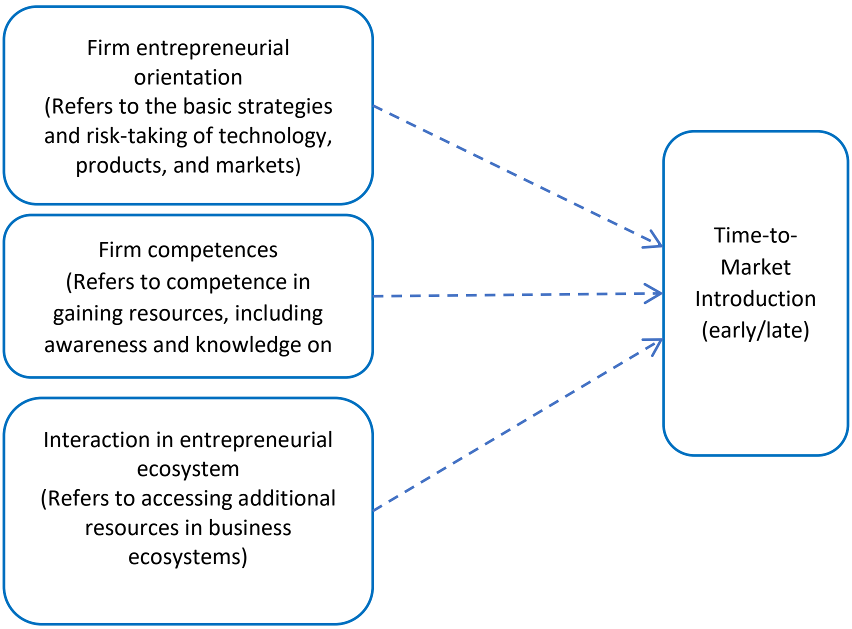
Fighting climate change, particularly in reducing greenhouse gas emissions, has emerged as a pressing concern in recent years within the European Union, among country governments, cities, universities, and businesses. This urgency is understood by various assessment reports and long-term strategic visions. Technology, both existing and emerging solutions, plays an important role, complemented by practical applications. In this context, high-tech startups are increasingly recognized as key actors in the transitional change of energy systems, as evident by the growing inclusion of such firms in (inter)national lists (e.g. Crunchbase 2019).

In principle, commercial entrepreneurship inherently involves risk-taking (Shane and Venkataraman, 2000). Entrepreneurship is surrounded with even greater risks and uncertainties when it aims to bring rapidly sustainable energy solutions to the market and to up-scale them. As highlighted in Chapter 1 (Section 1.5.1), initiating change in energy systems, particularly the substitution of fossil energy sources, requires engaging a multitude of actors—both technical and social—along with their networks and interconnections. Consequently, this involves addressing resistance to structural change or transition (Geels, 2011).

Resistance in energy transition may emanate from incumbent firms, as seen in the opposition of grid providers against decentralization, given the capability of renewable energy sources, such as wind and solar, especially the latter, to facilitate more decentralized production of energy. Additionally, resistance from consumers may arise due to a higher price, often accompanied by lower user comfort in early years. In conclusion, the market introduction of sustainability energy technologies is more complicated and necessitates greater risk-taking compared to technology without such transformative aspect. This is particularly evident in the need for a more robust mobilizing of resources through networking, with emphasis on financial resources (Leete et al., 2013; Karltorp, 2014).

The aforementioned circumstances underscore the rationale for placing distinct emphasis on varying levels of risk-taking and risks mitigating strategies within the framework of the research. As explained in Chapter 1, specifically in Sections 1.5.3 and 1.5.4, access to resources and a supportive ecosystem emerge as additional pivotal factors that facilitate the growth of startups engaged in energy transition. In alignment with insights derived from the literature review (see Section 1.5), the design of the framework for this pilot study is comprehensively detailed in Section 2.3. This approach allows for a nuanced exploration of the multifaceted challenges and opportunities associated with sustainable entrepreneurship in the dynamic landscape of energy transition.

Figure 2.1 ***Simplified Conceptual Model of the pilot study***



2.3 Research Framework

To evaluate the feasibility of detecting causal influences and operationalizing the measurement of spin-off market introduction, including the time involved in the process, the study considers the pertinent aspects of firm antecedents. This examination will specifically focus on understanding how factors such as risk-taking and access to resources, acquired within a supportive environment, influence the time needed for market introduction of sustainable energy innovation of USOs.

In line with this approach, the pilot study employs a preliminary and simplified model grounded in resource-based theory, with a particular emphasis on competence and risk-related factors. Additionally, the study takes into account the influence of the urban environment. The simplified model, along with its concepts and assumed relations, is presented in Figure 2.1.

2.4 Methodology

2.4.1 Selection of Variables and Data

A subset of 37 university spin-off firms was purposefully chosen from a larger sample of a hundred university spin off firms originating from The Netherlands, Norway, Denmark, Finland and Sweden. These spin-off firms are involved in diverse sustainable energy technologies such as solar, wind, biomass, hydro-power and new type of fuels. The rationale behind the case selection aimed to capture diversity in time to market introduction and explore various (causal) relationships, taking into account the roles within networks, different positions of firm's technology, and external conditions affecting the spin-off, such as availability of venture capital.

In line with these objectives, the pilot study aims to assess the feasibility of identifying factors (conditions) that either facilitate or hinder a rapid market introduction in sustainable energy, while also assessing their relative importance. Time towards market holds particular significance for small, new entrepreneurial firms operating in a high-tech market with advanced products and technologies. This criticality arises from the risks associated with market uncertainty, technological uncertainty, competitive volatility, and other characteristics inherent in a high-tech environment (Mohr et al., 2013). Hence, the dependent variable in this study is the time to market introduction. This is measured based on the time it takes from firm establishment to the first market introduction. In this regard, university spin-off firms that are five years old or younger and are already in the market or close to that (e.g. prototype in niche market), are classified as having a positive development and are recorded in a binary qualitative status as "Positive". University spin-off firms that are older than five years and have not progressed beyond the development stage of their innovation, are categorized as experiencing negative development, and are recorded as "Negative". As illustrated in Figure 2.1, three key concepts related to market introduction (or positive/negative development in market introduction) are identified: firm's entrepreneurial orientation, firm's competences, and interaction with the entrepreneurial ecosystem. Operationalizing and measuring these concepts involve the use of several indicators, including six indicators for firm entrepreneurial orientation, two indicators describing firm's competences, and two indicators are focusing on the firm's interaction with the entrepreneurial ecosystem. A total of nine indicators are incorporated into the rough set analysis as "condition attributes". The detailed description and categorization of these nine condition attributes are presented in Table 2.1. The table is elaborated in the text below, starting with strategies which refer to the entrepreneurial orientation regarding risk taking/avoiding in technology, product, and market.

1. *Strategy on basic or supplementary innovation*: two classes are made 1) innovation of main products and 2) innovation of supplementary products or services (exemplified by new types of high-efficient solar cells and improved equipment to repair solar cells/panels, respectively). These classes indicate differences in contribution to transition of the new product and also amount of risk-taking.
2. *Strategy on type of energy technology*: the sampled firms are active in several different technologies, which vary in strength of risks and uncertainty involved. The classes that are identified are two well developed and accepted ones, namely 1) solar, and 2) wind. This alongside 3) automotive/ electrical vehicle and 4) other sustainable energy.
3. *Innovation strategy:* This indicator reflects the firms' eagerness and speed in dealing with challenges but also risks/uncertainties in developing innovations. The degree of product novelty is directly related to technology uncertainty and uncertainty in the market. In a simplified way, two classes are distinguished: first mover and followers. Although being first mover is accompanied by more uncertainty and risks, it also gives some advantages such as high revenue, and participating in setting the rules and standards (Mohr et al., 2013).
4. *Diversification strategy (product/market)*: This indicator reflects potential diversity and richness in firm's market and technology (and risk-mitigation); the distinguished classes are a focus strategy and a diversified strategy.

The firm cognitive resources are addressed by competences or skills owned by founders, through education and/or prestart experience, but also as gained externally and accessed through networks. Three indicators are considered as follows.

1. *Marketing skills*: Marketing skills of founders is measured by taking pre-start commercial experiences into account. The indicator comes with two classes: with business experience and without business experience.
2. *Technical skills*: Technical skills of founders is evaluated by taking depth of their technical education into account, as indicated by two classes of highest degree: Master or also PhD.
3. *Networks providing skills*: This indicator reflects size and potential diversity of firm's network and considers the multiplicity (and richness) of networks to acquire external competences. It refers to collaboration with actors involved in the market or technology, like large companies, government, universities, and customers, and is categorized in two classes: multiple networks and not multiple (simple) networks.

External circumstances may affect the firms' speed towards market through interaction with the entrepreneurial ecosystem of their location. Two partial indicators have been chosen, namely, access to investment capital, which is in early years often local or regional, and strength of the National Innovation System which may boost or hinder firms' performance towards the market. These indicators are as follows:

1. *Access to investment capital*: This indicator reflects a more or less supportive entrepreneurial ecosystem, and is measured in two classes, namely, having received substantial investment capital and absence of this.
2. *Countries' National Innovation System*: Three classes are distinguished based on differences in scores of the countries involved in the past years. 1) *Innovation leaders* are Denmark, Finland and Sweden, witnessing relatively high scores, 2) *Innovation followers* with The Netherlands witnessing somewhat lower scores, and 3) *Moderate follower* with Norway being somewhat behind (Innovation Union Scoreboard, 2015).

Including the dependent variable of *Market Introduction Speed*, Table 2.1 gives a list of 10 indicators used in measurement of the model variables (condition and decision attributes), and descriptive statistics. Note that the percentage shares do not indicate statistical representativeness, as the sample has been composed to include important 'theoretical' positions of USOs.

Table 2.1 ***Indicators and share of classes in the sample***

Indicators	**Measurement and shares (in sample)**
Firm entrepreneurial orientation (risk taking/avoiding)	
Strategy on innovation relevance (basic/ supplementary)	Main relevance (basic in energy innovation): 65% Supplementary product/services: 35%
Strategy on type of energy technology	Solar PV: 32% Wind: 21% Automotive: 18% Remaining sustainable energy: 29%
Innovation strategy	First mover in innovation: 35% Follower: 65%
Diversification strategy (product/market)	Focus: 74% Diversification: 26%
Firm's competences	
Marketing skills of founders	With business experience: 56% Without business experience: 44%
Technical skills of founders	PhD: 70% Master: 30%
Networks providing skills	Multiple: 53% Not multiple: 47%
Firm interaction with entrepreneurial ecosystem	
Access to investment capital	No: 59% Yes: 41%
Countries (2015)	Finland, Denmark, Sweden (Innovation leader): 38% Netherlands (Innovation follower): 41% Norway (Moderate innovator): 21%
Decision attribute (Dependent variable)	
Market Introduction Speed	Positive: 59% Negative: 41%

2.4.2 Rough Set Analysis

Rough set analysis (Pawlak, 1991) is applied in this pilot study to identify (causal) relationships in the sample. The method is often used to discover structural relationships within imprecise, small set or noisy data, contrary to crisp (precise) data. Rough set theory was introduced by Pawlak in the 1980s based on the initial assumption that with every object of the universe of discourse, we associate some information (Pawlak and Skowron, 2007). It is a methodology of data mining or knowledge discovery in relational databases and is extensively used for pattern recognition in revealing potential regularities.

Most of the data in this pilot study is qualitative, featuring somewhat ambiguous boundaries between categories, thus, the utilization of rough set analysis, as a non-parametric method, aligns well with this pilot study. Unlike conventional regression analysis, rough set analysis does not assume a normal distribution of the data, and it doesn't rely on linear or cumulative modes of thinking. Other advantages that make rough set analysis appropriate for the pilot study include several key factors. Firstly, the analysis allows for the elimination of redundant variables, facilitating a focus on minimal subsets of variables crucial for the time of market introduction. This capability enables the construction of a preliminary model and assumptions based on these essential variables (Chen, 2009). Secondly, the analysis yields result in the form of a set of easily understandable rules. Finally, these rules are derived from the *learning experience* inherent in the method and are well-supported by a set of real-life examples, a process that strengthens the argumentation for causal relations.

While a comprehensive grasp of rough set theory necessitates delving into seminal works within the field (e.g., Pawlak, 1991; Pawlak, 1998; Bonikowski et al., 1998; Yao, 2003, Yao, 2015), this method is introduced here by elucidating four key concepts of rough set (RS) theory and its application within the pilot study.

a) ***Information table***. In RS theory, data are presented in an information table (S), which is represented as follows: $S = (U,\text{A},V,D)$ where U represents a universe with a finite set of N objects $\{x1,\ x2,...,\ xn\}$, A is a finite set of N attributes $\{a1, a2, \ldots, an\}$, V is the value of attribute a in an information table, and D is the decision function.

In this study, U is represented by sets of 37 university spin-off firms. The nine condition attributes $\{a1, a2, a3, a4, a5, a6, a7, a8, a9\}$ used in this study are described in Table 2.1: Value creation of technology, Type of energy technologies, Network structure, Innovation strategy, Diversification, Market(ing) skills of founders, Technical skills (depth) of founders, Access to investment capital, and Countries' NIS quality. These indicators represent the independent variables and are expected to have influence on the speed of market introduction. Time-to-market introduction is the decision attribute, or the dependent variable recorded in a binary qualitative status of "Positive or Negative".

Rough set analysis works with a so-called Information Table. In this study, the Information table gives an overview, including the 37 university spin-off firms ('objects'), nine condition attributes and one decision attribute. Rows of the table correspond to the 'objects' of university spin-off firms and columns to attributes which refer to characteristics of the objects.

Table 2.2 ***Information table of the study including 37 objects, 9 condition attributes, 1 decision attribute***

USOs (U)	Innov. Relevance ($a1$)	Energy type ($a2$)	Network structure ($a3$)	Innovation strategy ($a4$)	Diversification ($a5$)	Marketing skills ($a6$)	Technical skills ($a7$)	Capital inv. ($a8$)	Country's NIS ($a9$)	Time to market (D)
USO1	Supplemt.	Solar	Multiple	First.M.	Diversified	No	Master	Yes	Nor/NL	Positive
USO2	Main	Wind	Multiple	Follow	Focus	Yes	PhD	No	D/F/S	Positive
USO3	Main	Solar	Multiple	Follow	Focus	No	PhD	Yes	Nor/NL	Negative
USO4	Supplemt.	Car	Not Multiple	Follow	Focus	Yes	PhD	No	D/F/S	Positive
.	.	.	.	.	.	.	.	.		.
.		.	.	.	.	.	.	.		.
.		.	.		.	.	.	.		.
USO37	.Main	Othe	Not Multiple	Follow	Diversified	No	Master	No	D/F/S	Negative

b) Indiscernibility of objects; Indiscernibility is the main concept of RS theory which refers to the similarities among different objects. The objects in this study refer to the university spin-off firms. It means that university spin-off firm characteristics listed in the Table 2.1 as condition attributes are indiscernible when they have same value of conditions. If the university spin-off firm number x and y have similar condition attribute sets of A, this indicates that there exists an indiscernibility among object x and y with regard to A. Indiscernibility is denoted by $IND(A)$ and is described as follows.

$$IND(A) = \{(x,y) | (x,y) \in U^2, \forall a \in (a(x) = a(y))\} \tag{1}$$

This indiscernibility relation, $IND(A)$, splits the given set of USOs into a family of equivalence classes $\{X1, X2, X3, \ldots, Xr\}$, called elementary sets. However, it is possible that all condition attributes for two or more university spin-offs be the same but the decision attribute be different. That is why the concept of upper and lower approximation is important as well (Greco et al., 2001; Pawlak and Skowron, 2007).

c) Set approximation: university spin-off firms in elementary sets are those that can be clearly distinguished based on condition attributes, defining them as belonging to a concept X. However, certain subsets of university spin-offs lack distinguishability in terms of the available attributes, making only rough definitions possible. The essence of rough set theory involves approximating a set using a pair of sets known as the lower approximation and upper approximation of set X. The rough set is then constructed from these two sets, dealing with inconsistencies by providing both lower and upper approximations of the target subsets.

Mathematically expressed, if $B \subseteq C$ is a set of condition attributes and $X \subseteq U$ is a set of university spin-off firms, then the sets $\{x \in U: [\llbracket x] \rrbracket\_B \subseteq X\}$ and $\{x \in U: [\llbracket x] \rrbracket\_B \cap X \neq \emptyset\}$ are called B-lower approximation of X (definitely belonging to X) and B-upper approximation of X (definitely and possibly belonging to X). The lower approximation contains positive speed university spin-off firms that are definitely in the set of positive speed group. The remaining university spin-off firms are either definitely not in the set of positive speed, or their rough membership is unknown. The area of uncertainty (or boundary region) represents the set of university spin-off firms that have the same condition attributes but a different decision attribute.

d) Decision rules induction*;* Decision rules can be obtained using rough set based inductive learning to analyse the conditions influencing time to market introduction. A decision rule comes in a simple statement such as ''if condition attributes $a7$ is considered Master and condition attributes $a8$ is considered Yes then the overall evaluation of time to market introduction is positive.'' Each rule is also associated with its absolute strength, defined as the number of university spin-off firms of the data set that share the same decision attributes.

Following the explanations of the core concepts of rough set analysis, the subsequent section will delve into the detailed explanation of the analysis results.

2.5 Discussion of the Results

The analysis utilized the Rough Set data explorer (ROSE2) system developed by Predki et al. (1998). Preliminary to executing the complete rough-set analysis procedure, a set of tests was conducted, revealing consistently robust analysis outcomes. The results of these tests are detailed in Appendices 2.1.

Table 2.3 presents the eight (8) strongest decision rules generated through rough set data mining using the ROSE2 software. The selection of these rules is based on their significant importance, as indicated by strength and coverage. The strength of a decision rule signifies the proportion of all university spin-off firms exhibiting the same combination of condition attributes and decision attribute among all university spin-off firms with the same value of the decision attribute. Rough-set analysis operates through AI learning in multiple iterations, during which the optimum number of rules becomes evident —a delicate balance between providing useful detail and avoiding redundant information. The majority of rules are comprised of combinations of specific scores on particular indicators, typically involving two or three.

The results outlined in Table 2.3 reveal that the highest strength achieved was 50 percent, with a corresponding coverage of 11 (representing the absolute number of spin-offs involved). To enhance credibility, rules with less than 15 percent strength or coverage lower than three spin-off firms were excluded from the result table (rules 6 and 7). It is worth noting that the selected procedure permits rules that may partially overlap. The interpretation of the main rules will be explained in the next subsection.

Table 2.3 ***Strongest Decision rules***

	Rules	Decision	Coverag e	Strength %
	Positive market introduction time			
1	Country's NIS (DK/FI/SE) & Networks (Multiple)	Positive	11	50
2	Technical skill (Master) & Capital Investment (Yes)	Positive	7	31.8
3	Energy technology (Wind) & Innovation strategy (Follower)	Positive	6	27.3
4	Type of energy technology (Automotive) & Networks (Multiple)	Positive	5	22.7
5	Energy technology (remaining) & Country's NIS (DK/FI/SE)	Positive	4	18.2
Negative market introduction time				
8	Energy technology (Solar) & Networks (not multiple) & Innovation strategy (Follower)	Negative	7	46.7
9	Country's NIS (Norway) & Diversification (Focus) & Technical skill (PhD)	Negative	4	26.7
10	Energy technology (remaining & Country's NIS (NL) & Innovation relevance (Main)	Negative	3	20

2.5.1 Interpretation of main Rules

As anticipated from the core determination results (see Appendix 2.1, Table 2.6), the type of energy technology, country's NIS (quality of National Innovation System), and networks (multiplicity) emerged more frequently than other factors in the outcomes. Specifically, they appear 5, 4, and 3 times, respectively, in the obtained credible rules. The following discussion focuses on the strongest four rules outlined in Table 2.3, starting with a positive development.

- Rule 1 indicates that the combination of operating in an Innovation Leader country (Denmark, Finland, or Sweden) and employing multiple networks in gaining competences (skills) makes a positive development towards the market very likely, at a strength of 50.0 percent. It points to a combined positive influence of the entrepreneurial ecosystem, regarding favourable national institutions and policy support together with USOs employing of rich (multiple) networks.
- Similar, but weaker (at a strength of 31.8 percent), Rule 2 indicates that the combination of mainly a Master's level as the highest education of founders and gaining substantial investment capital, makes a positive development to market likely. This result suggests that a more practical and less in-depth academic/scientific orientation tends to be an advantage.

- Somewhat weaker (at 27.3 percent), Rule 3 indicates that the combination of wind energy technology and being a follower in the market makes a positive development likely. The rule points to a positive impact from taking smaller risks as a follower in an already more or less established market.
- Likewise (at 22.7 percent), Rule 4 indicates that the combination of automotive fuel technology and being active in developing multiple networks makes a positive development likely. This rule puts an emphasis on the benefits of multiple networks in a situation of potential resistance from established automotive technology.

Understanding the rise of negative development towards the market is more complicated, as the rules exhibit somewhat smaller strength and are often combinations of three condition attributes, rather than two. The two most robust rules, both with a strength of more than 25 percent (Rules 8 and 9), are as follows:

- Regarding Rule 8, the combination of Solar PV technology, a single collaboration network (only with one partner, either university or industry or government and so on), and acting as follower, makes a problematic development likely, at a strength of 46.7 percent. It suggests that despite taking smaller risks (as follower), multiple network collaboration is required in bringing solar energy solutions to market, also referring to competition from large Chinese solar cell producers active in Europe at a relatively low customer price (Van Geenhuizen and Ye, 2018).
- Rule 9 is less strong (at 26.7 percent) and indicates that spin-offs in Norway, with a strong focus and high scientific skills (PhD) are likely to develop in a problematic way. This rule suggests problematic risks in maintaining scientific orientation, instead of market orientation. Such spin-off firms may face the 'valley of death' or they may have gained substantial investment capital in time, however, at a too short refunding period.

The validation of rules was checked and proved by so-called K-fold cross validation technique (Chen, 2009). More detail about this validation technique and the results are presented in Appendix 2.2. In the next part, the lessons learned from the pilot study will be discussed.

2.6 Conclusion and Lessons learned.

The twofold aim of the pilot study, specifically, investigating the feasibility of identifying meaningful relationships—such as those between spin-off firms' entrepreneurial orientation in risk taking/mitigating, their competences, their interaction, and time to market introduction—and evaluating the quality of measurements of key concepts in a longitudinal approach, has yielded valuable insights. These findings have instilled sufficient confidence to proceed with the broader research endeavour.

Regarding the first aim of the pilot study, to identify strong causal trends in relationships, as revealed by Rough Set Analysis, can be summarized as follows. Energy technology, characterized by its risk-taking nature, prominently features in rules pertaining to both positive and negative developments. Furthermore, the entrepreneurial ecosystem demonstrates a substantial influence in which it shows positive development in countries with higher degree of NIS and negative speed of development in countries with lower degree of NIS. Conversely, a negative development on the road to market happens more often in combination with negatively working risk-related strategic choices, such as a focus on basic innovation in new energy technologies.

In summary, the results convincingly suggest that relationships between speed to market and firms' entrepreneurial orientation, firms' competences, and the utilization of firms' entrepreneurial ecosystems do exist in both positive and negative directions, with discernible differences in strength.

Concerning the second aim of the study, which was to explore operationalization and measurement issues (e.g., coverage, accuracy, and validity), several valuable lessons were learned, guiding the refinement of the considered measurements for the main study. The lessons are summarized in bullet points below and in Table 2.4.

- *Strategy on relevance (value creation) of technology* is found to be not recognizable in an accurate way by respondents. This due to different perspectives on what technically core inventions and side (or supplementary) applications are (including respective risks) and to different roles in the distinguished energy technology systems. For the main analysis in next chapters, importance (and risks) are now operationalized by the business model in service or manufacturing, as well as whether the inventions are more or less radical.
- *Strategy on type of energy technology* showed to be very important because of the different amount of risks involved in new energy sources and their use. In the main study, this variable is replaced with newness of market which represents exactly the main risks involved in new energy technology.
- *Innovation strategy* was considered as addressing the position of first mover versus follower in the market. This division into two faced some specific measurement issues, namely difficult to determine by respondents (differences and nuances not sufficiently clear). This situation follows from using diverse spatial (global) context of qualification (reference) and different level of detail in perceiving the technology invention. It is replaced with radicalness of product innovation in the main study, which is easier to determine.
- *Networks (structure)* was broadly measured using the categories of poor-single network or multiple networks. The distinction was, however, difficult to make in practice due to virtual absence of single networks (one actor). Network importance is now refined by turning towards the timing, and accordingly the time of first important collaboration is considered in the main study. The same holds for access to investment capital, of which timing is added.

- Referring to the concept of *entrepreneurial ecosystem*, the complexity involved requires a selection of indicators. Using access to investment capital and quality of the national level NIS, is not sufficient. For example, absence of access to investment capital due to self-investment of USOs as alternative, is not measured as a positive situation. In addition, the NIS is not necessarily fully present at local levels. At the end of the pilot study a new idea emerged about roles of local authorities and facilities in larger cities regarding creation of a supportive startup environment. This has led to adding of two new indicators in the main study that consider the effect of quality of urban ecosystems (benefits in metropolitan area) and, more specifically, the university ecosystem (see below under type of university).
- With regard *to Countries' NIS*, the following change is introduced. Considering slightly different scores on NIS quality regarding sustainable energy and young high-tech firms, the decision was made to merge the country's NIS into two groups for the main study. The Netherlands and Norway form one group, while the other three countries (Denmark, Finland, Sweden) constitute another group due to their comparable NIS quality. The Netherlands and Norway experienced several years of relatively weak NIS support, attributed to a strong focus on fossil fuels and scored lower than the other three countries. This reclassification also aims to achieve a more balanced frequency distribution of spin-offs.
- Being located in a *university incubator (or university faculty lab)* was among the preliminary indicators in the pilot study, representing specific effects of ecosystem support. However, it was removed from the pilot study because most university spin-off firms have been incubated for a few years, without sufficient difference. Instead, the *type of university*, specifically whether it originates from a technical university or a more general university, has been included as an indicator to explore the impact of the entrepreneurial environment on university spin-off firms.
- In addition, we decided to consider the effect of the *period* of spin-off establishment. This decision was made to address the previously overlooked impact of macroeconomic conditions on the performance of small firms. Consequently, the economic crisis of 2008 was included in the main study, and firms operating during this crisis were compared with those established outside this period.
- And finally, it is difficult to measure *time-to-market introduction* in an equivocal way, causing serious issues of validity. Principally, such measurement is meant to determine the duration from the decision to develop the invention into a marketable product to actual introduction to the market. Such knowledge is important if acceleration of the transition is necessary, like in sustainable energy matter and climate change. However, non-response may occur due to a changed (or mixed) organizational context of knowledge transfer, e.g. from university and large firm to spin-off firm. Memory-bias may also occur, namely due to 'positive self-image' of founders, or simply a weak memory on such matter among scientists. Time of patent application is sometimes forwarded as an alternative. However,

patent application may come with delay, due to strategic and time-intensive issues in clarifying (in a legal sense) the sharing of ownership between different persons and organizations. In addition, time of patenting could be far removed from market introduction, dependent on whether the patented product is a fundamental invention (far from the market) or a practical new product ready for use. Also, patents do not work for most services and incremental innovations. An alternative is to focus on development time in entrepreneurial context, starting with time of firm establishment, and this is what we adopted in the pilot study and will adopt in the main study.

Another lesson learned is that there are different approaches to what actual *market introduction* is and how to measure. Market introduction may be a process instead of a single event in time (Mohr et al., 2013). This follows from increased popularity of having new inventions launched by a large firm or other large organization. Similarly, the relatively new strategy of co-development (co-creation) with customers points to market introduction as a process and pre-market involvement of customers. Such strategies may take some time, reason why in the main study, time of market introduction is taken as the year in which the product/service is brought to market as a solid strategy decision (and not a long-term trial or merely starting collaborative design).

Table 2.4 Refinement of indicators and measurements after pilot study

Indicators	Learnings from pilot study	Use in main study
Technologies and strategies of USOs		
Strategies as an indicator of importance (radicalness) of technology used	Relevant measurement issue. Reason: the differentiation is not sufficiently clear for respondents because of different perspectives on technically basic and side applications, and different roles (radicalness) of new technology	Deleted and replaced by rough indicator of type of business model, i.e. manufacturing-oriented versus services, as well as innovation radicalness: radical versus incremental innovation
Strategies on type of energy technology	No measurement issues, but concomitant risks can be better measured by newness of markets involved.	Replaced by: Newness of market
Innovation strategy at start (first mover/follower)	Measurement issue. The differentiation is not sufficiently clear as it depends on level of detail in perceiving the technology	Deleted and replaced by more nuanced indicator: as Innovation radicalness
Diversification (at start or in early years)	No measurement issue (often correctly self-reported and easily checked)	Maintained
Related to founders' capabilities/resources, and networks		
Market skills of founders at start (pre-start experience)	No measurement issue (often correctly self-reported and easily checked)	Maintained
Technical skills level of founders at start (pre-start education)	No measurement issue (idem)	Maintained
Network structure's multiplicity (multiple versus single) as indicator of external competences/skills achieving (richness)	Relevant measurement issue. Shift in emphasis on importance to *timing* of the network establishment and type of actors involved.	Added: new emphasis using external resources involved: - time of collaboration with large firm/organization, time of access to substantial financial investment, and early marketing person in the team
Entrepreneurial Ecosystem conditions		
Access to substantial investment capital in early years	No measurement issues (often correctly self-reported; also often mentioned by venture consortium in annual report or otherwise in media)	Added and made more specific: timing of receiving first substantial investment (see above for other networking)

Countries' NIS	No measurement issue, as NIS measurement is available during observation period. Overall, NL improved very recently. Further, NIS is too broad to distinguish between quality of local ecosystems	Regardless of slight difference, Norway and NL are merged in one category for the whole period. However, attention is given in interpretation of outcomes to recent change concerning NL. Added: Metropolitan character of local ecosystem
Metropolitan character of location University ecosystem	Not used	Added, as these are more comprehensive for characterization of the local situation.
Period of firm establishment	Not used	Added, due to potential influence of economic downturn.
Decision attribute (dependent variable)		
Time to market introduction (age)	Measurement Issue: The year in which serious R&D started at university or in a (large) firm should count but is often not exactly known.	By taking firm establishment year as the baseline, emphasis is put on time used in *entrepreneurial context* for development towards market introduction.

Appendixes

Appendix 2.1

As a result of experimentation and also of checking the robustness, the number of classes per variable was mostly reduced to two (binary variables). It is important to have a right balance between classification power and detail that is redundant, particularly for the decision attribute. Market introduction is measured based on having first sale or not, and to classify it as positive or negative (also considering the firms' age at first sale). For firms faced with a somewhat vague borderline between last testing and customer market by using launching customers, the year of main launching customer activity as indicated by the firms is taken. Overall, the first result obtained in Rough Set Analysis of the coded information table is the approximation of the decision classes and the quality of classification. Table 2.5 shows that quality of classification and the accuracy of two classes equal 1.00 (including almost all objects) which means the doubtful region is empty and variables (attributes) provide satisfactory discrimination between the classes.

Table 2.5 ***Approximations of the decision classes***

Classes	#Objects	Lower approximation	Upper approximation	Accuracy
Positive	20	20	20	1.00
Negative	14	14	14	1.00

The next step in the analysis is determination of core attributes. The core in rough-set analysis indicates the certain condition attributes that are necessary to explain a feature of the decision attribute. The outcome of the analysis shows three core attributes, i.e. Type of energy technology, National Innovation System (NIS) of the countries, and multiplicity of university spin-off firms networks. The quality of classification for attributes in the core in this study equals 0.84 which is acceptable. Also, the overall quality of classification and the accuracy of two classes equal 1.0 (Table 2.6).

Table 2.6 ***Quality indicators of the rough-set procedure***

Quality of classification for	
All condition attributes	1.00
Condition attributes in the core (3 attributes)	0.84
Quality of classification (two classes)	
Accuracy of approximation of positive outcome	1.00
Accuracy of approximation of negative outcome	1.00

Appendix 2.2

Validation of the obtained rules was achieved by using by k-fold cross validation technique, where k is fixed to be 10. K-fold cross validation is a technique to evaluate predictive models by randomly partitioning the sample into K subsamples in which one of them plays as validation set for testing the model and the rest of $K-1$ subsamples are put together to form a training set. The K-fold cross validation process is repeated K times in a round until each of the K subsamples be used one time as a validation set and $K-1$ times in training sets. The result of K-fold cross validation is the average of all rounds (Chen, 2009). Table 2.7 shows the evaluation results derived by ROSE2. The overall result of 70.0 percent plus/minus 33.9 indicates a sufficient accuracy of the obtained rules.

Table 2.7 ***Validation of the rules***

Average Accuracy %	Correct	Incorrect	None
Total	70.00 ± 33.99	20.83 ± 23.35	9.17 ± 14.17
Positive	68.33 ± 41.13	23.33 ± 39.58	8.33 ± 17.08
Negative	61.67 ± 43.49	18.33 ± 32.02	10 ± 30

Chapter 3. Research Design and Methodology

3.1 Introduction

To conduct an empirical analysis of time to market introduction and survival of university spin-off firms in sustainable energy within specific countries, the study follows two essential steps. First, it establishes a representative sample of university spin-off firms from the countries under study. Second, the most suitable quantitative methods of analysis are chosen based on the study's conceptual framework, as outlined in Chapter 1 (see Figures 1.2 and 1.3). This chapter explains the sampling process, data collection procedures, variables, measurements, and the methods of analysis used in the study.

Chapter 3 unfolds as follows. Section 3.2 is dedicated to the collection and characteristics of the longitudinal sample used throughout this thesis. As data were not readily available, multiple sources such as in-person interviews, telephone and email interviews, and spin-offs' and branch organizations' websites and publications were used. Next, Section 3.3 discusses the variables in the study along with their measurements. Specific attention is paid to latent variables and their translation into indicators, as well as the validity of measurement. With regard to selection of the appropriate quantitative methods of analysis, Section 3.4 explains the overall concepts of survival analysis, and theory and mathematics behind the Kaplan-Meier estimator, Cox proportional regression model, and Competing risk regression. However, the methods are also briefly discussed in the context of their use in the empirical part of the study, namely Chapters 4, 5, and 6, respectively. The present chapter will proceed with the research design of the study in Section 3.5. Section 3.6 concludes the chapter by providing a short summary of the matter and methods addressed.

3.2 Population, Sample, and Data Collection

To obtain the relevant data for this empirical research, the study population is first defined based on the criteria discussed in Section 3.2.1. The required data, for the present study, were not readily available, and as a result, a sample has been composed, as representative as possible, and a variety of data collection methods has been utilized. This section discusses the characteristics of the population, sample and the methods used in data collection and formation of a longitudinal panel.

3.2.1 Population and Sample

The present study focuses on the role of university spin-off firms in the sustainable energy sector. A large group of startup firms was investigated and to be included in the sample under study, the startups firms on had to meet three criteria:

1. *Origin*: The startups must be university spin-off firms to be included. University spin-off firms in this study refers to independent firms established based on research activities conducted within the university with the aim to bring them to market (Pirnay et al., 2003).
2. *Technology:* University spin-off firms must be working on sustainable energy technologies in a broad sense, to be included. The technologies (or fields) are hydro-energy, wind, solar, bio-based energy, electric vehicles, battery storage, more sustainable fossil fuel extraction, and increased energy efficiency in use. A small number of university spin-off firms connects with hydrogen and with sea-based wave technology, as these technologies just emerged during the study period.
3. *Time and place of foundation:* The study includes university spin-off firms established between 1998 and 2014 and engaged in sustainable energy technology in the Netherlands, Finland, Sweden, Denmark, and Norway. The Nordic countries were selected because they are all undergoing an energy transition and have favourable small firm and innovation conditions, which enable observing the market introduction and long-term survival of young university spin-offs. Note that two countries have shown some less favourable conditions in particular years, as a result of heavy reliance on fossil fuels and risk-avoiding business culture, namely, Norway and the Netherlands (Innovation Union Scoreboard, 2015).

As there are no comprehensive lists of sustainable energy university spin-off firms per country, it is necessary to rely on several different sources. First, we investigated the websites of all universities in the countries under study, while focussing on faculties related to sustainable energy, like material science, electrical and mechanical engineering, and architecture. Many university websites provided lists of such spin-offs, which then needed to be checked for technology relevance. Next, the lists of startups collected by branch organizations and branch journals focused on sustainable energy, such as Nordic Green, were screened for being university spin-off firms. Also, venture capital consortia (mainly Nordic countries) published lists of their investments in high-tech startups, among others spin-off firms in sustainable energy. In addition, in some cases, experts and other founders informed us about some hidden university spin-offs (snow-ball procedure). In total, 106 university spin-offs could be identified that met the three above-mentioned criteria.

After this structured search, it can be claimed that the unique database covers a majority of university spin-off firms in sustainable energy technology established between 1998 and 2014 in the five countries under study. However, it should be noted that any university spin-off firms established after 1998 and closed before end of building the data base, without leaving a visible trace (documents), may have been neglected. Altogether, on the basis of educated guess, a share of 65 to 70 percent of the population is covered by the sample.

3.2.2 Methods of Data Collection

The data collection process, which aimed to reconstruct the spin-off firms' past development, commenced in 2013 and continued until late 2018. The goal was to produce longitudinal data covering the period from 1998, which was the earliest year of firm foundation, up to late 2018. The ultimate objective of the data collection was to explore the influence of several factors on the firms' development over time, regarding time to market and survival. As an advantage, the study had access to existing interviews which were conducted for other and similar purposes in previous years and needed to be updated through the existing channels. Accordingly, the study was granted access and use of the available database collected by Soetanto and Taheri (Taheri, 2013), which contained information related to university spin-offs from the technical universities in Delft (NL) and Trondheim (Norway). The available interview data provided an adequate starting point for the process of data collection.

The main step in data collection of the current study involved self-reported data using a standard questionnaire[2] send via email to the founder or co-founder of each firm. After a reminder, one week later, only approximately 10 percent of the responses were received. To address the remaining gaps in the data, a telephone interview was performed, which proved to be successful. Among the remaining firms, about 73 percent were reached by phone and were willing to answer clear and specific questions about their firms during a brief conversation. To supplement the data collection, desk research was conducted using a variety of sources, including the firms' websites, investment consortia websites, specialized journals such as Nordic Green, and national sector (policy) reports on sustainable energy like lists of top energy start-ups. And finally, to ensure the validity of the data, the researchers performed

[2] Before the data from the questionnaires and interviews was used in this study, we asked for consent by the respondent to use their data to report it at the aggregate level for this study. We ensured that the results in this study cannot lead back to individual firms. In this respect, we followed the Data Management Plan procedures of TU Delft.

extensive cross-validation and checks to identify any inconsistencies or errors in the data, e.g. due to self-reporting. The collected data were used to construct a longitudinal panel.

In the next section, the panel is described showing how it was formed by looking forwards and backwards to the firms' life events and development.

3.2.3 Longitudinal Study and Panel Data

To capture the dynamics of a firm's characteristics and performance over the observation period 1998-2018, a longitudinal study utilizing panel data was designed. A longitudinal study is a type of picturing dynamics of changes which is conducted over an extended period, during which researchers collect data from the same subjects over time to identify the changes (Elliott et al., 2008; Lynn, 2009; Hsiao, 2022). This characteristic distinguishes a longitudinal study from other types of research, as it provides a comprehensive view of changes on the micro-level in a given population over time rather than offering a single snapshot at a specific moment (cross-sectional). While the primary advantage of longitudinal studies lies in their ability to uncover existing trends and relationships in real-time, a significant drawback is the substantial time investment by researchers, resulting in higher costs. The extended duration also increases the risk of researchers or sampled firms being lost for various reasons, potentially leaving the study incomplete (Caruana et al., 2015). Nevertheless, if the longitudinal study proves successful and is completed, it cumulatively creates a unique and valuable database, which is the first outcome of the current research regardless of the specific results obtained.

Panel data, which is a data type used in longitudinal studies, involve repeated observations of the same entities (firms) over time with respect to specific characteristics (Lynn, 2009). In this study, the panel is structured in a rectangular format, where each row represents a firm, and each column represents a variable measured at different points in time. Firms were included in the panel in the year they were established, and they have been observed annually until 2018. Multiple observations were taken because some factors are time-dependent and change over time. For example, firms may enter the market or make their first collaboration at any time during the observation period. University spin-off firms that closed during the observation period were excluded from the panel in the years following closure, while those that remained functioning until the end of 2018 were retained in the data panel. In this way, panel data records the time-ordering of events and thus it is possible to investigate how an event changes the outcomes.

The observation period is from 1998 to 2018, however, the observation period for each individual firm in this study, varies significantly for each firm. It starts from university spin-off firm's establishment until occurrence of the event under study: either market introduction or firm's closure. Figure 3.1 visually depicts the diversity in observation periods for each firm, as well as the overall characteristics of an open panel: on the left side open due to different time of being established after 1998, and on the right side open due to firms' closure that may take place prior to end of the observation time in 2018.

Furthermore, there are some situations in which another, earlier, event may substantially impact the risk of a primary event under study. In such cases, the earlier event is termed an intermediate event, and the analysis is done using multi-state models (Putter et al., 2007). A multi-state model extends time-to-event analysis by evaluating the outcome of the final event following the occurrence or non-occurrence of an intermediate event. This thesis considers several intermediate events, such as the impact of time to market introduction on a firm's longer survival. The hypothesis involved (Chapter 6, Hypothesis 6.7) is based on the assumption that a faster (early) market introduction reduces the likelihood of firm closure. However, such assumed relationships introduce some complexities.

Figure 3.1 Observation time for individual university spin-offs and multi-state events

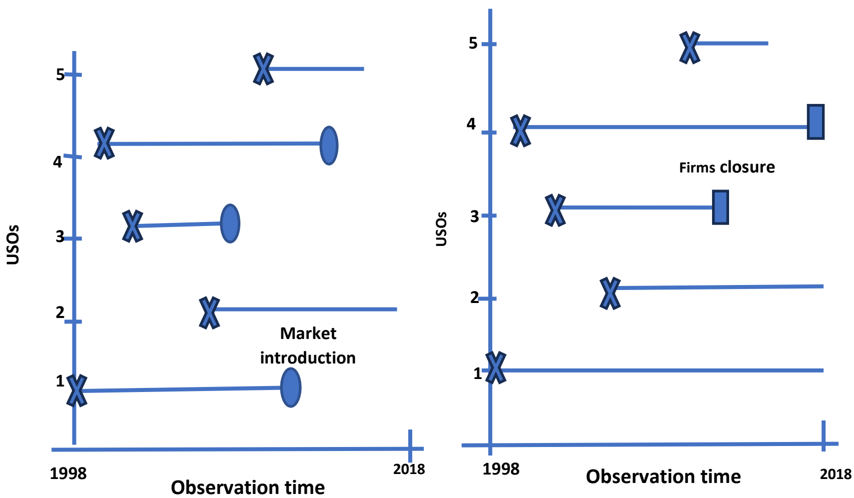


Figure A: Time to occurrence of an event.
*Length of lines represents the observation time for each USO.
**Crosses indicate the firm establishment and circles represent the time when market introduction happened.

Figure B: Time to firm's closure (dependent variable)
*Length of lines represents the observation time for each USO.
** Crosses indicate the firm establishment and rectangles represent the time when firms closed.

First, not all firms may introduce their innovation to market during the observation period. Second, even among firms that do have market introduction in the observation period, the event of firm establishment and the time taken for market introduction can vary widely. Figures 3.1A and 3.1B visually illustrate this complexity. Figure 3.1A displays the time to market introduction, which varies between firms, considering differences in establishment years and varying ages at market entry or non-entry (ovals indicate market introduction). Figure 3.1B displays the survival of the same firms (rectangles denote firm closures). Accordingly, among others the objective is to assess the effect of events in Figure A as an intermediate event on firms' closure in Figure B.

Referring to the main framework of analysis (Figure 1.2), this research considers significant events in firms' lifespan, including firm closure, market introduction, collaboration with large firms, receiving substantial financial investment, and recruitment of a marketing specialist. These events have been registered in any year they occur, with the corresponding cell in the database remaining empty if the firm did not experience the event by the end of the observation period.

3.3 Concepts, Variables and Measurement

In the previous chapter, lessons learned have been presented derived from data measurement in the pilot study. This section adds to this by discussing the types of variables in the main study, with a focus on whether the used measurements are appropriate, as this directly influences the quality and reliability of the study's findings. The following subsections will discuss the type of variables (subsection 3.3.1), and the checking of validity of measurements (subsection 3.3.2).

3.3.1 Types of Variables

A distinction is made between observed and latent variables, and between control variables and dependent and independent variables. Accordingly, in the first analysis, on market introduction, presented in part of Chapter 4 and Chapter 5, the time to market introduction is examined as a dependent variable, which is an observable variable measured by the number of years between a firm's establishment and its first market introduction. Firms that did not introduce their innovation to market by the end of the observation period (i.e., 2018) were labelled as "without market introduction", and the years from their establishment until 2018 (or until they ceased to exist) were counted for this category. The second analysis, on survival, presented in Chapter 4 and Chapter 6, examines the dependent variable of firm survival time, which is an observable variable measured by the number of years between a firm's establishment and its closure. For firms that were still in business at the end of the observation period in 2018, their age at that point is considered as the survival time.

To develop a model that explores the conditions or factors influencing time to market introduction and firm survival, three latent variables were formulated based on the theoretical concepts identified in Chapter 1, Section 1.5: firm entrepreneurial orientation, firm resources and capabilities, and quality of the entrepreneurial eco-system. Latent variables are not directly observed but are inferred from a set of observable variables or proxies. In this study, latent variables are defined using observed variables and proxies, using measurable indicators. Table 3.1 provides the types of variables and their respective indicators. Further details on the portion of each variable within the sample, and the descriptive analysis of the sample, is presented in Table 5.1 of Chapter 5.

Table 3.1 Type of variables used in the study

Concepts	Type of Variables	Indicators
Time to market introduction	Observed dependent variable	Duration between firm establishment and first market introduction
Firm survival	Observed dependent variable	Duration between firm establishment and closure
Year of firm establishment	Observed control variable	Beyond economic crisis or within economic crisis (2007-2010)
Business model	Observed control variable	Services or manufacturing oriented activity
Firm Entrepreneurial Orientation (risk related)	Latent independent variable	Radicalness of product Newness of market Diversification
Firm Resources and Capabilities (Owned by founding team, and accessed externally)	Latent independent variable	Founding team's highest education Founding team size Founding team business experience Firm age at receiving first investment. Firm age at first formal collaboration Firm age at recruitment of marketing staff
Quality of Entrepreneurial Eco-system	Latent independent variable	National Innovation System (NIS) Metropolitan area Type of university of incubation

3.3.2 Validity of the Variables

This section examines the appropriateness of the measurement in this study by discussing the validity and reliability of indicators and their measurement. Validity refers to the extent to which a measurement captures the intended concept, while reliability pertains to the consistency and stability of measurement instruments across different occasions or contexts (Fitzner, 2007; Heale and Twycross., 2015; Mohajan, 2017). In particular, content validity is the degree to which a measurement tool accurately captures the specific domain of the concept being measured (Taherdoost, 2016). Since latent variables were used in this study (see Table 3.1), which cannot be measured directly, the content validity check was crucial and done cautiously. Accordingly, it was established first through a comprehensive literature review partially presented in Chapter 1 and then further tested in Chapter 2 (pilot study). Table 3.2 illustrates the detailed measurement of selected indicators for the latent variables, and references to literature that employed the same (or similar) indicators for corresponding variables.

Table 3.2 Measurement used in the study drawing on existing literature

Latent Variables	Indicators (elaborated)	Literature
Firm Entrepreneurial Orientation (risk-related)	Radicalness of new product: radically new, or incremental innovation	Aspelund et al., 2005; Avlonitis & Salavou, 2007; Covin & Wales, 2012; Bessant et al., 2014; Morgan et al., 2014; Rodeiro-Pazos et al., 2021.
	Newness of market: existing or emerging and new	Avlonitis & Salavou, 2007; Covin & Wales, 2012; Kim, 2018.
	Diversification: diversified product and/or market, or absence	Eisenmann, 2002; Bailey et al., 2008; Covin & Wales, 2012; Wilson et al., 2019.
Firm Resources and Capabilities (risk-related)	Founding team education	Aspelund et al., 2005; Criaco et al., 2013; Scholten et al., 2015; Soetanto & Van Geenhuizen, 2015; Taheri & Van Geenhuizen, 2019.
	Founding team size	Colombo et al., 2004; Aspelund et al., 2005; Scholten et al., 2015; Taheri & Van Geenhuizen, 2019.
	Founding team business experience	Aspelund et al., 2005; Heirman & Clarysse,2007; Criaco et al., 2013; Scholten et al., 2015; Soetanto & Van Geenhuizen, 2015; Khodaei et al., 2016
	Receiving investment	Heirman & Clarysse,2007; Soetanto & Van Geenhuizen, 2015; Guesalaga et al., 2018; Rodeiro-Pazos et al., 2021.
	Formal collaboration with large firms/organisations	Walter et al., 2006; Heirman & Clarysse 2007; Scholten et al., 2015.
	Marketing staff	Grant, 1991; Auh & Menguc, 2009.
Quality of Entrepreneurial Eco-system	National Innovation System: presence of favourable startup and sustainable energy policy	Patel & Pavitt, 1994; Ylinenpää, 2009; Stam & Spigel, 2016.
	Metropolitan area: city size and distance to economic core region	Fotopoulos & Louri, 2000; Carlino et al., 2001; McCann, 2006; Tsvetkova et al., 2014; Soetanto & Van Geenhuizen, 2015.
	Type of incubating university	Audretsch et al., 2005; Miller& Acs, 2017; Hayter et al., 2018; Breznitz & Zhang, 2019, Fuster et al., 2019; Mathisen & Rasmussen, 2019; Prokop, 2021.

In detail, the table illustrates the operationalization of Entrepreneurial Orientation through several risk-related firm choices. Firm Resources and Capabilities are operationalized through various founding team characteristics that provide competence and information/knowledge, as well as competences through network relations, like with venture capitalists/consortia, large firms or other large organizations, and recruitment in the labour market. In addition, at a higher level of abstraction, the table shows the multi-level character of the place of location of spin-off firms, where the quality of the local entrepreneurial eco-system is influenced by the National Innovation System, while displaying different potentials in itself, namely derived from city size and location in the country with respect to the economic core area, and from the type of university ecosystem.

3.3.3 The Measurements

This section discusses the measurement of each variable included in this study. Two different **dependent** variables are addressed: time-to-market introduction and firm survival. Additionally, two control variables and 12 explanatory variables are included. The following part explains the measurements and categorization of all involved variables one by one.

Dependent variables

Market introduction is measured as the year of first sale of the main innovative product or service in market. The focus of this variable is specifically on the time to the market introduction of the firm's sustainable energy innovation, therefore, sales of side products or services in addition to the primary innovation are not considered for market introduction. Furthermore, testing of prototypes or pilot projects are not classified as market introduction, but the inclusion of launching customers is recognized as such, in the final year of launching activity. ***Firm survival*** has a straightforward measurement. It is calculated by the years from firm establishment until the year of firm’s closure or alternatively, firm age at 2018 (end of observation).

Control variables.

Period, indicated by the ***year of establishment*** was the first available data obtained after identifying startups as university spin-off firms, primarily through their websites. This factor considers whether the firm was established within the economic crisis that started about 2007 and lasted till 2010, or not, and acts as a control variable.

Concerning the 2nd control variable, ***Business model***, the focus was on the benefits that firms could achieve by offering services, especially in terms of generating quick cash flow without high investment in production means. If a business was active in integrated products and services and offered both, it was categorized as a service-oriented business. The main criterion used to distinguish between a manufactured product and a service was the tangibility vs. intangibility of what the business activity offered.

Independent variables

Innovation radicalness was assessed based on the extent of changes contained in the technology or its differences with existing technologies. If the innovation was entirely new for customers (individuals or industry), it was categorized as a more radical innovation. Otherwise, it was categorized as a more incremental innovation.

Newness of market is a complex measurement as it differs per technology and per speed of acceptance in the market over the study period. It was measured based on the share of related energy sources in the market. The types of sustainable energy technologies used in this study are mentioned in Chapter 4, Section 4.2.2. Utilizing available information from the International Renewable Energy Agency (IRENA), the newness of the market was categorized into three, based on the size of the market for each sustainable energy source and its growth across the years of observation: 1) Established Market, encompassing energy sources and technologies that already cover the majority of energy usage in the market; 2) Emerging Market, including those that are fast-growing in the market or already exceed one percent share in energy supply technologies; 3) New Market, referring to energy sources and technologies with a small market share of less than 1 percent of energy supply. According to this categorization, the type of market based on the different sources of energy was categorized as follows. PV Solar Technologies: Before 2017, they were considered part of the new market, transitioning to the emerging market category after 2017. Other innovations in solar technologies such as improving efficiency or quality of solar cells were classified as part of the emerging market. Wind Energy: In Denmark, wind energy was categorized as a new market before 2000, shifting to an emerging market after 2000. In other countries, wind technologies entered the new market before 2008 and became part of the emerging market after 2008. Further, biofuel was considered part of the new market before 2004 and transitioned to the emerging market after 2004. Other types of bio-energy were classified as part of the new market. Hydro, wave, and tidal energy: In Norway, hydro energy had an established market, while in other countries, it was considered part of the new market. Technologies related to tidal and wave energy at sea (coasts) were categorized as part of the new market for all countries. Hydrogen: The technologies involved belonged to the new market throughout the observation period. Sustainable automotive technologies: Until 2012, electric cars were considered part of the new market, transitioning to the emerging market after 2012. Innovations related to other types of electric vehicles and new fuels were classified as part of the new market. Energy Storage and Batteries: Technologies related to energy storage were considered part of the established market with improvement gained through increasing of efficiency. Energy-saving in industrial processes and buildings (like offices), and Sustainable Extraction of fossil fuels (incl. sensor technology): Innovations involved were categorized as part of the established market. Further, ***Business diversification*** was assessed by examining the products and services offered by a firm with the aim of risk mitigation. Firms choosing an additional, less risky, related product or service were categorized as diversified. This categorization also applied to firms diversifying in the market, allowing entry into a less risky market in addition to the new or emerging sustainable energy market.

Size of the founding team was measured by counting the number of mentioned founders. Similarly, the ***Highest education of founding team*** and ***Business experience of the founding team*** were measured based on self-assessment made by founders in interviews or on their own webpages***.*** For ***USO's age at first collaboration with a large firm,*** the first formal collaboration involving mutual agreements, such as being a launching customer, supplier, investor, consultant, or any other type of substantial partnership that publicly announced by the university spin-off firm was considered. Large firms in this context refer to any companies that do not qualify as startups. If such relation was developed with a large public actor, it was included in the measurement. Regarding ***USO's age at getting access to substantial financial investment,*** only investments exceeding one million euros in total were taken into account. Regarding Marketing staff, as measured by the variable ***USO's age of recruiting first marketing staff (MS)***, this refers to any individual with expertise in marketing, either through relevant professional experience or educational background. Joining of marketing staff is often mentioned by spin-off firms on their websites. The age of the firm at these events was calculated in years, starting from the establishment of the firm and ending in the year the respective event occurred.

With regard to Entrepreneurial Ecosystem, the ***Quality of National Innovation System of countries (NIS)*** was measured based on EC Innovation Union Scoreboard report published by the European Commission in 2015. This report served as a tool to compare and rank the national innovation capacity of different countries. The different ***Locations*** of university spin-off firms were categorized into three groups as follows. 1) Metropolitan area which refers to the large capital cities or other large cities acting as important manufacturing and/or commercial services centres; 2) Small cities in less dense area with access to metropolitan area within one hour, considering both distance and transportation network; 3) In addition, small and medium-sized cities far from metropolitan area fall in a separate category. The ***Type of incubating university*** is categorized in technical university or general university.

3.4 Quantitative Methods in Data Analysis

Quantitative methods used in this thesis are derived from survival analysis or broadly speaking time-to-event analysis. This analytical approach encompasses various techniques, including Kaplan-Meier analysis, Log-rank test, Cox regression (both proportional hazard and accelerated failure models), and Competing risk analysis. Subsection 3.4.1 elaborates on the distinctive features of time-to-event analysis, providing a foundational understanding. Subsequent sections delve into main survival analysis methods like Kaplan-Meier, (Subsection 3.4.2), Cox regression model (Subsection 3.4.3), and Competing risk regression (subsection

3.4.4). Further in-depth explanations of specific methods, such as Log-rank test, will be presented in relevant chapters where the respective analyses are conducted.

3.4.1 An Introduction to Survival Analysis

Studies that investigate the occurrence of events over the life-time of organizations (including firms) have already been conducted since the 1980s, i.e. in a specific branch of organization studies, named organizational ecology (Hannan and Freeman, 1989). The aim has been to depict age -and period-dependency of life-events of organizations in a population, in particular failure. Though event-analysis and survival analysis have remained attracting attention in sociological and organization studies, longitudinal event analysis is more commonly conducted in specific medical studies in which the primary focus is on time to death, time to disease recurrence, time to appearance of symptoms, and so on. In economics or organization-science, the analysis of time-to-event and underlying factors is usually referred to as duration analysis (e.g. Hensher and Mannering, 1994; Van den Berg, 2001). The present study uses the terms 'survival analysis' and 'time-to-event analysis' interchangeably to refer to the same methodological approach.

In this methodological approach two questions are simultaneously taken into account: Did the event occur and When did it occur? Both of these questions deal with probabilities. The answer to the first question provides a statistical rate of occurrence in a population at a certain point in time, while the latter looks at an interval of time and addresses the distribution of events over time. The key concept in survival analysis is the hazard function, which broadly represents the probability that a person, machine, or business will cease to exist in the next instant, given that it has survived up to time t (Clark et al., 2003; Jenkins, 2005; Tierney et al., 2007; Emmert-Streib and Dehmer, 2019). In other words, it shows the probability that the event happens in the next time period, given that it didn't happen in the current time period. The hazard function can be estimated using specific statistical methods, such as the Kaplan-Meier estimator and Cox proportional hazard regression. The Kaplan-Meier estimator is used in Chapter 4 and Cox regression model is used in Chapter 5 and Chapter 6.

Time-to-event data are longitudinal data in which subjects (firms) are followed from a clearly defined starting time until they either experience the event of interest or reach the end of the observation period. Consequently, two unique features mostly are seen in time-to-event data that require distinct treatment from regular data (Clark et al., 2003). Firstly, time to event data are often skewed because the majority of event under study tends to occur early/late for most subjects, deviating from a normal distribution. For instance, in a study on firm lifespan, it is logically conceivable that startups are more likely to launch their product soon after establishment rather than later. The second distinctive feature in time-to-event data is the presence of censoring, indicating the inability to fully observe the time-to-event value for all subjects. This is due to various types of censoring, with the most common being right censoring (Leung et al., 1997; Emmert-Streib and Dehmer, 2019). Right censoring occurs when a subject (in this study, a firm) does not experience the event of interest during the observation period, thus their last observed follow-up time is less than their time to event. Time-to-event data are often represented as a step function that drops at event times to depict the probability that an event happened after a given time. It reflects the fraction of subjects (firms) that did not experience the event beyond a given time. The next three subsections will introduce the Kaplan-Meier estimator, the Cox regression model, and Competing risk regression.

3.4.2 Kaplan-Meier Estimator

The Kaplan-Meier estimator (KM) is a widely used technique for estimating and plotting the probability of time to an event as a function of time. It is often employed as the initial step in survival analysis or event-analysis due to its minimal assumptions and simplicity. KM curves provide a valuable exploratory tool for comparing survival functions among groups of firms that have been exposed to different conditions (Hosmer et al., 2008).

In detail, Kaplan-Meier graph (Kaplan and Meier, 1958), which is also named survival graph shows the probability of facing an event (mostly death or closure for firms) over a timeline. The Kaplan-Meier estimator takes into account the fact that some subjects (firms) may be lost to follow-up or may be censored, meaning that their event time is unknown or unobserved. The estimator calculates the probability of an event at each observed event time and then multiplies these probabilities together to obtain the overall survival probability. This results in a stepwise function that plots the probability of an event over time. The formula for calculating the Kaplan-Meier estimator (Andersen and Keiding, 2002), as applied to firms is as follow:

$$s(t) = \prod_{i:\, t_i \leq t} [1 - \left(\frac{d_i}{n_i}\right)] \qquad (1)$$

where $S(t)$ is the probability that the firms survive longer than time t , t_i is a time when at least one event happened (time to market introduction for firm i or time to firm's closure), d_i is the number of events that happened at time t_i, and $n_i$is the number of firms known to have survived or have not yet had an event or been censored up to time t_i.

A plot of the Kaplan-Meier estimator typically consists of a series of declining horizontal steps that, with a sufficiently large sample size, approaches the true survival function for the population being studied. Aside from plotting the graphs, the Log-rank test can be used to compare two KM curves and determine whether they are significantly different (Goel et al., 2010). However, when the variable under study has more than two categories or is continuous or when multiple predictors need to be considered in a single model, the Kaplan-Meier estimator may not be suitable. In such cases, the Cox regression model is often used to answer the relevant questions.

3.4.3 Cox Proportional Regression Model

Cox proportional hazard regression analysis (Cox, 1972; Royston and Lambert, 2011) is a semi-parametric survival model to investigate the effects of different factors on probability of firm survival till a particular time. A Cox proportional hazards (Cox PH) model can be estimated using the following formula (Kumar and Klefsjö,1994; Royston and Lambert, 2011):

$$h(t; x) = h_0(t)e^{\beta x} \qquad (2)$$

Here $h_0(t)$ is the baseline hazard (t is time). The baseline hazard is the hazard when covariate x is equal to zero, thus $e^{\beta(0)} = e^0 = 1.$ x is a covariate and β is a parameter to be calculated representing the effect of the covariate on the outcome. In fact β shows that for each unit increase in the covariate x, the hazard will be multiplied by e^x. Various covariates could be added to the Cox proportional hazard model, in a broader form of the equation which reads as follows:

$$h(t; x_{1,\dots,}x_{n)} = h_0(t)e^{\beta_1 x_1 +,\dots+\beta_n x_n} \qquad (3)$$

Semi-parametric methods, such as the Cox proportional hazard model, do not require any assumptions to be made about the overall shape of the hazard function. Instead, these methods rely on the assumption that the hazard ratio - defined as the ratio of the hazard function to the baseline hazard -, remains constant over time and is independent of time throughout the follow-up period (Allison, 1982). The proportional hazards assumption is a key limitation of the Cox model and must be checked beforehand. If this assumption is violated, the results can be misleading. Another limitation is that the Cox model provides estimates of relative risks (hazard ratios) rather than absolute risks. This means it can indicate how the hazard of an event changes with covariates but cannot provide direct estimates of the probability of the event occurring at a specific time.

Despite its limitations, the Cox proportional hazards regression model remains the most commonly used tool for studying the relationship between survival time and predictor variables (Austin, 2013). By using this method, researchers can gain a better understanding of the factors that influence the risk of an event occurring over time. Chapter 5 and Chapter 6 of this thesis employ the Cox regression model to analyse the time to market introduction and the survival function, respectively. Additionally, Chapter 6 utilizes an extension of the Cox regression model known as Competing risk regression. Next Section explains the Competing risk regression methodology, introducing the cumulative incidence function (CIF) of the event of interest.

In the application of Cox regression analysis, there are some situations in which another event may substantially affect the risk of the event under study. In such cases, the second event may be called an intermediate event which may be analysed by Multi-state models (Putter et al., 2007). A Multi-state model is an extension of time to event analysis aiming to evaluate what happens to the final event after the intermediate event happened or did not happen.

3.4.4 Competing Risk Regression, the Fine-Gray Model

Survival methods can be extended to the analysis of situations where there are different possible end events, and their risk of happening is mutually exclusive. This means the occurrence of one event automatically eliminates the risk of other events happening. In such cases, an alternative method introduced by Fine and Gray (1999), known as competing risk survival regression or the Fine-Gray model, becomes valuable as it accounts for the presence of these competing events. Competing risk analysis refers to a special type of survival analysis that aims to estimate the probability of an event in the presence of other competing events. Traditional methods to describe the survival process, such as Kaplan-Meier and Cox regression methods, are not designed to accommodate the competing nature of multiple causes for the same event. Therefore, they tend to produce inaccurate estimates when analysing the probability of an event considering the paths towards the event.

When a firm undergoes either acquisition or bankruptcy, it is no longer at risk of experiencing the other event. That is why these events are referred to as competing risks in the modelling of time to events. For instance, when studying the time to bankruptcy, the acquired firms represent cases where neither survival nor failure took place. Treating them as censored cases would lead to misleading analysis since their likelihood of bankruptcy has already ceased. To address this issue, Competing event analysis is employed, which focuses on one event while treating the other as a competing event, signifying the termination of observation due to a different reason.

Assuming the risks of event's occurrence (e.g. bankruptcy and acquisition) are independent, the log-likelihood for the competing risks model is additively separable into K terms, each being a function of the parameters of a single cause-specific hazard (Narendranathan and Stewart,1991; Austin et al., 2016). Thus, to estimate these models, one must proceed with the estimation of a single-risk hazard (for instance the hazard of bankruptcy) while treating any other type of exit as censored at the point of completion.

The introduction of the Cumulative Incidence Function (CIF) in competing risk analysis provides a means to depict the incidence of an event while considering the presence of competing risks. There exists a connection between the sub-distribution hazard function and the cumulative incidence function. The sub-distribution hazard model enables the estimation of the impact of covariates on the cumulative incidence function for the event of interest. In fact, competing risk regression model analyses this function, in the presence of competing risk events (Narendranathan and Stewart ,1991). The cumulative incidence function represents the cumulative probability of experiencing a specific event (e.g., bankruptcy) in the presence of competing events (e.g., acquisition).

In competing risk analysis, instead of hazard function which is shown in equation (2), the sub-distribution hazard function is used which describes the instantaneous failure rate of a particular event in the presence of competing risks. The Fine-Gray model (Fine and Gray, 1999) is described by following formula.

$$h_{ij}(t) = h_{0j}(t) \cdot e^{\beta' X_{ij}} \tag{4}$$

where $h_{ij}(t)$ is the sub-distribution hazard for event j at time t. And $h_{0j}(t)$ is the baseline hazard function for event j representing the hazard at time t for a firm with all covariates equal to zero. $\beta' X_{ij}$ is the linear predictor representing the sum of the product of each covariate's coefficient (β), and the corresponding covariate value (X_{ij}). In fact, the coefficients (β) indicate the direction and magnitude of the impact of covariates on the hazard of the specific event. The Fine-Gray model allows to analyse the competing risks of firm exit through bankruptcy and acquisition, considering various covariates and their impact on the hazard functions. Chapter 6 of this thesis utilizes the Fine-Gray method to enhance insights into firm survival and the factors influencing this event.

All statistical analyses, including Kaplan-Meier, Cox regression, and competing risk analysis, were conducted using Stata 16, as it provides robust support for time-to-event analysis. The software's capabilities make it well-suited for handling such models effectively.

3.5 Research Design

This thesis is an explanatory study with the aim of answering research questions related to the factors that may facilitate a quicker market introduction and longer survival for small high-tech firms, particularly university spin-offs, in the sustainable energy sector.

Referring to Figure 1.3, which illustrates the structure of the thesis and aligns with the typical approach in explanatory research, the study began with a comprehensive literature review. This review is meant to inform the formulation of hypotheses in Chapter 5 and Chapter 6 related to the research questions. During this stage, three primary theory streams crucial for explaining the factors influencing market introduction and survival of small high-tech firms in the sustainable energy market were identified: firm entrepreneurial orientation, firm resources and capabilities (owned and gained), and the entrepreneurial ecosystem. Based on these factors, the conceptual model was established (see Figure 1.2).

In order to check the feasibility of the research and determine the possibility of measurement and test its quality, a pilot study was designed and reported in Chapter 2. The goal of this pilot study was not finding accurate causality effects or generalization of the rules, but rather to conduct a qualitative empirical study using Rough Set analysis to gain an overall understanding of the phenomenon of market introduction by finding similarity patterns in a small database of university spin-off firms in the sustainable energy sector. After refining the variables and adding new ones, and improving measurements through results of the pilot study, the population and sample of the study was determined, and the database was built using different sources and methods (see Section 3.2). The quantitative studies in this thesis employed different methods (see Section 3.4) which were introduced in the current chapter.

With a database covering 106 university spin-off firms dealing with sustainable energy technologies, it can be claimed that this unique database covers almost the whole population and is representative to a large extent for university spin-off firms established since 1998 in Nordic countries and the Netherlands in sustainable energy technologies. A descriptive analysis of this population enhances the understanding of the current status of this topic and provides valuable insights. Accordingly, Chapter 4 presents the results of the descriptive analysis of dynamic change of different categories of university spin-off firms in relation to market introduction and survival. The main quantitative studies are conducted next and the results are presented in Chapters 5 and 6. Chapter 5 investigates the first market introduction and its speed, which is a crucial event in the life of firms enabling them to build up sales and raise cash flow in attempts to scaling-up. In Chapter 6, the focus of the study shifts to firms' survival, addressing conditions that may lead to longer survival of small high-tech firms. The results of the quantitative analyses and modelling are then integrated with the qualitative analysis already conducted, and the interpretation of the results providing valuable insights into the factors influencing small high-tech firms in the sustainable energy.

Chapter 7 concludes the study by providing reflections towards entrepreneurs, policymaking and towards universities, but also by mentioning the limitations of the study. The findings can be used by entrepreneurs, policymakers, large firms and other stakeholders who care about sustainable energy transition in supporting the growth of small high-tech firms in this sector.

3.6 Summary

Constructing the longitudinal database proved to be one of the most time-consuming aspects of the current study, however, it stands as a key outcome. This chapter delved into the creation of the unique database after selecting the study population. It provided detailed insights into the types of variables and the validity of the measurements used for statistical analysis, recognizing their crucial role in data analysis and modelling.

As this study employs both qualitative and quantitative techniques across various chapters, the current chapter provided an overview of the analytical quantitative methods utilized to analyse the data and answer specific research questions addressed in individual chapters (Chapter 4, 5, and 6). Finally, this chapter elaborated on the study design based on the structure of the study presented in Chapter 1. The next chapter provides a descriptive analysis of the sampled spin-off firms, and Kaplan-Meier estimations of their market introduction and survival.

Chapter 4. Evidence on Different Firm Dynamics

4.1 Introduction

University spin-off firms (USOs) in the sustainable energy sector can be seen as small high-tech startups with a promising technology that may play a significant role in enhancing transition to sustainable energy. They, however, face high risk and may also fail (Jacobsson and Johnson, 2000; Hockerts and Wüstenhagen, 2010; Bergset and Fichter, 2015; Singh et al., 2021; Dall-Orsoletta et al., 2022). The potential role of university spin-offs in the energy transition, stems from a mixture of their unique innovative technologies, strategic choices in bringing their innovations to the market, and from the universities' willingness to support university spin-off firms in their ambition to contribute to the energy transition (Pappas, 2012; Fini et al., 2018). Accordingly, in recent decades (2000s and 2010s), new directions of university research have emerged, emphasizing energy transition through using new (non-fossil) energy sources and energy saving, and supported by public research funds (like the EU Horizon 2020 program). The actual contribution of university spin-off firms in the energy transition has, however, not been researched so-far with regard to market introduction, and with regard to years of survival in which upscaling in the market may be undertaken. While university spin-off firms may have a significant contribution to energy transition, the path to developing the new technologies into commercial applications is full of risks, both in technology and market, like lock-in and path dependency (Klitkou et al., 2015).

The present thesis focuses on two primary events/developments in the life of university spin-off firms: 1) time to market introduction of sustainable energy innovation, and 2) survival of the spin-off firms. Prior to addressing these events/developments, it is important to know and understand several key characteristics of the sampled university spin-off firms that are connected to entrepreneurial orientation, in particular risk-taking and risk-mitigation.

Accordingly, this chapter attempts to answer three main research questions:

1) What are the characteristics of the university spin-off firms, regarding sustainable energy technology, and assumed influencing factors like period of establishment, entrepreneurial orientation (risks), resources and capabilities of the founding team and early networking, and regarding quality of the entrepreneurial ecosystem?
2) What are the dynamics of market introduction of sustainable energy technologies among different categories of university spin-off firms, regarding time needed, given these influencing factors?
3) What are the dynamics of firm survival among different categories of university spin-off firms with regard to time of survival, given the influencing factors?

This chapter provides a descriptive analysis of characteristics of university spin-off firms, and the pattern of their market introduction and survival. The patterns are presented by graphs that plot time to market introduction and firm survival against influencing factors, like the newness of technology and newness of the market. Other influencing factors that are used to analyse the pattern of market introduction and firm survival are the selected strategies and risk-taking, such as doing business in services (as opposed to manufacturing) and diversification with related products or services, may influence time to market introduction and survival. Additionally, it will be investigated whether the time to market introduction and firm survival is affected by founding team characteristics, such as team size, team's previous business experience, and the highest education of team members. Access to external resources and capabilities is also taken into account, in particular, the time of first networking with a large firm, the time of first substantial investment, and recruitment of marketing staff. Furthermore, the role of entrepreneurial ecosystem in market introduction and firm survival will be considered. The entrepreneurial ecosystem may hold important external opportunities to gain additional resources that can help to mitigate risks. In a multilevel approach, the focus is on national innovation system (NIS) and metropolitan conditions of the location of university spin-off firms, including character of the type of incubating university.

Chapter 4 unfolds as follows. First, Section 4.2 describes the sample, focusing on university spin-off firms' energy technologies and other key characteristics, like indicators for owned resources and capabilities. Next, in Section 4.3, the focus shifts to internal and external firm factors and how they influence the dynamics of market introduction among university spin-off firms, by comparing different categories of these firms. This is followed by a similar investigation of the role of firm internal and external factors in the differences in survival among university spin-off firms in Section 4.4. Section 4.5 examines the relationship between market introduction and firm survival within the sample. The chapter concludes in Section 4.6 with findings and a summary of the factors' roles. The trends in factors' influence will then be used in the next chapters (Chapter 5 and Chapter 6) to formulate hypotheses.

4.2 Descriptive Analysis of the Sample

A representative sample collected for this study stands out as one of the research outcomes, unique in its field of university spin-offs in sustainable energy across five Northwest European countries. Detailed insights into the methods of data collection and the formation of the database have been provided in Chapter 3, Section 3.2. The current section offers a descriptive overview of the sample, with a specific focus on the primary characteristic of the sample, namely their sustainable energy technologies (discussed in Section 4.2.1), and Section 4.2.2 provides an overview of the other characteristics of the sampled university spin-off firms, namely, the entrepreneurial orientation, resources and capabilities owned by founders and access to network resources, and quality of the entrepreneurial ecosystem.

4.2.1 Sustainable Energy Technologies of Sampled Spin-offs

The study includes university spin-off firms that operate in a variety of sustainable energy technology sectors in five European countries. In total, we identified seven sub-sectors, presented in Table 4.1 and ordered by the number of university spin-off firms involved in each sub-sector. These are: 1) efficiency in conventional technology (such as energy-saving, cleaner production, and spill prevention); 2) solar PV (photovoltaic); 3) onshore and offshore wind energy; 4) transport applications (also named Automotive) including new fuels/power such as in electric vehicles, as well as new motor technology; 5) new biomass and biogas (including membranes used in the process of upgrading); 6) new hydro-power (particularly tidal, current, and wave power at sea); and 7) energy storage, such as more efficient batteries (European Commission, 2013, 2019). The energy sub-sector for hydrogen was merged with energy storage as a result of the small number of university spin-off firms operating in this sub-sector until 2014 which represents the latest year of firm establishment in the database.

Finally, the question of representativeness of the pattern of the technologies may be raised. Representativeness is difficult to determine as it connects with the area for which it would act, i.e. the five countries in sum, European Union at large, etc. With regard to the variety of technologies, Table 4.1 shows that efficiency improvement of existing technology (21 percent), solar PV (20 percent) and Wind (15 percent) are the three largest segments in the sample.

Table 4.1 Types of energy technologies in sample

	Type of Energy Technologies	*Number of USOs (percentage share)*
1	Efficiency improvement of existing technology	22 (20.7%)
2	Solar Photovoltaic	21 (19.8%)
3	Wind (off-shore and on-shore)	16 (15.1%)
4	Transport technology (electro motor, new fuels)	14 (13.2%)
5	New Biomass and Biogas	13 (12.3%)
6	New Hydro Power	11 (10.4%)
7	Remaining: Battery Storage, Hydrogen	9 (8.5%)
	Total	106 (100%)

4.2.2 Main Characteristics of the Sampled Spin-offs

In order to understand dynamics of market introduction and survival, it is necessary that the structure (composition) of the sample is known. The spin-off features that are important in this structure are derived from the theoretical part in Chapter 1 and the operationalization in Chapter 2. Due to the small size of the sample (n=106), in identifying the different categories of spin-offs, a maximum of three categories per firm characteristic was taken. However, the sometimes small size of the categories called for merging three into two categories (a binary variable). The interpretation of descriptive statistics of the sample regarding firm characteristics, shown in Table 4.2, can be summarized as follows.

Considering the effects of macro-economic crisis on firm's performance, it has been observed that 40 university spin-off firms in the sample were founded in the period between 2007 and 2010, potentially influenced by the economic crisis of 2008 and its consequences. This observation prompted the categorization of the firms based on their year of establishment, whether founded within the period from 2007 to 2010 or beyond. With this categorization, approximately 38 percent were established during the crisis period, while 62 percent were founded outside of that timeframe.

Next, the sample pictures quite some variation in risk-taking and mitigation, and in (gaining) external competences through networks and inherent entrepreneurial ecosystem. With regard to business sector, a minority is involved in services (25.5 precent) while a large majority is involved in manufacturing-oriented activity (74.5 percent). Incremental innovation is practiced by 59 percent of the university spin-off firms and more radical innovation by 41 percent of them. With regard to newness of markets, established and emerging markets have been accessed by 26 and 50 percent, respectively, with completely new markets by 24 percent of the sampled university spin-off firms. Further, as a risk-mitigation strategy, diversification including for example adding services in the target market, is undertaken by about half of the spin-offs (52 percent).

Regarding competences/capabilities related firm characteristics, founding team size is on average slightly more than two persons, leading to three categorizations. Approximately 35 percent of university spin-off firms were founded by a single person, 38 percent by two persons, and a minority of 27 percent of firms have a founding team consisting of more than two people. With regard to education, Master level as highest education is present among 26 percent of the university spin-off firms, and PhD level is present among 74 percent. Pre-start business experience is owned by 52 percent of the university spin-off firms and absent among 48 percent.

In terms of access to resources and capabilities, this study focuses on the timing of external acquisition of competences and other resources by considering the age of the firm at which these resources and capabilities were acquired. In the descriptive analysis, utilizing log-rank tests and Kaplan-Meier, continuous variables like the age of firms at their first formal collaboration and the age of firms when receiving their first substantial investment were transformed into binary or categorical variables (refer to Table 4.3 and Table 4.6). The statistics of these variables of age at gaining a resources /capability among the sample is as follows. For university spin-off firms' age at first collaboration with large firms the data reveals distinct patterns. 22 percent of university spin-off firms never engaged in a collaboration during the observation period, while 78 percent actively participated in a collaboration. For those university spin-offs that did engage in collaborations, the average age at the time of the first formal collaboration equals to 3.2 years, reflecting a relatively early stage in the lifespan of these firms. The distribution of ages at first formal collaboration demonstrated quite some variation, with a minimum age of 1 year and a maximum age of 13 years, highlighting the diverse timelines at which university spin-off firms established their initial collaborations with large firms. For university spin-off firms' age at getting access to the first substantial financial investment, the sample shows that 43 percent of the firms did not seek or receive any investment capital during the observation period, and in contrast, 57 percent of the firms obtained substantial investment. For those university spin-off firms that received investment capital, the average age at the time of receiving the first substantial investment was 4.3 years, with the youngest age being 1 year and the oldest reaching 15 years. In exploring the age of joining a first marketing person to the team, the provided data offers the following insights: 48 percent of university spin-off firms, integrated their first marketing staff from the founding team, 29 percent decided not to hire a marketing person during the observation period, and 23 percent recruited a marketing professional later in their development. For those university spin-off firms that introduced a marketing person to their team, the average age at the presence of the first marketing person was 4.3 years, and ranged from a minimum age of 2 years to a maximum of 13 years. The standard deviation (SD) of 0.54 suggests a relatively tight distribution around the mean age, indicating consistency in the timing of this strategic addition.

And finally, the quality of the entrepreneurial ecosystem is measured through three broad indicators; quality of NIS, metropolitan character of location, and university ecosystem. About half of university spin-off firms (53 percent) is facing a strongly supportive NIS (Sweden, Finland and Denmark) and about a similar share (47 percent) is facing a less supportive NIS, at least during a main part of the study period. Further, a substantial share of sampled university spin-off firms (41.5 percent) operates in large metropolitan area, like Randstad-Netherlands and Stockholm region, while 58.5 percent operates in adjacent area or in a small city at large distance from metropolitan areas. Finally, in terms of the university ecosystem, 45 percent of university spin-off firms have their origin in technical universities, while 55 percent originates from general or more theoretical/fundamental universities.

Overall, the participation of university spin-off firms in energy transition is only possible if they bring successfully their innovation to the market and scale it up while surviving. Accordingly, Section 4.3 presents results on the dynamics of market introduction among university spin-off firms and Section 4.4 will present the same for dynamics of firm survival.

Table 4.2 Characteristics of USOs regarding influential factors

USO's characteristics	**Categories**	**Abs. (% share)**
Year of establishment	Out of the period of economic crisis Within the period of economic crisis (2007-2010)	66 (62%) 40 (38%)
Business model	Service oriented Manufacturing oriented	27 (25.5%) 79 (74.5%)
Entrepreneurial orientation		
Innovation radicalness	Incremental More radical	63 (59%) 43 (41%)
Newness of market	Established market Emerging market New market	28 (26%) 53 (50%) 25 (24%)
Diversification (product/market)	Focus Diversified	51 (48%) 55 (52%)
Owned resources/capabilities		
Founding team size	More than 2 persons 2 persons 1 person	30 (27%) 39 (38%) 37 (35%)
Founding team's highest education	Master PhD	28 (26%) 78 (74%)
Founding team business experience	No Yes	51 (48%) 55 (52%)
Access to resource/capabilities		
USO's age at first collaboration with large firms	Never With collaboration Average age at first collaboration	23 (22%) 82 (78%) Mean age: 3.2 (SD: 2.6) Min: 1 Max: 13
USO's age at getting access to substantial investment	Never Received investment; Average age at first collaboration	46 (43%) 60 (57%) Mean age: 4 (SD: 3.01) Min: 1 Max :15
USO's age at joining of first marketing professional in team	Among the founding team Never Recruited later Average age at joining of first marketing professional	51 (48%) 31 (29%) 24 (23%) Mean age: 4.3 SD(.54) Min: 2 Max:13
Quality Entrepreneurial Ecosystem		
Quality of National Innovation System (NIS)	High Lower	56 (53%) 50 (47%)
Location	Metropolitan area Adjacent to metropolitan area Small city at large distance	44 (41.5%) 26 (24.5%) 36 (34%)
Type of Incubating university	General University Technical University	58 (55%) 48 (45%)

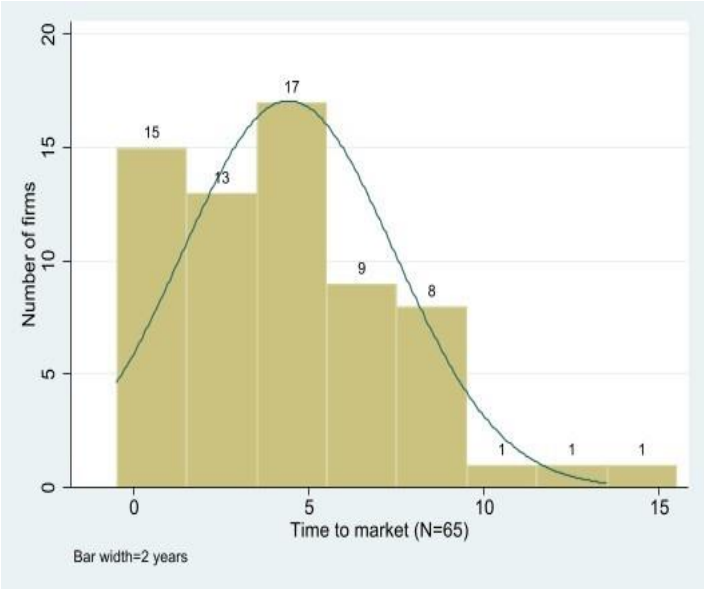
4.3 Dynamics of Market Introduction

4.3.1 Introduction

Time-to-market introduction in this study, refers to the interval time between a firm's establishment and the first sales of the innovation in the market. Fast market introduction is important because the energy transition needs to be accelerated. Additionally, from a business perspective, fast market introduction of innovative products may give the firm the benefits of being a leader in the market, which increases credibility and makes it stronger against competitors. Furthermore, leading firms have a greater chance to influence the establishment of standards and distribution channels of new innovations (Schoonhoven et al., 1990; Kessler and Chakrabarti, 1996; Dong et al., 2019). However, leading firms may also take huge risks compared to followers if the technology is not sufficiently mature, which can lead to additional development costs, or even failure. On the other hand, followers may learn from first movers and avoid their mistakes, which allows them to change the game and take the lead (Mohr et al., 2013).

The time to market introduction is measured by the duration between establishment of the firms and their first sales. Among the sample of 106 university spin-off firms that were established between 1998 and 2014, the distribution is as follows: 65 firms sold their first product or service during the observation period, which started from firm's establishment and lasted until 2018, and 41 did not. For the 65 firms that had their first sales in the period between their year of establishment and 2018, 45 firms (69 percent) had a market introduction within the first five years after establishment. Within the first four years after establishment, 28 firms out of 65 (representing 43 percent) had a market introduction (see Figure 4.1). The first bar in Figure 4.1 represents 15 university spin-off firms, which had their first sales within two years after establishment. These university spin-off firms mainly deal with services, but also with manufacturing inventions that were almost fully developed in a university laboratory before the establishment. Further, among the observed university spin-off firms, the average age of market introduction is 4.4 years. However, a few university spin-off firms had market introduction after their eight year of establishment, which resulted in a skewed distribution of time to market in our sample. Considering these observations and ensuring robustness in the analysis, the fifth year is used as a threshold for the majority of firms to have market introduction (69 percent) and market introductions after the fifth year are labelled as a late market introduction (31 percent).

Figure 4.1 Firm's age at market introduction



Taking five years as a threshold to distinguish early and late market introduction, the attention will now move to the question: which categories of university spin-off firms – given several influencing factors– come with a significantly larger share of early market introduction? The first exploration is the comparison of early market introduction versus late market introduction for all influencing factors involved in the preliminary model (Chapter 2).

4.3.2 Early/late Market Introduction and Log-rank test

Table 4.3 presents the frequencies of market introduction as binary categorization for early market introduction, which means it happened within the first five years after establishment, and later market introduction, which refers to the firms that experienced market introduction after 5 years of establishment. The last category also includes firms that did not have market introduction till 2018. The results of the log rank test are presented in Table 4.3. The categorization borderlines between categories of influencing factors have been carefully chosen to ensure a balance between effectiveness in revealing differences and sufficient sizes of categories.

Table 4.3 demonstrates relatively strong difference between the categories of early and late market introduction for six factors (a relatively strong difference here refers to a difference of about 20 percent or more between early and late market introduction.). When the sample is split for the type of business model, i.e. service or manufacturing oriented, it shows that service-oriented university spin-off firms have earlier market introduction: 78 percent of the university spin-off firms in services versus 33 percent of firms in manufacturing had early market introduction. When compared on innovation radicalness, 57 percent of the university spin-off firms with incremental innovations had early market introduction, against 21 percent of university spin-off firms with radical innovations. Regarding newness of market, it could be observed that among the university spin-off firms that entered an established market, 63 percent had early market introduction, while for entering an emerging or new market it is limited to 35 percent. Finally, a significant difference (*$p<0.05$*) for the role of Founding team's highest education is noticeable. Among the university spin-off firms with a Master degree as the highest degree of founding team members, it is observed that 61 percent had early market introduction, and for teams with a Ph.D degree as the highest education, only 36 percent had early market introduction. In addition to Business model, Radicalness of Innovation, Newness of Market, and Founding team's highest education, university spin-off firms' age at first collaboration with large firms tends to matter. Approximately 68 percent of university spin-off firms that initiated collaboration after 5 years or never collaborated at all, experienced late market introduction. Conversely, among those with early collaboration (within the first five years), 57 percent achieved early market introduction. Notably, only 32 percent of university spin-off firms with late collaboration managed market introduction within the initial five years. Finally, the result shows significant differentiation ($p<0.01$) in Type of University with regard to timing of market introduction; 55 percent of firms originating from technical universities had early market introduction while, 67 percent of university spin-off firms originated from general universities have later market introduction.

Finally, in Table 4.3 the Log-rank Test is presented to assess the significance of the differences in early market introduction between different categories of spin-offs. The Log-rank test is an extension of non-parametric rank test used to compare two or more distributions for censored data (Mantel, 1966; Bland and Altman, 2004). It tests the null hypothesis of no differences in time to event between two or more categories of spin-offs.

The advantages of Log rank test for the type of data used in this analysis, namely survival type data, is that it does not require to know anything about the shape of the survival curve or the distribution of survival times (Bland & Altman, 2004). The Log-rank test is based on the same assumptions as the Kaplan-Meier estimation, it means censoring is assumed to be unrelated to the time and the probability of occurrence of event is the same for subjects come earlier or later to the study. However, compared to Kaplan-Meier test, the advantages of Log-rank test is that at the end it sums up the differences and takes the differences for the whole follow up period into account, and not just comparing each time period together. *As limitation*, Log-rank test is purely a test of significance and it cannot provide an estimate of the size of the difference between the groups or a confidence interval. In order to do that some other methods such as Cox proportional hazards model will be used in the study.

Results of the Log-rank test suggest the same pattern as the above comparative analysis (Table 4.3). In more detail, the results point to the following trends: A higher likelihood of early market introduction is observed for spin-offs that are services-oriented, engage in more incremental innovation, enter established markets, have a founding team with mainly Master level education, originate from technical universities, and initiate collaboration with a large firm early on. This pattern aligns with the notion that late market introduction is more common among spin-offs lacking support from technical universities, taking relatively strong risks in strategic choices, and failing to compensate with early collaboration. Also, it supports views on PhDs influence in founding teams, namely, to hinder early market-orientation and favour academic orientation. As a next step, to visualize the above differences between categories of university spin-off firms, Kaplan-Meier (KM) graphs are plotted separately to display the time to event (i.e., time to market) for each category of university spin-off firms. The graphs are presented in Appendix 4.2 and the results are summarised in the following section.

Table 4.3 Frequency of early/late market introduction (MI) among categories and Log rank-test

Influencing factors (in two categories)	Early MI Abs.(% share)	Later/No MI Abs. (% share)	Log-rank (P-value)
Control variables			
Year of establishment			
- Out of the period of economic crisis	31 (47%)	35 (53%)	1.00 (0.31)
- Within economic crisis (2007-2010)	14 (35%)	26 (65%)	
Business Model			
-Services	21 (78%)	6 (22%)	32.64 (0.00)**
-Manufacturing oriented	24 (33%)	55 (67%)	
Entrepreneurial orientation (risk related)			
Innovation radicalness			
-Incremental	36 (57%)	27 (43%)	19.50 (0.00)**
-More radical	9 (21%)	34 (79%)	
Newness of market			
-Existing	17 (63%)	10 (37%)	6.41 (0.01)*
-Emerging/new	28 (35%)	51 (65%)	
Diversification (product/market)			
-Diversified	24 (44%)	31 (56%)	2.30 (0.12)
-Focus	21 (41%)	30 (59%)	
Owned resources/capabilities			
Founding team size			
-Larger (more than 2 pers.)	15 (50%)	15 (50%)	0.37 (0.54)
-Smaller	30 (39%)	46 (61%)	
Highest education of founding team			
-Master	17 (61%)	11 (39%)	4.00 (0.04)*
-PhD	28 (36%)	50 (64%)	
Business experience of the founding team			
-Yes	27 (49%)	28 (51%)	2.94 (0.08)
-No	18 (35 %)	33 (65%)	
Access to resource/capabilities			
First collaboration with large firm			
-Early (within the first five years)	25 (57%)	19 (43%)	5.52 (0.009)**
-Late (incl. no networking)	20 (32%)	42 (68%)	
Access to first substantial investment			
-Early (within the first five years)	19 (44%)	24 (56%)	0.80 (0.36)
-Late (incl. no investment)	26 (41%)	37 (59%)	
Joining of first marketing professional			
- Present at start and early joining	25 (49%)	26 (51%)	1.29 (0.25)
- Joined late (incl. no joining)	20 (36%)	35 (64%)	
Quality Entrepreneurial Ecosystem			
Quality of NIS			
- High (DK, FI, SE)	19 (34%)	37 (66%)	2.49 (0.11)
- Lower (NL, NO)	26 (52%)	24 (48%)	
Location			
- Within metropolitan area	26 (43%)	34 (57%)	0.96 (0.32)
- Outside metropolitan area	19 (41%)	27 (59%)	
Type of Incubating university			
-Technical University	26 (55%)	22 (45%)	6.53 (0.01)**
-General University	19 (33%)	39 (67%)	

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

4.3.3 Kaplan-Meier Estimation and Factors Affecting Early Market Introduction

A Kaplan-Meier graph (Kaplan and Meier, 1958), which is also named survival graph, shows the probability of firms to face an event (mostly death or closure for firms) over a time line, and in the current context, market introduction. Accordingly, the horizontal axis shows the university spin-off firms age when it has the first market introduction and the vertical axis demonstrates the *probability of* ***no*** *market introduction*. Time zero reflects university spin-off firms at age zero i.e. in the establishment year, thus the probability of not reaching the market at age zero is 100 percent. The probability of remaining without market introduction (not facing the event under study), would decrease over time for the obvious reason that as long as the time passes, some firms would have market introduction, thus the KM curves are decreasing over the follow up time. The steps in the KM plot indicate the number of university spin-off firms that 'leave the panel' due to market introduction in each time interval, which causes a drop in the graph, because less university spin-off firms remain to have chance of facing the event (market introduction).

The Kaplan-Meier (KM) graphs for the factors that showed a significant influence on market introduction, as determined by the Log-rank test, are presented in detail in Appendix 4.2. The graphs will visually highlight the differences between the categories and demonstrate how they evolve over time. Table 4.4 below summarises the obtained results of KM graphs (see Appendix 4.2) and presents the probability for each category and the differences in the probability for the main influencing factors at a threshold of five years. Table 4.4 indicates the largest differences in probabilities regarding Business model, namely 55 percent.

Table 4.4 Probability of market introduction till 5 years in categories based on KM graphs

Influencing factors with significant difference	Categories	Probability of market introduction at threshold (5 years)	Difference in probability between two categories
Business model	Services	100-25% = 75%	75-20 = 55%
	Manufacturing	100-80% = 20%	
Innovation radicalness	Incremental	100-40% = 60%	60-20 = 40%
	Radical	100-80% = 20%	
Newness of the market	Established	100-35% = 65%	65-35 = 30%
	Emerging	100-65% = 35%	
Highest education of founding team	Master	100-40% = 60%	60-35 = 25%
	PhD	100-65% = 35%	
First collaboration with large firm	Early	100-40% = 60%	60-35 = 25%
	Late	100-65% = 35%	
Type of university	Technical	100-50% = 50%	50-25 = 25%
	General	100-75% = 25%	

The KM graphs visually confirm the results of Log-rank test on significant influence of five factors on time to market introduction but also provides more information about the dynamics of time to market of these factors. In the following section, the obtained result of Log-rank test and Kaplan-Meier graphs are discussed, while in Chapter 5 Cox Regression model will be applied.

- ***Business model (services versus manufacturing)***: Between the two categories for Business Model, the difference in probability between service-oriented and manufacturing-oriented university spin-off firms at the threshold of five years is almost 55 percent. The university spin-off firms in services have faced 75 percent probability of market introduction till age 5 as compared to 20 percent of the manufacturing-oriented USOs. The result that service-oriented university spin-off firms have faster market introduction can be explained by the fact that service firms are usually not involved in huge and/or risky investment in equipment and its financing that might cause delay, thus the development time tends to be shorter. The result can also be explained by *Inseparability* which is known as one of specific characteristics of service firms. It implies that services are generated and consumed concurrently (Mohr et al., 2013; Hole et al., 2018) and as soon as a new service is provided, it could also be offered to the market.

-Innovation radicalness (incremental versus radical): For incremental innovation compared to radical innovation, the difference at the threshold of five years is 40 percent, with incremental innovation having a probability of 60 percent of market introduction against 20 percent for radical innovation. In contrast to incremental innovation, more radical innovation requires large and varied resources, new processing abilities and new skills, and often entails smaller markets and lack of customer experiences (McDermott and O'Connor, 2002), therefore university spin-off firms dealing with radical innovation, need more time and capital for development of products and services and need more preparation before market entry, eventually abroad (Schoonhoven et al., 1990; Kessler and Chakrabarti, 1996; Goktan and Miles, 2011; Marvel and Patel, 2018; Hsieh et al., 2019). The obtained result in Table 4.4 is consistent with the mentioned studies with regard to radical innovation which needs more time for market introduction.

-***Newness of market (existing versus emerging/new):*** For newness of the market, the university spin-off firms targeting an established market are more likely to have market introduction till age 5, namely 65 percent, as compared to targeting an emerging market, 35 percent, with a difference of 30 percent. It should be noted that not all radical innovations create a new market, and conversely new markets would not be run just by radically new products. This means that a high degree of product innovativeness does not necessarily lead to creation of a new market. For instance, LED lamp was a breakthrough technology of low energy lightning introduced to an existing market of lightning. In contrast, producing software in order to stimulate wind flow of wind turbine doesn't count as a novel technology but will place in emerging market of wind energy. Making distinction between existing and new markets and their different characteristics and behaviour has been investigated in some studies (McDermott and O'Connor, 2002; Min et al., 2006). Entering a new market comes with inherent uncertainties, such as the size and growth of the market, customer perceptions, the success of the innovation (like in customer satisfaction), and the establishment of new standards. These uncertainties increase the level of risk associated with market entry, resulting in a more cautious approach and a longer time to market when compared to established markets, where the situation is more clear and more predictable.

- ***Highest education of founding team (PhD versus Master degree)***. Teams with a Master education are more likely to have market introduction (60 percent at five years) compared to university spin-off firms with PhD as highest education, who had 35 percent probability of market introduction; a difference of 25 percent probability for this influencing factor. Drawing on resource-based theory of the firm (Barney, 1991), it could be argued that a higher educational degree among the founders would increase the firm's knowledge resources leading to a better performance and potentially faster market introduction. However, the results of the Pilot study (Chapter 2) already indicated a faster market introduction for university spin-off firms with Master degree compared to PhD level in founding teams. Explaining this result from an entrepreneurship point of view, it can be imagined that founders with Master degree are more practical and focus stronger on concrete marketing actions to achieve clearly useful objectives with a more or less immediate reinforcement (Clough and Vissa, 2022).

- First collaboration with a large firm (early versus later). The role of first collaboration also has a difference in probability of 25 percent, with early collaboration at **60** percent probability for market introduction until age 5 compared to 35 percent for late collaboration. In line with the existing literature (Lavie, 2006; Heirman and Clarysse, 2007; Wang et al., 2015; Stam and Van de Ven, 2021), the argument is that external networking with a large partner may act as a booster for new startups since it gives access to resources and capabilities. The timing of networking needs, however, also to be taken into account because young university spin-off firms may need more support in the first phases when they are more vulnerable due to liability of newness and smallness (Heirman and Clarysse, 2007). KM graph and log-rank test confirm the trend of early collaboration with large firms influencing early market introduction.

- Type of university (technical versus general university) . The Type of University also comes with a difference in probability of 25 percent, with Technical Universities having a probability of 50 percent for early market introduction compared to General universities with a 25 percent probability of market introduction at the threshold of five years after establishment. Whilst universities are part of larger regional and national innovation systems, they are also generating their own entrepreneurial ecosystem fostering economic growth and wealth creation in the region (Diaconu and Dutu, 2015; Miller and Acs, 2017; Breznitz and Zhang, 2019). Recognizing the university campus as an entrepreneurial ecosystem and as a place with nodes of larger networks (Miller and Acs, 2017), the university's culture toward entrepreneurship is also considered an element that influences the outcomes of university entrepreneurial activities (Hayter et al., 2018). University entrepreneurial culture may potentially either enhance or constrain individuals' propensity to engage with industry, patent inventions, and establish spin-off companies (Hayter, 2015; Fuster et al., 2019). On the other hand, entrepreneurial activity generally reinforces entrepreneurial culture, as successful academic entrepreneurs become role models for their peers, departments, universities, and regions.

Historically and pragmatically, technical universities are more engaged with industry partners and involved in the development of innovative products and the submission of patents compared with general universities. Thus, it could be argued that technical universities benefit from a richer entrepreneurial environment and provide better practical support for the creation and success of university spin-offs. The Kaplan-Meier graphs and the results of the log-rank test confirm such trend, indicating that university spin-off firms originating from technical universities experience faster market introduction compared to those from general universities.

All-in all, while the six factors that tend to influence time to market introduction were discussed here, it would be necessary to discuss the factors that turned out not to be significant as well. However, as mentioned before, one should not read too much into non-parametric estimates since they do not include the interaction of all model variables, and this may mislead the results and understandings. In Chapter 5 and 6, Cox regression analysis will be presented taking all influences and interactions into account, and the results will be discussed there in more detail. In the next section, attention shifts to firm survival and probabilities concerning different categories of spin-off firms.

4.4 Dynamics of Firm Survival

4.4.1 Introduction

New and young firms are the most exposed to the risk of exit as compared to older firms (Cefis and Marsili, 2006; Tsvetkova et al., 2014), especially in the first few years after establishment. This is known as liability of newness (Freeman et al., 1983) which states that at the point of founding a firm, the risk of dying is highest, and it decreases over time while the firm is aging and becoming more mature by learning experience and establishing several networks. Although some forms of firms’ exit, like merger and acquisition, do not count as a failure, or even are regarded as a successful exit for the business, from a broader perspective of policy makers, spending time and resources on establishment of a short-lived firm could be perceived as inefficient and negative. This is particularly true for university spin-offs that receive support from university and local authorities. For this reason, this study first presents an overview of the firm survival by making distinction between the closed ones and acquired ones, and all non-survived firms will be treated identically as being involved in a negative event in the firms life. In Chapter 6, analyses of firm survival make a distinction between non-survived firms through bankruptcy and acquisition.

Table 4.5 shows the survival rate and the average age of each category in the sample. Throughout the observation period (which starts from firm establishment until firm closure within the years of 1998 till 2018), 70 spin-offs (66 percent) survived, while 36 (34 percent) spin-offs closed down, either following bankruptcy (22 spin-offs; 21 percent) or following acquisition and integration (14 spin-offs; 13 percent). The observed survival rate is consistent with a recent study on firm survival done by Rannikko et al. (2019) which estimated 72 percent survival rate for high-tech startups founded in 2006 in Sweden in a time period of 8 years. It is worth noting that given the varying start and end points of university spin-offs between 1998 and 2018, the current study focuses on each firm's age. The end of the observation is in 2018, so the age of surviving firms is calculated until that year. For closed firms, whether through bankruptcy or acquisition, the average age is determined based on the period from establishment to closure.

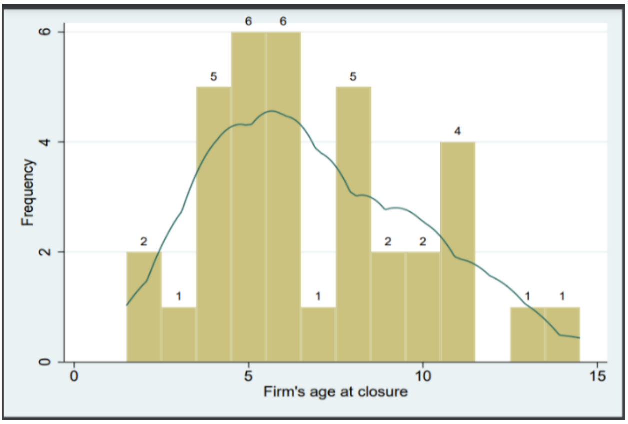
The average age reached among all university spin-off firms is 8.4, for survived university spin-off firms the average age is 9.2 years and for non-survived ones this is 6.9 years. To provide

Table 4.5 Survival rate and average age of USOs in the sample

Firms' status in 2018	Abs. (% share)	Average age of USOs
Survived	70 (66%)	9.2
Not-survived	36 (34%)	6.9
Not-survived: Acquired	14 (13%)	7.8
Not-survived: Closed down	22 (21%)	6.3
Total	106 (100%)	8.4

more detail, Figure 4.2 gives an overview of age of all closed firms when they died (acquired and integrated, or closed down). The density curve shows that the mortality rate decreases after age 6. It seems that the out the criticality of age between 4 and 6 is critical for firm's survival. While some studies, such as Cantamessa et al. (2018) and Kalyanasundaram et al. (2021), have identified a younger age, like 3 years, as critical for the failure of startups, it is important to note that these studies did not focus their analysis on high-tech startups. In contrast, a study by Tsvetkova et al. (2014), concentrating on high-tech startups, found that about half of the startups in the high-tech industry survive beyond five years. The findings of our study on university spin-offs active in sustainable energy technologies align with the results of the latter study.

Figure 4.2 Firms age at closure (n=36)



4.4.2 Survival/Closure

Table 4.6 provides the frequency of firm survival over the different categories of firm features. Among them, business diversification shows a large difference in survival rate (more than 20 percent). This points to a larger probability of university spin-off firms to survive if they are diversified (related product/market) in early years (82 percent) compared to the ones that have adopted (strong) focus (49 percent). Also, newness of the market shows a large difference, pointing to a larger probability to survive if university spin-off firms deal with existing markets (81 percent) compared to USOs dealing with emerging and new markets (60 percent).

The Log-Rank test produces results consistent with the findings, except for the newness of the market, which does not exhibit a significant effect on survival rates. In addition, another notable factor affecting survival rates is the founding team size. This result is as follows: smaller founding teams have a higher probability of survival (71 percent) compared to larger founding teams (53 percent). Kaplan-Meier Graphs illustrating these differences are presented in Appendix 4.2. Further in-depth discussions based on Log-Rank test results and Kaplan-Meier graphs are provided in the subsequent section below.

Table 4.6 Frequency of firm survival among categories and Log-rank test

Influencing factors (in two categories)	Survived USOs Abs.(% shar)e	Non-survived USOs Abs.(% share)	Log-rank (P-value)
Control variables			
Year of establishment			
- Out of the period of economic crisis	45 (68%)	12 (25%)	0.28 (059)
- Within economic crisis (2007-2010)	25 (62.5%)	15 (37.5%)	
Business model			
-Services	21 (78%)	6 (22%)	1.61 (0.20)
-Manufacturing oriented	49 (62%)	30 (38 %)	
Entrepreneurial orientation(risk related)			
Innovation radicalness			
-Incremental	42 (67%)	21 (33%)	0.22 (0.63)
-More radical	28 (65%)	15 (35%)	
Newness of market			
-Existing	22 (81%)	5 (19%)	1.27 (0.07)
-Emerging and new	48 (60%)	31 (40%)	
Diversification (product/market)			
-Diversified	45 (82%)	10 (18%)	11.66 (0.00)**
-Focus	25 (49%)	26 (51%)	
Owned resources/capabilities			
Founding team size			
-Larger (more than 2 pers.)	16 (53%)	14 (47%)	3.95 (0.04)*
-Smaller	54 (71%)	22 (29%)	
Highest education of founding team			
-Merely Master	20 (71%)	8 (29%)	0.31 (0.57)
-PhD in team	50 (64%)	28 (36%)	
Business experience of the founding team			
-Yes	34 (62%)	21 (38%)	2.17 (0.14)
-No	36 (71 %)	15 (29%)	
Access to resources/capabilities			
First collaboration with large firm			
-Early (within first 5 years)	29 (66%)	15 (34%)	1.33 (0.24)
-Late (incl. no networking)	41 (66%)	21 (34%)	
Access to first substantial investment			
-Early (within first 5 years)	27 (63%)	16 (37%)	0.80 (0.36)
-Late (incl. no investment)	43 (68 %)	20 (32%)	
Joining of first marketing professional			
- Present at start and early joining	32 (63%)	19 (37%)	1.50 (0.22)
- Joined late (incl. no joining)	38 (69%)	17 (31%)	
Quality of Entrepreneurial Ecosystem			
Quality NIS			
-High (DK,FI,SE)	38 (48%)	18 (52%)	1.25 (0.26)
-Lower (NL,NO)	32 (64%)	18 (36%)	
Location			
- Within metropolitan area	39 (55%)	21 (45%)	0.00 (0.96)
-Outside metropolitan area	31 (59%)	15 (41%)	
Type of Incubating university			
- Technical university	28 (58%)	20 (42%)	2.71 (0.09)
- General university	42 (72%)	16 (28%)	

p<0.05; **p<0.01

4.4.3 Kaplan-Meier Estimation and Factors Affecting Firm Survival

The frequency table and Log-Rank test results (Table 4.6), along with KM plots (Appendix 4.3), offer an informative overview of the firms' survival across different categories. According to the Log-rank test, only business diversification and the size of the founding team are identified as influencing firm closure. The Kaplan-Meier (KM) graphs for factors with a confirmed significant influence on firm survival, as indicated by the Log-rank test, are plotted and made available in Appendix 4.3. Considering the information from Figure 4.2, which suggests that the mortality rate decreases after age 6, and recognizing the greater accuracy in timeline of graphs at age 5, a five-year threshold was chosen for interpreting the KM graphs on firm survival. Table 4.7 summarizes the KM results, displaying the probability of firm survival over time for each category at the five-year threshold and illustrating differences in probabilities between categories. In contrast to Table 4.4, where the KM graph represents the probability of *not having market introduction*, and analysing market introduction requires calculating the probability of market introduction by subtracting the probability of not market introduction from 100, here the Kaplan-Meier graph directly provides the probability of non-closure, indicating firm survival—meeting the specific analysis needs. Thus, an extra calculation is not required.

Table 4.7 Probability of firm survival till 5 years in categories based on KM graphs

Influencing factors with significant difference	Categories	Probability of firm survival till 5 years	Difference in probabilities between two categories
Business diversification	Diversification in market/product	90%	90 – 75= 15%
	Focus	75%	
Founding team size	Larger (more than 2 pers.)	75 %	90 -75 = 15%
	Smaller	90%	

The result, that only two out of 14 investigated factors show to be influential in the time to firm closure, is quite unexpected. This outcome may be attributed to the restriction of the Log-Rank test, which includes only closed firms in the analysis (focussing on a small amount of university spin-off firms, i.e. 36) and excludes the surviving ones. In other words, the non-parametric estimation alone may not suffice to accurately describe the firms' survival using the given database, and additional analysis is needed. Accordingly, Chapter 6 of the thesis will discuss the survival analysis of the firms in more detail, utilizing more accurate and comprehensive methods (Cox regression analysis and competing risk analysis). However, the preliminary results obtained from Log-rank test and KM graphs are very insightful and provide the initial thoughts for further analysis in the thesis. The results are discussed below.

- ***Business diversification***. Between the two categories of business diversification, the difference in the probability of survival until age 5 is nearly 15 percent, favouring university spin-off firms employing a diversification strategy over those with a focus strategy. University spin-off firms with a diversification strategy demonstrate a 90 percent probability of survival until age 5, while, during the same period, university spin-off firms with a focus strategy had a 75 percent probability of survival. The strategy of diversification is a common approach to minimize uncertainty and risk in business by adding a lower-risk business alongside the primary one. This approach has the potential to increase a firm's market size or expand into adjacent new markets, as well as increase cash production to avoid to be dependent on venture capital injections. According to this thinking, the pattern in the above analysis shows that university spin-off firms that adopted a diversification strategy have a higher survival rate. This result is consistent with previous studies (Borghesi et al., 2007; Coad and Guenther, 2012) and emphasizes the importance of diversification as a viable strategy, particularly for young small firms operating in the risky sustainable energy market.

- Founding team size. The results indicate a 15 percent higher probability of survival until age 5 for USOs with smaller founding teams (one or two persons) compared to those with larger founding teams (more than two persons). Specifically, there is a 90 percent probability of survival until age 5 for university spin-off firms with smaller teams, whereas larger founding teams have a 75 percent probability of survival during the same period. The impact of founding team size on firm performance and survival has been a topic of debate, with arguments for both larger and smaller teams. Some studies, based on resource-based theory, suggest that a larger founding team has more resources available to start a new firm, leading to better performance (Eisenhardt and Schoonhoven, 1990). However, other studies argue that smaller founding teams can be more agile and take quicker advantage of startup opportunities (González-Cruz et al., 2020). Consistent with the finding of the latter study, our study shows longer survival for firms with smaller founding teams. This result cannot only be explained by the greater agility of such firms, but also by the reduced potential for conflicts, especially among founders of university spin-offs who are often less acquainted with the business environment and may encounter more challenges.

4.5 Firm Survival and Market Introduction

As previously stated, the main focus of this thesis is on the time to market introduction and firm survival. This raises the question whether there is a relationship between market introduction and firm survival. In other words, is the timing to market introduction a critical factor in firm survival? While it may initially seem that market introduction would enhance the chances of survival, the relationship between the two could be more complicated or even opposite. Agarwal and Gort (2002) explored the survival of firms across the product life cycle and concluded that in the early years when new products are introduced to the market, the risk of firm survival increases due to technical changes. In another study conducted by Banbury and Mitchell (1995), it was demonstrated that introducing incremental innovation to the market before rivals could increase market share, subsequently improved the chances of firm survival. However, it's crucial to note that this result was derived from the analysis of a specific industry, namely the cardiac pacemaker industry, so generalization should be taken cautiously. Further, it can be assumed that market introduction is one milestone, but what often follows, namely scaling-up of production, comes with new challenges, like operating in international markets with a sales organization, etc. (Taheri and Van Geenhuizen, 2019). This thesis specifically investigates the influence of a firm's age of first market introduction on its survival in the sustainable energy market.

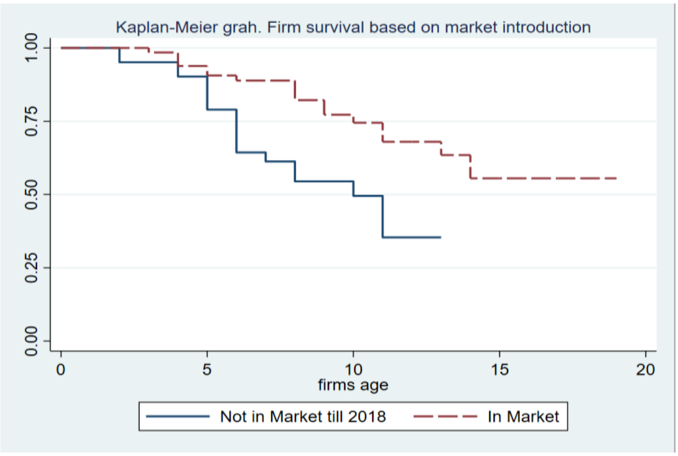
Table 4.8 provides a comparison between university spin-off firms in the market and those not in the market and type of non-survival. The table reveals that 17 out of 22 university spin-off firms that closed (77 percent of closed firms) did not experience market introduction. In contrast, 12 out of 14 acquired university spin-off firms (86 percent of all acquired firms) did experience market introduction before acquisition. These contrasting results, though based on relatively small numbers, underscore the significance of market introduction for firms' survival.

Table 4.8 Market introduction and firm survival

	Survived Firms	***Acquired Firms***	***Closed Firm***	***Total***
In Market (share among all in market USOs)	48 (73.8%)	12 (18.5%)	5 (7.7 %)	65 (100%)
Not in Market (share among all not in market USOs)	22 (53.7%)	2 (4.9 %)	17 (41.5%)	41 (100%)
Total	70	14	22	106

With regard to Kaplan-Meier graphs, Figure 4.3 depicts the survival function among two groups of university spin-offs —those with market introduction and those without. Here, the vertical axis demonstrates the survival rate of firms (percentage of firms that did not close), and the horizontal axis is the analysis timeline, representing firms' age from 0 to 15 years. The two plots refer to two categories of firms: in red, those with market introduction and in blue, those without market introduction till 2018. Although there are no significant differences in the probability of survival until age 5 for the two categories, clear differences appear when survival until age 10 is considered. Firms with market introduction have a 75 percent probability of survival until age 10, whereas firms without market introduction have a 50 percent probability of survival for the same time period.

Figure 4.3 Firm survival based on market introduction



Examining the graph from another perspective reveals different insights, and a distinct contrast emerges. Approximately 55 percent of firms with market introduction survived at the end of the observation period, whereas this number decreases to about 35 percent for firms without market introduction. The Log-Rank test was employed, and the results confirm significant differences between the two plots, with a p-value smaller than 0.01. In Chapter 6, the effect of age at market introduction on firm survival will be quantitatively analysed using Cox regression model.

4.6 Summary and Conclusion

The survival rate and average time to market of sustainable energy spin-offs are important metrics for universities, entrepreneurs and policymakers dealing with accelerating energy transition. However, these metrics are highly dependent on industry type and time intervals, making it challenging to generalize.

This chapter provided valuable insights into the role of characteristics of university spin-off firms in the sustainable energy market, i.e. market introduction and survival, through analysing the database of 106 university spin-off firms retrospectively over the observation time from 1998 to 2018. The results in this chapter can be summarized as follows:

- Market introduction is reached by more than half of the sample, i.e. 65 firms (or 61 percent), with most market introduction at age five or earlier. Relatively early market introduction is reached by the following spin-off segments: active in services, involved in incremental innovation, in established markets, and education of the founding team at Master level. Conversely, spin-offs active in manufacturing-oriented activity, radical innovation and emerging/new markets are faced with relatively late or no market introduction, thereby reflecting a stronger risk-taking. From a transition point of view, this situation is not favourable, because there is a need for more radical innovation that is also brought to market in a quick manner.
- Survival at the end of the observation period is reached by 70 firms (66 percent) in the sample. Survival is most often reached by spin-offs that adopted diversification, and by spin-offs managed by a relatively small founding team. The former may contribute to risk mitigation, while the latter may aid in reducing conflicts within the managerial team. Survival also tends to be enhanced by early market introduction.
- This descriptive analysis suggests that the relationship between early market introduction and firm survival is more complex than expected. Factors that contribute to faster market introduction did not exhibit a clear impact on firm survival and vice versa. Therefore, the observations indicate that the relationship between market introduction and firm survival is not straightforward and requires a more comprehensive analysis.

The non-parametric methods used in the chapter, Log-Rank test and Kaplan-Meier estimator, are widely applied in survival analysis given their simplicity and flexibility. However, these methods do not consider the interaction between different factors and consequently have less validity compared to semi-parametric methods such as Cox proportional hazard regression. Despite this limitation, non-parametric methods provide a broad overview of the scene prior to the regression analysis in this thesis. The methods can identify important variables that are associated with particular events and survival and provide insights into general trends and patterns in the data. As a next step, Chapter 5 and 6, are dedicated to exploring statistical models that examine the relationships more thoroughly, using Cox proportional hazard regression analysis.

Appendixes

Appendix 4.1 Explanation of Log-Rank test

Log-Rank test is a nonparametric test and appropriate to use when the data are right skewed and censored (Bland and Altman, 2004). Like survival analysis, Log-rank test is widely used in clinical trials to establish the efficacy of a new treatment in comparison with a control treatment when the measurement is the time to event. It tests the null hypothesis that there is no difference between the samples in the probability of occurrence of an event (here market introduction/firm closure) at any specific time. The analysis is grounded on the number of events that occurs in each time slots. For each of these instances, the test computes both the observed number of the event within each group (for example, the group of incremental innovation vs. radical innovation) and the expected number under the assumption that there is no actual difference between the groups.

Below, the Log-Rank test analysis will be elucidated by calculating the actual numbers of market introductions between two groups of university spin-off firms with incremental innovation versus radical innovation. Table 4.9 serves as a life table, tracking all firms in the sample in two groups based on the radicalness of their innovation from age 1, and then progressing one year at a time until the age at which the firm has market introduction. If the firm did not have market introduction, the observation continues until the end of 2018.

Table 4.9 Age of USOs at first market introduction and types of innovation radicalness

Age of USOs at first MI	Firms exposed to MI	Firms with MI	Censored firms *	Incremental innovation/ MI	Radical Innovation/ MI
1	106	15	0	14	1
2	91	3	1	3	0
3	87	10	1	7	3
4	76	9	8	7	2
5	59	8	5	5	3
6	46	3	2	2	1
7	41	6	4	4	2
8	31	5	4	3	2
9	22	3	7	2	1
10	11	1	3	0	1
11	8	0	4	0	0
12	4	1	1	1	0
13	2	0	1	0	0
14	1	1	0	0	1

*Firms get censored either by firms closure before MI or through not facing the event (MI) till 2018

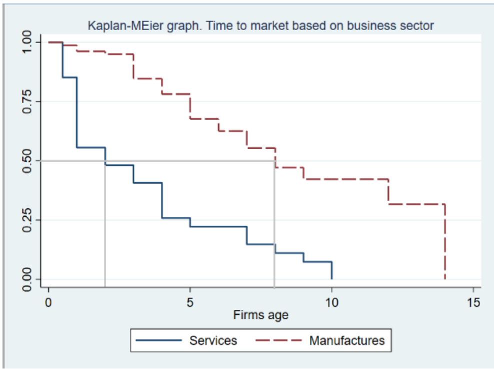
Appendix 4.2 Kaplan-Meier graphs and time to market

The probability of early market introduction in different categories is plotted by KM graphs. The vertical axis in KM graph demonstrates the rate of firms (percentage) that did not have market introduction and the horizontal axis is the analysis timeline from 0 to 15 years which is the firms' age when they have market introduction. Discussing KM graphs below is limited to the factors that were found statistically significant in the previous analysis.

Business model

Figure 4.4 X displays the time to market which is plotted in two different lines showing the probability that university spin-off firms in different categories have market introduction in a given period of time.

Figure 4.4 Time to market based on business sector



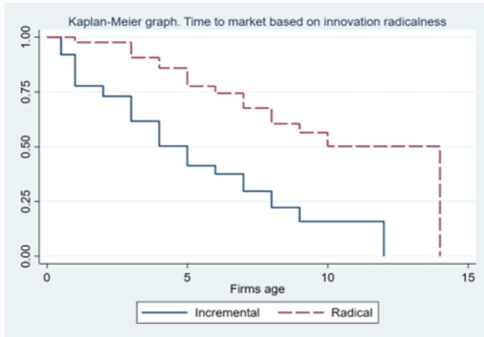
The first insight can be derived by examining the time when 50 percent of firms in each group had market introduction. This can be achieved by drawing a line starting from 0.50 on the vertical axis to intersect with the red and blue line graphs, pinpointing the corresponding time period on the horizontal axis. This comparison reveals differences between the two categories (about age 2 versus about age 8). However, additional interesting information may be provided as well, such as firms entering the market much sooner or later than the time of 50 percent.

Accordingly, the graph also shows that there is 75 percent probability for manufacturing-oriented university spin-off firms to be not in the market at age 6, while for service firms this age is only 1. It means service firms have the market introduction in the at first year with a probability of 25 percent. The KM graph also indicates that the differences of time to market introduction between the two groups of service and manufacturing-oriented university spin-off firms hold true throughout the time span considered. Throughout the 15-year observation period, service-oriented university spin-off firms consistently had a higher probability of market entry than their manufacturing-oriented counterparts, as indicated by the relatively constant distance between their respective curves.

Innovation radicalness

Again, obvious differences are observed between categories of radicalness of innovations in Figure 4.5. It takes about 10 years for university spin-off firms with more radical innovation to have market introduction with a probability of 50 percent (red-dashed line), while it takes only take 5 years for firms with more incremental innovation to be in the market by probability of 50 percent. In addition to this point, the last high step of radical innovations starts at 0.50 in vertical axis. Since steps in the plot demonstrate the university spin-off firms that do not have the chance of '*not having market introduction*' any more through reaching the market, the long step for radical innovations counts 50 percent chance for firms with radical innovation to not have market introduction till end of the observation period. This ratio for incremental innovation is about 10 percent, which means there is 10 percent probability for university spin-off firms with incremental innovation and 50 percent for firms with radical innovation to not have market introduction till end of the observation period.

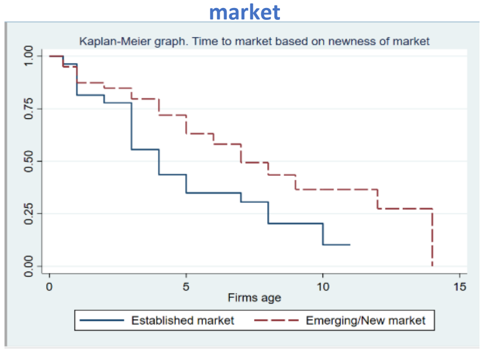
Figure 4.5 Time to market based on innovation radicalness



Newness of the market

Although not as clear as previous figures, the two KM plots in Figure 4.6 show different moments for market introduction between university spin-off firms in established or in emerging/new markets. It indicates that there is more than 25 percent probability for the firms in emerging/new market to not have market introduction, while this number reduces to 10 percent for firms in established markets. After 10 years since their establishment, only around 10 percent of firms in established markets may not have achieved market introduction. In contrast, during the same period, about 45 percent of university spin-off firms in new/emerging markets may still not have market introduction. However, the graphs show that the firms behave very similar in terms of market introduction to the two types of market in the first three years, and there is 75 percent probability for firms in both markets do not have market introduction till age 3.

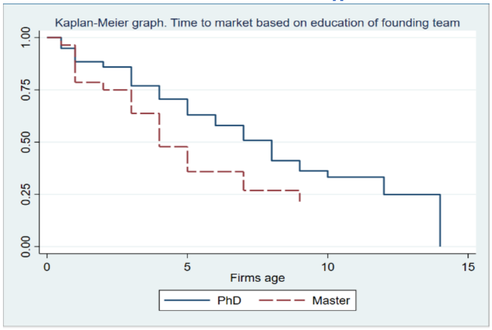
Figure 4.6 Time to market based on newness of market



Highest education of founding team

Figure 4.7 reveals that when the founding team members hold Master's degrees as the highest educational degree, the university spin-off firm experienced faster market introduction as compared to teams with PhDs. Till the age seven, 75 percent of the firms with Master degree have had market introduction but 75 percent of firms with PhD among founders would have market introduction till the age 12 after establishment.

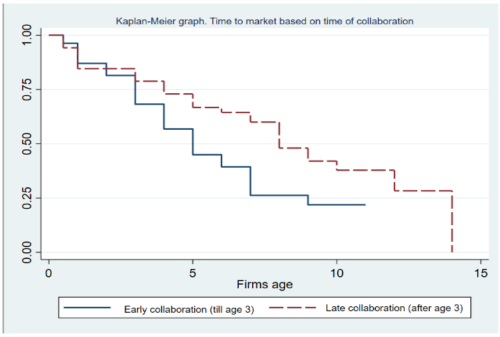
Figure 4.7 Time to market based on education of founding team



First collaboration with large firm

The KM plots in Figure 4.8 indicate that both categories of university spin-off firms with early and late collaboration have very similar market introduction till age 4 when 75 percent of firms in both groups did not have market introduction. However, in the middle of the time span, the graphs show clear distances. Till age 5, 50 percent of the firms that had early collaboration with larger firms (first collaboration till age 3, have had market introduction. This age for firms with late or no collaboration is age 7.

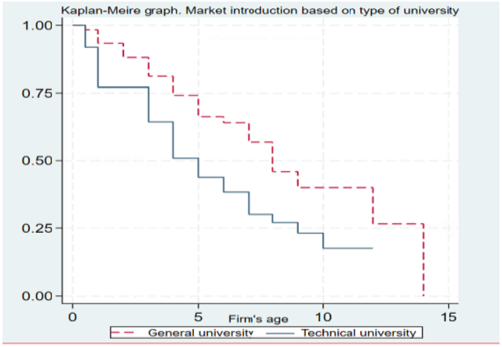
Figure 4.8 Time to market based on first collaboration with large firms



Type of university

A clear distinction between the Kaplan-Meier (KM) plots related to technical universities and general universities is depicted in Figure 4.9. At age 5, the graph indicates that 50 percent of university spin-off firms originating from technical universities had early market introduction, whereas this percentage is 25 percent for firms from general universities. As time progresses until age 10, 80 percent of university spin-off firms from technical universities have achieved market introduction, while during the same timeline, only 60 percent of the firms from general universities have achieved market introduction.

Figure 4.9 Time to market based on type of university



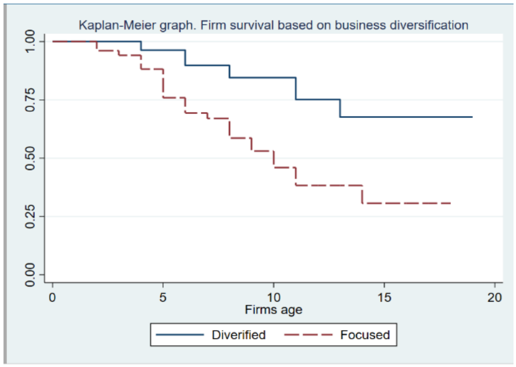
Appendix 4.2 Kaplan-Meier graphs and firm survival

The probability of firm survival in different categories is plotted by KM graphs. The vertical axis here is the probability that firm survive. A steeper slope plot would represent faster failure rates and less probability for firm to survive.

Diversification (product/market)

Figure 4.10 indicates a clear difference in survival according to business diversification. It could be observed that while 50 percent of firms with a focus strategy could survive till year 10 survival. firms with a diversification strategy seem to survive much longer. By the end of the observation period in 2018, about 70 percent of the diversified firms survived. Notably, around 80 percent of these diversified firms managed to survive until the 10th year.

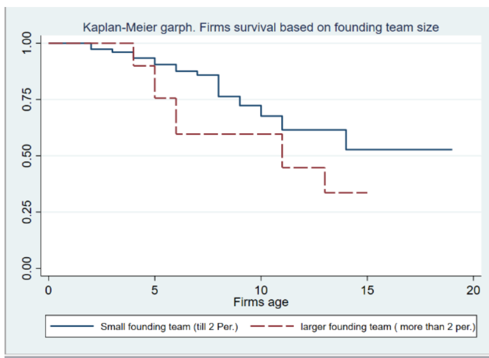
Figure 4.10 Firm survival based on business diversification



Founding team size

Based on the graphs in Figure 4.11, firms with smaller founding team size survive longer than firms with bigger founding team. While 50 percent of the university spin-off firms with larger founding team could survive till age 10, the blue graph shows that a little more than 50 percent of firms that have smaller founding team will remain survived until the end of the study.

Figure 4.11 Firm survival based on size of founding team



Chapter 5. University Spin-offs' Time-to-Market Introduction in the Sustainable Energy Sector

5.1 Introduction and Research Questions

The demand for innovative sustainable energy solutions is on the rise. University spin-off firms (USOs) are recognized as significant contributors to bringing new technologies to the market that can address this demand. However, sustainable energy solutions are part of a larger energy system, and for success in market introduction, alignment with this system is crucial. In this context, the role of risk-taking or -mitigating strategies, resources and capabilities, and the impact of the entrepreneurial ecosystem become important. Concerning market introduction, university spin-off firms may leverage benefits from multiple networks and facilities of the entrepreneurial ecosystem to compensate for any missing resources and capabilities, particularly those related to risk assessment, risk-mitigation and risk-avoidance (Hayter, 2016; Teece et al., 2016). Such networks and facilities can accelerate the adoption and utilization of sustainable energy to combat climate change, underscoring the importance of national and local support in this regard (Lerman et al., 2021).

The focus on university spin-off firms in this study stems from their unique status as startups independently established by university graduates and/or staff, aiming to bring novel university knowledge to the market (Pirnay et al., 2003; Shane, 2004). This choice is driven by their close association with research universities, providing them with cutting-edge technology, and their relatively higher chances of surviving the initial years due to specific incubation support (Van Geenhuizen and Soetanto, 2009; Soetanto and Jack, 2015). The current study aligns with the consolidation of the third mission at universities in Europe and North America, emphasizing a growing interaction with civic society and focusing more on societal problems and needs within the realm of knowledge commercialization (Goddard and

Vallance, 2013; Van Geenhuizen et al., 2016; Politis et al., 2019; Fabiano et al., 2020; Cai and Amaral, 2021).

It should be noted that young university spin-off firms have distinct resource needs, primarily for two reasons. First, university spin-off firms are established in a research environment, which is often less acquainted with business activities, and the support structures for operating in a business environment are frequently absent or poor-developed (Rasmussen et al., 2014). Secondly, founders of university spin-off firms may also lack experience in developing radically new products or entering new markets (e.g., Covin and Lumpkin, 2011; Bessant et al., 2014). This can partly be attributed to the formation of teams in founding university spin-off firms, which is often an informal process stemming from friendships between graduates, shared preferences, specific knowledge gained during Master's studies, or patent ownership among university professors (Clough and Vissa, 2018). In such situations, a large team may be burdensome and counterproductive, but knowledge about founding team dynamics and high-risk levels in more radical energy innovations is lacking. In addition to these considerations, similar to other high-tech startups, emphasis should be placed on addressing missing resources and capabilities, such as financial support and reputation, already recognized in the early 1980s as the liability of newness or smallness (e.g., Freeman et al., 1983). Along similar lines, attention should be drawn to threatening situations, like the 'valley of death' when a final round of (pilot) testing is required before market introduction can be undertaken, while capital providers exhibit reluctance (Auerswald and Branscomp, 2003; Bocken and Snihur, 2020).

Besides the absence of resources, university spin-off firms in sustainable energy may face market barriers to adopt their solutions. This may happen due to strongly hold positions of existing energy systems and incumbents (Hockerts and Wüstenhagen, 2010; Hoogendoorn et al., 2019). Energy systems can be seen as socio-technical systems, including layers of different dynamics and resistance to change (Geels 2005, 2014; Smith et al., 2010; Markard et al., 2016). Specifically, the so-called *regime* acts as a solid structure that preserves stability in the energy system, derived from rules that direct and coordinate social and economic behaviour in reproducing system activities, including lock-in mechanisms, like sunk costs, vested interests, user preferences, experienced business models, pricing-systems, etc. In contrast, so-called *niches* are seen as acting at another system level (Lopolito et al., 2011; Quitzau et al., 2012; Smith and Raven, 2012) in which practical learning is possible under protected circumstances (e.g. beyond influence of market mechanisms), encompassing customer demand, regulation (standards), and legitimacy towards large firms and governments, etc. The implications of all this for university spin-off firms - attempting to bring energy inventions to market and grow, thereby taking several risks - are not well-understood and justify in-depth study.

The absence of business experience in an environment that may resist change and the adoption of new solutions bring about a number of *knowledge gaps.* However, consensus on the factors that influence the market introduction of technology startups (including university spin-off firms), is missing. In one view, these firms are acknowledged for disrupting innovations due to their flexibility, willingness to take risk, creativity, responsiveness and forward-looking attitude (Janssen and Moors, 2013), thereby quickly shifting to specialized markets at global level supported by smart networking (Teixeira and Coimbra, 2014; Amelang, 2019). In another view, stronger attention is given to the vulnerability of these firms in market adoption of new (disruptive) solutions, specifically for those solutions being more expensive for customers or coming with user inconvenience.

The significance of the entrepreneurial ecosystem for high-tech startups cannot be overstated. The environment in which university spin-off firms in the sustainable energy sector operate at the country, urban, and university levels might facilitate the success of market introduction and other startup activities. At the country level, the current study considers national innovation systems (NIS) (Lundvall, 2007; Jacobsson and Bergek, 2011). At the urban/regional level, it explores entrepreneurial/innovation ecosystems, often associated with different city sizes and the scale advantages of agglomeration (McCann, 2006; Florida et al., 2017). At the university level, the focus is on supporting technology development and its commercialization (Miller and Acs, 2017; Sjöö and Hellström, 2019), with a distinction made between technical universities and general universities. However, there has been limited investigation into the practical impact of these local/regional qualities on risk mitigation and faster market introduction.

Given the above knowledge gaps and contrasting views, the following three research questions are addressed:

1) To what extent do university spin-offs firms successfully bring sustainable energy innovations to the market, and what is the time frame involved?

2) What factors influence the time patterns of market introduction, particularly in terms of risk-taking and risk-mitigation strategy factors and availability of resources and capabilities?

3) For highly innovative university spin-off firms, to what extend do entrepreneurial ecosystems affect time patterns of market introduction?

The current study is one of the first empirical studies that bridges energy systems and energy entrepreneurial studies in the context of innovation and commercialization studies. Also, as one of the first it reveals - using descriptive analysis and quantitative modelling - significantly later market introduction for radically new products/processes compared to incremental innovations, and for new (emerging) markets compared to existing markets. The outcomes also reveal positive influence of early access to resources, i.e. early main collaboration (large firm) and early substantial investment. Furthermore, it confirms that technical universities provide more support for university spin-off firms and contribute to faster market introduction. All in all, despite the relatively small number of indicators used in the study, the trends of delay from risk-taking and speeding-up through early access to the resources are sufficiently convincing.

The structure of the chapter is as follows: Section 5.2 discusses theoretical perspectives and the design of hypotheses, followed by a presentation of the methodology in Section 5.3. In Section 5.4, the analysis and its results regarding the time-patterns of market introduction and the influences on these patterns are identified and characterized. The findings of this modelling will be discussed in Section 5.5. Finally, Section 5.6 sums up the chapter by highlighting the main outcomes and presenting several recommendations.

5.2 Theoretical Perspectives and Hypotheses Development

The theoretical approach adopted in investigating time to market introduction in the current study includes entrepreneurial orientation and strategic choice mainly concerning risk-taking and mitigation of risks' impacts, and this is coupled with a competence-based perspective on resources that are owned by firms and gained by them among others through networks (e.g. Hayter, 2015, 2016; Van Geenhuizen and Nejabat, 2022). The study also explores the effects of the entrepreneurial ecosystem at different levels. These sets of conditions are discussed in more detail below.

5.2.1 Entrepreneurial Orientation and Strategic Choice

Strategic choices of firms reflect among others their entrepreneurial orientation in terms of risk-taking and -mitigation, like in degree of innovativeness, pro-activeness and competitive aggressiveness, in particular risk-taking and -avoiding (Covin and Lumpkin, 2011; Roper and Tapinos, 2016; Teece et al., 2016). The choices included in this study, encompass the firm's business model either to be engaged in manufacturing-oriented activities or fully engaged in service-oriented activities, the radicalness of the energy technology itself (incrementally new or more radically new) (Bessant et al., 2014) and also newness of customer markets. Newness of markets distinguish between accepted markets, e.g. wind energy markets, in contrast to markets facing resistance, like hydrogen as carrier/energy source (IEA 2018). Next, a further strategic choice related to entrepreneurial orientation (risk-taking), is to adopt a certain diversification strategy (e.g. with services, or related traditional products), for example, aimed at raising cash in the face of the 'valley of death' (Miller, 2006; Mohr et al., 2013).

Building upon the arguments presented earlier, the following hypotheses are proposed, indicating the conditions favouring earlier market introduction:

Hypothesis 5.1. USOs in sustainable energy that have adopted an incremental innovation strategy, have earlier market introduction compared to USOs that have adopted a radical innovation strategy.

Hypothesis 5.2. USOs in sustainable energy that enter established markets, have earlier market introduction compared to USOs that enter new markets.

Hypothesis 5.3. USOs in sustainable energy that adopt a diversification strategy in product or market, have earlier market introduction compared to USOs adopting focus strategy.

5.2.2 Resources and Capabilities

The entrepreneurial orientation of a firm, reflected in its risk-taking strategic choices such as incremental innovation, market establishment, and product and market diversification, entails varying resource and capability requirements for effective implementation (Barney and Clark, 2007). In this respect, the study fits into a literature stream on firm performance as influenced by certain firm-specific and certain firm-external conditions, mainly focusing on knowledge and capabilities (competences) as a critical resource (Mathisen and Rasmussen, 2019). In the competence-based view, emphasis in the current study is placed on two sets of directions. The first set revolves around the resources owned by the firm, particularly focusing on the characteristics of the founding team, including its size, higher education, and business experience (e.g. Van Dierdonck and Debackere, 1988; Clarysse and Moray, 2004). The second set involves firms' accessing of external resources and capabilities, in particular age at which this occurs, i.e. age of first formal collaboration, firms' age at receiving first substantial investment capital, and firms' age at inclusion of the first marketing person in the team. Emphasis in the second set, is placed on the timing of acquiring these resources, assuming that earlier use is associated with greater advantages.

Founding team competences

The study takes into account the characteristics of the founding team as a crucial aspect of university spin-offs. Founding team characteristics have often been subject of attention in literature addressing potentials of university spin-offs. A larger size of founding teams remains a debated issue, with some advocating for its potential to bring diverse information, knowledge, and opinions to the firm, while others argue that it may lead to the emergence of fault lines within teams, causing delays in decision-making and increased conflict (Heirman and Clarysse, 2007; De Cleyn et al., 2015; Bjørnåli et al., 2016). However, for small high-tech university spin-offs, the diversity of information and knowledge might be important, and the study supports this idea.

Similar debates exist concerning the education level of the founding team. A dominance of a PhD education may delay a practical business orientation, as compared to a team with Master level education. In contrast to the diversity of information in larger founding teams (as stated above), this study argues that a strong business and market orientation is more important for university spin-offs compared to a mix of academic (science) and market introduction; accordingly, business that are run by Masters could be more successful than those with PhD holders (Blank, 2013; Caldera et al., 2019).

Further, owning business experience before founding a university spin-off firm is considered an advantage that many university spin-offs might lack. Given that university spin-off firms are primarily established by individuals with academic backgrounds, having team members with prior business experience would enhance the firm's capabilities and count as a valuable resource, enhancing market introduction.

Building on these arguments, the study formulates the following hypotheses:

Hypothesis 5.4. USOs in sustainable energy when founded by a larger team have earlier market introduction compared to USOs founded by a smaller team.

Hypothesis 5.5. USOs in sustainable energy with founding team that have a Master as highest education, have earlier market introduction compared to USOs with a PhD degree among the founding team.

Hypothesis 5.6. USOs in sustainable energy which involve a founding team member with pre-business experience, have earlier market introduction compared to USOs without involvement of a founding team member with pre-business experience.

Timing of access to external resources and capabilities

In addition to examining the resources owned by firms, the capability to acquire specific resources is crucial, providing distinct advantages. Moreover, it is imperative to consider the timing of resource acquisition, a factor that has often been overlooked. Few studies have explored the temporal aspect of resource acquisition by linking it to the life cycle or growth stages of firms (e.g., van Geenhuizen and Soetanto, 2009). Building upon this view, the study delves into the age at which university spin-offs secure resources, assessing the impact of the duration of time on the time to market introduction. This temporal dimension adds a nuanced layer to the understanding of how resource acquisition timing influences the market entry of university spin-offs. The key underlying assumption dwells upon the liability of newness for startups (Stinchcombe, 1965), expecting that earlier access to resources leads to better firm performance, including product development and market introduction. Consequently, the following hypotheses are formulated.

Hypothesis 5.7. USOs in sustainable energy that develop collaboration with large firms early after start, have earlier market introduction compared to USOs that develop collaboration later or not at all.

Hypothesis 5.8. USOs in sustainable energy that gain substantial financial investment early after start, have earlier market introduction compared to USOs that gain financial investment later or not at all.

Hypothesis 5.9. USOs in sustainable energy that own market knowledge or attract marketing staff early after start, have earlier market introduction compared to USOs that attract marketing staff later or not at all.

5.2.3 Entrepreneurial Ecosystem

The impact of environmental conditions, specifically the entrepreneurial ecosystem, holds significant relevance in startup studies, particularly within the context of university spin-off firms. This study delves into larger (geographic) systems where firms operate and establish networks to acquire competences and resources. Attention is directed towards various levels, encompassing concepts such as the National Innovation System, urban innovation ecosystems (city size), and the university as the initial incubating environment for spin-offs. The term “ecosystem” in this context denotes the mutual interdependence and evolutionary development of core actors, as well as associated actors, and their networks enabling boundary spanning, intermediation, and new entrepreneurship (Heaton et al., 2019; Stam and Van de Ven, 2021).

National Innovation Systems (NIS) represent the intricate web of institutions, policies, and interactions that collectively influence a country's approach to innovation and technological development. Within this system, the government, industry players, universities, and research institutions collaborate to create an environment conducive to fostering innovation and driving economic growth. National Innovation Systems vary in their approaches to promoting entrepreneurship and energy innovation, employing mechanisms such as subsidies, tax exemptions, and research support for specific energy technologies (Lundvall, 2007; Jacobsson and Bergek, 2011).

In examining the location of firms, the characteristics of metropolitan areas are important. City size, considered one of the indicators for the qualities of urban innovation ecosystems, underscores benefits such as information density (knowledge spillovers), diverse labour markets, and the size of customer markets, providing scale advantages through agglomeration economies (McCann, 2006). Large metropolitan cities, in particular, are associated with relatively high quality levels, enhanced by the presence of several networks, institutions, and communities that foster entrepreneurship and risk-taking behaviour (Burch et al., 2013; Spigel, 2017; Acs et al., 2017; Florida et al., 2017; Stam and Van de Ven, 2021).

The impact of incubating universities, as the initial ecosystem for university spin-off firms, is well-acknowledged in recent research (Heaton et al., 2019). Models like the Triple Helix have attracted attention, framing the concept of interactions among academia, industry, and government to foster economic development. While such models emphasize the crucial roles of universities and provide a predetermined list of actions to strengthen their ecosystems (Etzkowitz, 2003; Cai & Etzkowitz, 2020; Cai and Amaral, 2021), it is essential to recognize the diversity in strategies that universities employ toward spin-off development and support (Clarysse et al., 2011). Universities vary in their primary focus, with some emphasizing fundamental research and others directing their efforts towards more applied sciences (Audretsch and Belitski, 2022). It can be anticipated that universities focusing on applied science and technology, often named technical universities, possess greater practical business development capabilities, actively encouraging the creation and support of spin-offs. Building on above insights from the literature, the following hypotheses are formulated.

Hypothesis 5.10. USOs in sustainable energy located in countries that rank high in the national innovation system, have earlier market introduction compared to USOs located in countries with a lower rank in this system.

Hypothesis 5.11. USOs in sustainable energy that operate in metropolitan area have earlier market introduction compared to USOs that operate in small cities, or at far distance from metropolitan area.

Hypothesis 5.12. USOs in sustainable energy that originate from a technical university, have earlier market introduction compared to USOs that originate from general universities.

In the next sections, the hypotheses on time to market will be empirically tested using a sample of 106 university spin-off firms and Cox regression analysis (explained in Chapter 3, Section 3.2 and 3.4).

5.3 Methodology Aspects

Following the methodological aspects, specific parts of Chapter 3 are included to enhance the clarity and consistency of the analytical part of the chapter below. Section 5.3.1 will discuss the database, variables, and measurements used in the analysis of this chapter, while Section 5.3.2 will specify the method of analysis.

5.3.1 Database, Variables and Statistics

The database of university spin-off firms is derived from northwest Europe, with detailed information available in Chapter 3, Section 3.2.1. The selection of countries —Denmark, Finland, Sweden— is motivated by the favourable environment for small and entrepreneurial firms, allowing for the observation of their market introduction and long-term survival. Norway and the Netherlands are included due to a less favourable environment for small entrepreneurial firms during several years of the observation period in this study (Global Entrepreneurship Monitor (GEM), 2010; Innovation Union Scoreboard 2015; Fagerberg and Fosaas, 2014; Dahl Andersen et al., 2019; Meijer et al., 2019). In the Netherlands, for instance, the high production and consumption of natural gas has served as a country-specific barrier to experimentation with sustainable solutions for several years.

The study includes data about the places of university spin-off firms foundation and their incubation sites. Cities involved range from large metropolitan areas like Copenhagen and North Randstad (e.g., Amsterdam) to larger and smaller cities at a distance, such as Trondheim (Norway) and Lappeenranta (Finland), as listed per country (Appendix 5.1, Table 5.3). The incubation sites are related to several universities (Appendix 5.2, Table 5.4).

The measurement of variables is thoroughly explained in Chapter 3, Section 3.3.3 and a comprehensive and detailed descriptive analysis of the sample regarding time to market is provided in Chapter 4, Section 4.3. In the current section, the descriptive statistics and the measurements will be explained. The model to be tested in this chapter includes one dependent variable (Time to market introduction), two control variables (Period of establishment and Business model) and 12 explanatory variables. All variables, the measurements and statistics of the sample are discussed in Table 5.1.

Overall, 61 percent of the sampled USOs reached market introduction, while 39 percent encountered challenges and delay, or failed in market introduction. The first row of Table 5.1 displays the average age of market introduction for firms that entered the market till end of the observation period, 2018. Also, for firms that did not reach the market by 2018, the average age of firms from establishment to the end of the observation period (2018) is presented.

Variables	Measurement (scale)	Results
Time to market introduction (MI)	Number of years between firm establishment and first sale (ratio)	Reached MI (61%): Av.=4.42; SD=3.24; Min-max: 1-14 MI not reached (39%): Av.=7.22; SD=2.8; Min-max: 2-13
Period (Year of Establishment)	Time period beyond economic crisis between 2007 till 2010 or within this period (ordinal)	1= Beyond economic crisis: 66 (62%) 2=Within economic crisis: 40 (38%)
Business model	Services or manufacturing-oriented (ordinal)	1=Services: 27 (25.5%) 2=Manufacturing-oriented: 79 (74.5%)
Innovation radicalness	Newness of innovation to the market and industry (ordinal)	1=More incremental: 63 (59.4%) 2=More radical: 43 (40.6%)
Newness of Market	Newness of the market (ordinal)	1=Established market: 28 (25.5%) 2=Emerging market: 53 (55.6%) 3=New market: 25 (18.9%)
Business diversification	Diversification in product or market (ordinal)	1=Focus: 51 (48.1%) 2=Diversified: 55 (51.9%)
Size of founding team	Number of founding team members at founding time (ordinal)	1= More than 2 persons: 28 (27%) 2= Two persons: 39 (38%) 3= One person: 37 (35%)
Founding team education	Master among founders, or PhDs involved (ordinal)	1= Master degree: 28 (28%) 2=PhD degree: 78 (72%)
Founding team business experience	Pre-business experience in founding team and/or firm management (ordinal)	1=Yes: 52 (48.1%) 2=No: 54 (51.9%)
Age at first collaboration	Years between firm establishment and first collaboration with large firms (ratio)	Never had collaboration till 2018: 23 (22%) With collaboration: 82 (78%) Mean age at first collaboration: 3.2 (SD: 2.6) Min. age at first collaboration: 1 Max. age at first collaboration: 13
Age at first investment	Years between firm establishment and receiving the first substantial financial investment (ratio)	Never received investment till 2018: 46 (43%) Received investment: 60 (57%) Mean age at receiving investment: 4 (SD: 3.0) Min. age at first investment: 1 Max. age at first investment: 15
Age at joining first marketing staff (MS)	Years between firm establishment and joining of first marketing staff (MS) in team (ratio)	Already among founders: 51 (48%) Never joined the team till 2018: 31 (29%) Recruit later after start: 24 (23%) Mean age at joining MS: 4.3 (SD: 5.4) Min. age at joining MS: 2 Max. age at joining MS: 13
Quality of National Innovation System (NIS)	The rank of countries based on EC Innovation Union Scoreboard 2015 (ordinal)	1= High: 56 (53%) 2= Lower: 50 (47%)
Metropolitan type Location	Cities according to size and distance to core metropolitan area (ordinal)	1= In metropolitan area: 44 (41.5%) 2= Adjacent to metropolitan area 26: (24.5%) 3= In small and far cities: 36 (34%)
Type of Incubating University	Type of university based on orientation towards technology (application) or to more basic research (ordinal)	1= Technical university: 58 (55%) 2= General university: 48 (45%)

Table 5.1 Variables, measurements, and statistics

5.3.2 Modelling: Cox Proportional Hazard Method

The Cox proportional hazard model implemented in this study is a discrete time proportional hazard model that aims to calculate probabilities of a certain event, here market introduction (Cox 1972; Vermunt and Moors, 2005; Allison, 2014). The estimation method allows for a fully non-parametric estimation of the baseline hazard. Cox model can be specified as follows (Audretsch, and Mahmood, 1995):

$$h(t;x) = h_0(t)e^{\beta x} \tag{1}$$

Where $h_0(t)$ is the baseline hazard; the baseline hazard is the hazard when covariate x is equal to zero thus $e^{\beta x} = 1$. x is a covariate, β is a parameter to be calculated representing the effect of the covariate on the outcome (in fact β shows that for each unit increase in the covariate x, the hazard will be multiplied by e^{x}). More details about Cox regression method are provided in Chapter 3 Section 3.4.3.

There are some specific situations when another event affects the risk of the event under study. In such cases, the second event may be called an intermediate event which may be analysed by multi-state models (Putter et al., 2007). A multi-state model which could be used as an extension of time to event analysis aims to evaluate what happens to the final event after the intermediate event happened or did not happen. Among all variables, this study uniquely evaluates the impact of occurrence and timing of three intermediate events (first collaboration with large firms, receiving the first substantial investment capital, and hiring the first marketing staff) on the duration of time to market introduction. This analysis sets the study apart, making it the first of its kind in applying multi-stage modelling in Cox regression analysis.

All the calculations were implemented using the statistical software Stata 16 which supports survival data analysis very well. Before proceeding with the analysis, two pre-tests were conducted. Initially, a check of the correlation matrix (Table 5.5 in Appendix 5.3) was performed to assess the presence of multi-collinearity among independent variables. The results revealed no significant collinearity, as all variation inflation factors (VIF) were below 2.00, with a mean VIF of 1.38. The next critical pre-test involved confirming the proportionality of the data (Table 5.6 in Appendix 5.4). The proportional-hazards assumption was assessed using Schoenfeld residuals in Stata. As indicated in Table 5.6, both the detailed test (per variable) and the global test (last row) yielded p-values greater than 0.05. Ideally, p-values should be greater than 0.05 for each covariate, indicating no significant deviation from the proportional hazards assumption. Therefore, since our p-values are greater than 0.05, there is no evidence to suggest a violation of the proportional hazards assumption.

5.4 Analysis and Results

This section will discuss the results of the analysis of time-to-market introduction, assessing influential factors to shorten this time. Section 5.4.1 will present different single and combined models obtained from Cox regression analysis and report the results, while in Section 5.4.2, the trends and the best model will be discussed, followed by a brief investigation of the hypotheses.

5.4.1 Modelling Time -to -Market Introduction

A stepwise method is employed to identify the optimal model fit for the data. The initial model incorporated two control variables, followed by four subsequent models, each evaluating variables as part of a specific set of factors in addition to the control variables. Model comparison is based on both Log-likelihood and the Akaike Information Criterion (AIC) as shown in Table 5.2. While Log-likelihood measures how well the model fits the data, AIC provides a way to compare models by balancing model fit and complexity. Unlike Log-likelihood alone, AIC helps prevent overfitting by penalizing more complex models, thereby guiding the selection of a model that explains the data with the fewest parameters (Akaike, 1981, 2011).

In the first step, the comparison of four individual models (Models 1 to 4) reveals that Model 2, covering indicators of team competences, was the weakest, while Model 3, associated with time of externally achieved resources and competences, emerged as the strongest. Consequently, in the subsequent step, the decision was made to exclude variables from Model 2 and retain Model 3. The next step involved creating new combinations by combining Model 3 with both Models 1 and 4, resulting in three new models labelled as Models 5 to 7. Considering the population size (106 firms) and the number of variables (14 variables), it has been decided not to include all variables in one model. Thus, the comparison will be done based on partial models.

By taking single models first (out of Model 1 to Model 4), the results on AIC level and Log likelihood indicate that the Accessed Resources/capability model (Model 3) is strongest and that this one is closely followed by the Entrepreneurial orientation model (Model 1).

Table 5.2 Cox Regression Results on Time to Market (HR is hazard rate)

Explanatory variables (hypotheses in brackets)	*Control model*	*Model 1* $HR(s.e.)$	*Model 2* $HR\ (s.e.)$	*Model 3* $HR\ (s.e.)$	*Model 4* $HR(s.e.)$	*Model 5* *HR (s. e.)*	*Model 6* $HR(s.e.)$	*Model 7* $HR(s.e.)$
Control variables								
Period (Year of establishment)	.39(.19)***	.56 (.17)*	.37(.11)***	.38(.11)**	.42(.12)***	.56(.18)*	.43(.13)***	.70(.22)
Business model	.19 (.5)***	.25(.07)***	.21(.06)***	.20(.05)***	.20(.05)***	.26(07)***	.20(.06)***	.25(.07)***
Entrepreneurial orientation								
Innovation radicalness (H5.1)		.42(.13)***				.50(.16)**		.39(.13)***
Newness of market (H5.2)		.72(.13)*				.63(.11)**		.61(.12)**
Business diversification (H5.3)		.95 (.26)				.99(.28)		1.2(.37)
Resources/capabilities owned by founding team								
Size of founding team (H5.4)			.93 (.15)					
Found. team education (H5.5)			.65 (.19)					
Found. team business experience (H5.6)			.87 (.24)					
Accessed resources/capabilities								
Age at first collaboration (H5.7)				1.7(.57)*		1.7(.61)*	1.8(.60)*	1.8(.65)*
Age at first investment (H5.8)				2.04(.64)**		2.01(.65)**	2.1(.69)**	1.9(.63)**
Age at joining first marketing staff (H5.9)				1.4(.47)		1.4 (.47)	1.7(.57)	1.6(.55)
Entrepreneurial ecosystem								
Quality of NIS (H5.10)					1.36(.34)		1.06(.44)*	1.4(.42)
Metropolitan Location (H5.11)					1.03(.17)		1.1(.19)	.99 (.19)
Type of incubating university (H5.12)					.54(.15)**		.47(.15)**	.40(.13)***
No. of USOs	106	106	106	106	106	106	106	106
LR Chi-square	.33.40	45.70	36.03	47.67	39.88	59.27	56.38	70.30
Log likelihood	-246.77	-240.62	-245.45	-239.63	-243.53	-233.83	-235.28	-228.32
P value	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
AIC	497	491	500	489	497	483	486	478

*$p<0.1$ **$p<0.05$ ***$p<.01$

The outcomes of Cox regression analysis, as presented in Table 5.2, provide hazard ratios (HR) for each model, comparing the ratio of events occurring among different categories of a variable. The first category in each variable, as outlined in Table 5.1, serves as the reference category for these ratios. It is crucial to consider the reference category (labelled as the first category in Table 5.1) when interpreting the results of Cox regression analysis.

The interpretation of Cox regression results follows guidelines outlined by Cox (1972). A hazard ratio close to 1 indicates minimal differences in time to market among different categories of the variable. A hazard ratio substantially less than 1 suggests a longer time to market introduction for the second category compared to the first. Conversely, a hazard ratio substantially greater than 1 indicates a higher probability of market introduction for the second category at any given time. As it has been mentioned previously, the interpretation should always consider the reference category for each variable, which is outlined in Table 5.1 as first category for each variable. For ratio variables, such as age at receiving investment, the hazard ratio explains the impact of a one-unit increase in the variable on the dependent variable.

Comparing the AIC levels and Log-likelihood across all models demonstrates a significant improvement in Model 7, which includes 11 variables. Therefore, this Model would be the chosen model of the study and the discussions will focus on the findings of Model 7. Out of the 11 explanatory variables in Model 7, 6 variables showed a significant effect on time to market introduction, confirming 5 hypotheses of the study (Hypotheses 5.1, 5.2, 5.7, 5.8, 5.12) plus a significant effect from one of the control variables. The influential factors, along with their direction and level of significance, are discussed below.

The business model emerges as the primary significant control factor in Model 7. The results indicate that, at any given time, university spin-offs in manufacturing-oriented activity have a 75 percent lower probability of early market introduction compared to service firms (calculated as 1 - 0.25). Alternatively, it can be stated that, on average, manufacturing-oriented firms take four times longer time to reach the market compared to service firms. The radicalness of innovation also demonstrates significance, suggesting that firms with more radical innovations experience longer time to market compared to those with incremental innovations. Additionally, the newness of the market is found to increase the time to market. This result implies that, at any given time, firms in emerging or new markets have approximately a 40 percent lower probability of early market introduction compared to established firms. Therefore hypotheses 5.1 and 5.2 of the study were confirmed. With regard to business diversification, the results turn out not to be significant, leaving hypothesis 5.3 as not confirmed. Further, also hypotheses about Resources/competences in the founding team (Hypotheses 5.4, 5.5, and 5.6) were not confirmed by the analyses, thus those were eliminated from the final model (Model 7).

In proceeding with the analysis, it appears that the age at which a university spin-off engages in its first collaboration and receives its first substantial investment, tends to act as an influential factor. Both indicate that delayed access to resources later in the process increases the time to market introduction, and conversely, early access gives a higher likelihood of early market introduction. Consequently, hypotheses 5.7 and 5.8 can be confirmed. Furthermore, the type of university plays a role, with incubation in technical universities shown to reduce the time to market introduction. This result confirms hypothesis 5.12.

Based on the results of this empirical study presented in Table 5.2, the following section discusses the trends influencing time to market.

5.4.2 Detailed Trends in Influences on Time–to-Market

The exploration of time to market introduction includes a control model, and eight partial models. The control model incorporates the economic crisis around 2007 and the firm's business model, under the assumption that macro-economic conditions may impact firms' accessibility to resources and market structure. Firms, however, may adapt to these conditions by selecting more flexible business models. Further, Model 1 addresses risk-related strategies (entrepreneurial orientation); Model 2 focuses on competences in the founding team, while Model 3 considers the time taken to acquire competences externally. Model 4 includes the quality of entrepreneurial ecosystem. Models 5 to 7 comprise various combinations (as outlined in Table 5.2 and explained in Section 5.4.1). Comparing the obtained models based on log-likelihood (refer to Table 5.2), Model 7 shows to have the highest level. However, when evaluating the models using the Akaike Information Criterion (AIC), as presented in the last row of Table 5.2, Model 7 shows the most significant improvement and proves to be the best fit for the data.

A more detailed analysis of the Cox regression outcomes per Model provides the following trends:

1. The Control model (Model 1) demonstrates statistical significance for both variables, suggesting that establishment of firms outside of economic crisis period and those operating in the service sector are associated with quicker market introduction, justifying the inclusion of both variables in subsequent models. The results also indicate that the time of establishment outside of the economic crisis period remains significance in Models 1 through 6. However, not in Model 7, considered as the optimal model. In contrast, the business model remains consistently significant across all eight models, including Model 7, suggesting faster market introduction for firms offering services.
2. As indicated above, the most robust (strongest) individual single model is the one concerning accessed resources and capabilities (Model 3, with a log-likelihood of -239.63). This model includes two significant indicators out of three, all pointing into the same direction, suggesting that delayed access to resources and capabilities increases the time to market. While the time spent on hiring a marketing person and integrating them into the team doesn't exhibit statistical significance, it does align with the overall trend, indicating that early access to resources contributes to a quicker market introduction.
3. The next strongest partial model is the entrepreneurial orientation of firms in terms of risk-taking/mitigation (Model 1), which includes innovation radicalness, newness of the market, and diversification. Two out of the three variables are statistically significant and maintain significance throughout all combined models (Model 5 to 7). The observed direction of influence aligns with previous assumptions, indicating that less risk involvement leads to faster market introduction. Consequently, producing incremental innovations and entering an established market are associated with early market introduction. However, the strategy of diversification does not exhibit a significant effect on time to market.
4. Regarding competences in the team, the single Model 2 appears to be the weakest model without any significance among the indicators. Accordingly, it has been excluded from the subsequent models. However, the direction of influence for all indicators is as it was assumed

5. With regard to quality of entrepreneurial ecosystems, although strength of the national innovation system (NIS) and of metropolitan character of spin-offs' location are not significant in the partial model (Model 4) the type of incubating university tends to be an influential factor on time to market. The result indicates that compared to general universities, being incubated at technical universities comes with relatively early market introduction.
6. Combined Model 7 suggests that combining entrepreneurial orientation and access to the resources and capabilities with quality of entrepreneurial ecosystem, provides the strongest results (log likelihood of -228.32 and AIC of 478). Accordingly, it suggests that avoiding risky situations and having early access to the resources and capabilities in addition to a supportive incubating university would lead to faster market introduction.

The primary outcome of the above modelling underscores the critical importance of the timing of access to resources for achieving faster market introduction, particularly in terms of securing financial investment and collaborating with large firms. It suggests that it is not only essential to have access to resources but also to obtain them promptly, with earlier access being preferable. On the other hand, the results indicate that risk-taking strategies necessary for accelerating energy transition often coincide with relatively late market introductions. While a more thorough interpretation of the above modelling results would be desirable, it is crucial to note that our understanding is somewhat limited due to the absence of comparable empirical studies. Existing studies either pertain to different types of firms, such as the broader category of SMEs (e.g. Heirman and Clarysse, 2007; Weiblen and Chesbrough, 2015; Dong et al., 2019), or focus specifically on eco-innovation within the operations of firms, which includes a different set of concepts and indicators (e.g. Brown et al., 2007; Shepherd and Patzelt, 2011; Bergset and Fichter, 2015). Despite these limitations, the following section delves into a discussion of the results.

5.5 Discussion of the Hypotheses

The empirical analysis indicates that out of the 12 hypotheses developed in Section 5.2, five hypotheses were confirmed by the empirical analysis, all in the expected direction (Hypotheses 5.1, 5.2, 5.7, 5.8, 5.12). In the following, all hypotheses will be one by one discussed.

Hypotheses 5.1, 5.2, and 5.3

Hypotheses 5.1, 5.2, and 5.3 posit that the adoption of suitable strategies, whether involving risk avoidance or risk integration, contributes to a faster market introduction through effectively managing the risks and uncertainties associated with innovation. The result of empirical analysis supports Hypothesis 5.1, indicating that university spin-off firms active in sustainable energy which have adopted an incremental innovation strategy have earlier market introduction. This finding aligns with most of the existing literature arguing that the more innovative a new product is, the more time, knowledge and efforts are needed to make it ready for market (e.g. Schoonhoven et al., 1990; Shane et al.,2016; Behrens and Patzelt, 2018). Thus, degree of innovativeness is an influential factor of time to market.

Hypothesis 5.2 is also confirmed, implying that university spin-off firms entering established markets in sustainable energy have earlier market introduction. This finding is consistent with initial assumption of the study on the positive effects of risk avoiding strategies enabling faster market introduction. In contrast, regarding Hypothesis 5.3, the result shows that the diversification strategy, while not statistically significant, has a negative effect on time to market introduction. This outcome may be attributed to the potential dilution of focus posed by diversification strategies, which could divert the firm's attention from the development and market introduction of its main innovative product, unlike the other two strategies that do not create such dilution.

Hypotheses 5.4, 5.5, and 5.6

Hypotheses 5.4, 5.5, and 5.6 evaluate the relationship of founding team competences (team size, education and business experience) on the time to market introduction. Despite the results aligning with the expected direction, none of them is statistically significant. This unexpected outcome may be attributed to the peculiar nature of the founding team in university spin-off firms, which has been highlighted in many studies (e.g. Clarysse and Moray, 2004; Visintin and Pittino; 2014; Clough and Vissa, 2017; Huynh et al., 2017). The lack of a rational basis underlying team formation, and the emphasis on academic founders originating from non-commercial environments, have led to recommendations in literature that these spin-offs address potential skill gaps by seeking external support (Würmseher, 2017). This may include consultations and assistance from university incubators, hiring more experienced staff, and acquiring relevant knowledge in efforts of 'balancing the founding team' (Van Geenhuizen and Taheri, 2024). The implication of such strategies (not all measured in the current study) might diminish the direct effect of the founding team itself on the firm's later performance, particularly in terms of time to market introduction. Therefore, to capture the true effect of the founding team, a more comprehensive and nuanced assessment of the team's characteristics is necessary.

Hypotheses 5.7, 5.8, and 5.9

Hypotheses 5.7, 5.8, and 5.9 assert that early access to resources and the acquisition of capabilities shortly after establishment increases the probability of early market introduction. Accordingly, Hypothesis 5.7 could be confirmed in the empirical analysis, by revealing that initiating collaboration with large firms in a relatively short time after establishment, increases the probability of early market introduction. Previous studies (e.g., Forrest and Martin, 1992; Scholten et al., 2015; Martínez-Ardila et al., 2023) have acknowledged the significance of networking and collaboration, particularly for high-tech startups. Given the inherent weakness of university spin-off firms in business and market knowledge, such collaborations offer potential avenues for the commercialization of knowledge and technology, e.g. through receiving additional investment, identifying of market segments and aligning with their customers wishes, thereby fostering an early market introduction of new innovations. The current study, inspired by previous researches connecting resource and capability acquisition to growth phases of university spin-off firms (e.g., Vohora et al., 2004; Van Geenhuizen and Soetanto, 2009), argues not only for the importance of collaboration but also emphasizes the critical timing of such collaborations. This idea has been empirically tested and confirmed by the current analysis.

Hypothesis 5.8 operates on a similar premise, positing the significance of securing financial investment for small high-tech firms (Lockett and Wright, 2005; Heirman and Clarysse, 2007; Huynh et al., 2017). It asserts that early access to financial resources may accelerate the time to market, particularly crucial for highly innovative products surrounded by increased risks and uncertainties later on. In such cases, investors are often hesitant to invest. The empirical analysis demonstrates that early access to financial capital correlates with early market introduction for small high-tech firms. However, there is a limitation here, which could not be covered by the current study. Positive impacts of collaboration and financial support are not only the result of the positive actions, but often also of prior positive selection of spin-offs by large firms and by investors (Bertoni et al., 2011; Hottenrott and Richstein, 2020).

Hypothesis 5.9 focused on enhancing the human resources of firms by adding marketing staff to the team at an early stage. Despite the results aligning with the expected direction, statistical significance was not observed. This outcome, consistent with the results of Hypotheses 5.4, 5.5, and 5.6, could be interpreted in light of the support that university spin-offs might receive from incubating industries, potentially mitigating the need for an explicitly designated marketing expert within the team. It is plausible that the role traditionally associated with marketing staff could be fulfilled by the incubating university more recently. Such situation is also congruent with new developments on "lean teams", in which focussed diversity, including prior market (customers) and early business experience, enable experimentation on "minimal" product design (Blank, 2013; De Cock et al., 2020). However, due to the lack of comprehensive data on strategies in management team change and the type of marketing support university spin-off firms have received after start, this interpretation remains a hypothesis that needs further investigation.

Hypotheses 5.10, 5.11, and 5.12

Hypotheses 5.10, 5.11, and 5.12 examine the impact of quality of entrepreneurial ecosystem at national, regional and local levels. The testing of Hypothesis 10, predicting faster market introduction for firms in countries with a higher level of National Innovation System (NIS), yielded results in the *opposite* direction. Statistical significance was observed only in Model 6, which is not considered the optimal model. This unexpected outcome may be attributed to the fact that countries with a higher level of NIS tend to more often foster radical innovation (e.g. by subsidies and integration in advanced national research programs, and by venture capital that is more often available in large amounts), as compared with countries with a lower level of NIS. This observation aligns with the first confirmed hypothesis of the study, which suggests that radical innovations tend to have a slower market introduction compared to incremental innovations.

Hypothesis 5.11, assessing the impact of metropolitan area conditions, could not be confirmed by the empirical analysis in the current study. The results suggest that the effects on the time to market introduction for firms in larger cities are relatively similar to those in small and remote cities. While ecosystems in metropolitan areas are typically thought to provide dense and richer knowledge spillovers and extensive networks, more advanced services and facilities (Anselin et al., 1997; McCann and Ortega-Argilés, 2013; Audretsch et al., 2005), some studies indicate that entrepreneurial ecosystems outside metropolitan areas tend to be smaller in scale and often specialized, particularly in collaboration with universities and local authorities, offering better access to resources (e.g. Dijkstra et al., 2013). Additionally, sustainable energy-related startups outside metropolitan areas benefit from lower expenses and better critical proximity to natural resources that are exploited, like woods, strong wind, strong currents (sea), solar radiation, and large deposits of silicon sands at hand, which are reasons for startup firms to develop in such locations. These circumstances contribute to a complex relationship between startups and metropolitan character of cities. Additionally, as results may indicate, through using compensation mechanisms in firm-based learning, time to market may not vary much between large metropolitan area and small cities in sparsely populated rural area (Flåten et al., 2015). Accordingly, a more detailed analysis is necessary to unpack and better understand this relationship.

Empirical validation of Hypothesis 5.12 confirms that university spin-offs originating from technical universities exhibit a positive impact, leading to faster market introduction. This finding underscores the pivotal role universities play in shaping their entrepreneurial ecosystems and aligns with the growing emphasis on the role of universities in economic growth, as evidenced by concepts like the Triple Helix (Etzkowitz, 2003; Zhou and Etzkowitz, 2021). Given that technical universities are inherently focused on the advancement of technological innovations and have historically maintained robust partnerships with industry, one could envisage that they are better positioned to offer enhanced support and incubation for new startups, facilitating faster time-to-market introductions.

In summary, the study indicates that opting for a service-oriented business model, focusing on incremental innovations, entering established markets, establishing formal collaborations soon after establishment, receiving substantial financial investments in young age, and originating from technical universities, all tend to contribute to faster market introduction. These intriguing results offer valuable insights for policymakers and practitioners aiming to accelerate energy transition or gain the advantages of radical innovation being a first mover in the market by reducing time to market. The following section will delve into the implications of these findings and provide additional insights.

5.6 Conclusions and Recommendation

This study enhances our understanding of market introduction and availability of up-to-date innovations that serve sustainable energy-related development goals, by focusing on the commercialization of such innovations through university spin-off firms. Reducing the time to the market is of significant importance for several reasons. Fast market introduction mitigates the risk of being negatively impacted by rapid technological changes, such as falling behind competitors or missing the opportunity to establish a first-mover advantage. It also includes an early anticipation of risks arising from environmental changes (like regulation), such as adapting to shifts in industry standards. Moreover, fast market introduction enhances the credibility of new startups, making them more attractive to potential investors and establishing a strong foundation for long-term success in the dynamic business landscape. Furthermore, it increases the likelihood of new firms' survival by generating early cash flow, eventually, affording them the advantages of being a first mover in the market. This strategic positioning can lead to a larger market share and greater resilience against competitors with new versions of technology solutions. Additionally, early market entrants can exert significant influence in shaping industry standards and distribution channels (Schoonhoven et al., 1990; Dröge et al., 2000; Chen et al., 2010). These advantages become even more critical in the context of accelerating energy transition, where radical innovations and swift market introduction are needed to achieve the sustainability transition goals on time. In the following, some suggestions for policy makers and entrepreneurs are put forwarded.

Drawing on a sample of 106 university spin-off firms in the Nordic countries and the Netherlands, it was observed that 61 percent of all firms faced market introduction, while for 39 percent, reaching the market was notably delayed, or there was failure in market introduction. This underscores the urgency of attention in both research and policymaking. The findings of this study put emphasis on the importance of risk-avoidant innovation strategies, particularly concerning innovation radicalness and newness of the market, for achieving faster market introduction. The results indicate that selecting a service-oriented business model, producing more incrementally new technologies, and entering established markets lead to faster market introduction. Additionally, the outcomes highlight the significant impact of establishing early collaborations with large firms and gaining early access to substantial financial investment on reducing the time to market, and the outcomes also put emphasis on the role of supportive universities in facilitating faster market introduction.

However, it is crucial to acknowledge that energy transition in a situation of an aimed acceleration of transitional change, necessitates the creation of new markets with more radical innovations (Adams et al., 2016; IEA, 2020). Thus, the question arises: how can the observed trend of small risk-taking be reversed towards manufacturing-oriented, radical product innovation, and new markets, all while maintaining a short time to market introduction?

Recommendations

In light of these insights, two recommendations can be forwarded: (1) policymakers should prioritize creating conditions that help startups mitigate risks associated with radical innovations and new markets; (2) policymakers should enhance a robust regional cluster policy such as establishing *innovation hubs* for sustainable energy technologies. This by first picturing existing nodes and networks on a regional level and next to enable the creation of local innovation hubs by providing funding for research and development collaborations among local energy companies and universities including their spin-offs, and fostering partnerships between government agencies, industry stakeholders, and academic institutions to promote innovation and entrepreneurship in sustainable energy. With regard to the Netherlands and Province of South-Holland, several studies and projects on existing and emerging hubs can be mentioned (The Hague Tech, 2022; Heliox, 2022; Port of Rotterdam/RTHA, 2023). For example, a hub is being established/reinforced on use of battery electric and liquid hydrogen in aviation at Rotterdam The Hague Airport, with strong links with the Port of Rotterdam regarding production of green hydrogen. The emerging local innovation hubs in this province aim to integrate innovative startups with production, conversion, storage and consumption of sustainable energy (like hydrogen) and match with local customer demand on a decentralized level, with several sites of R&D (university, large firms, incubation centres) and practical experimentation places beyond research labs. Important aspects are financial and institutional, the last including legal, regulatory and organisational issues, and adoption of flexible approaches in management. Main aims of the hubs are not only fast increasing sustainable energy production and use, but also to guarantee safety and security. The following part provides more details regarding distinct stakeholders: (local) policymakers, spin-off entrepreneurs, and universities.

Accordingly, for policymakers, seeking to accelerate energy transition, supporting initiatives that facilitate these early collaborations and provide timely financial resources to startups can be instrumental. Creating supportive frameworks, such as incubation programs and innovation hubs, can foster an environment where startups can engage in strategic collaborations and secure the necessary financial backing. Additionally, policymakers could consider offering targeted incentives or grants to startups involved in energy transition, encouraging them to adopt risk-taking strategies, yet accelerate their market entry. The model of launching customers, whether facilitated by the government and/or performed by large firms, emerges as a crucial component in this context. Policymakers may explore mechanisms to encourage or facilitate partnerships between startups and potential launching customers, providing startups with an initial market and financial support to accelerate their market introduction (Arendsen and van De Wijngaert, 2011). Specifically, municipalities may collaborate with university spin-offs by acting by themselves as launching customers, as well as facilitators of testing places (sites) in real world conditions, like for new types of charging equipment of electric vehicles (Van Geenhuizen and Nejabat, 2021).

Entrepreneurs, on the other hand, can leverage these findings by actively seeking collaboration opportunities with established firms in the early stages of their ventures. This not only enhances their access to resources but also contributes to the reduction of market entry barriers. Furthermore, entrepreneurs should explore diverse funding options (including self-investment) and establish financial partnerships early on, ensuring a more stable and expedited path to market introduction, in which over-investment and building of unsurmountable debt should be avoided. The identification and cultivation of launching customer relationships become pivotal for startups, offering a valuable avenue to secure initial market traction and financial support. Further, universities can actively follow the culture of technical universities and orient their studies towards more applied sciences, aligning their efforts with industry needs and market demands. Crossing borders between faculties in interfaculty meetings and cross-faculty research programs may also enhance advanced aims in acceleration of energy transition at university. Such proactive orientation of universities can equip spin-offs with cutting-edge technologies and solutions, streamlining their journey to the market.

Limitations and reflections

The study is faced with some limitations and challenges that offer avenues for future research. First, our modelling effort of time-to-market could be extended by including more indicators of risk-taking and risk-avoiding, and ways of gaining competences concerned, in particular a longitudinal picture of changes in strategy in years following firm establishment and following first substantial collaboration and access to financial capital. This would also imply to extend the database of university spin-off firms. Secondly, risk-avoiding strategies deserve much closer research attention concerning critical practice in application, like type and strength of diversification, type of lean model used and co-creation, in particular the concomitant networking. For example, specific attention is needed to critical advantages and limits of co-creation for university spin-off firms in radical innovation and required capabilities in learning in often asymmetric relations with large firms (Scaringella et al., 2017; Fierro and Perez, 2018; Caldera et al., 2019; Felin et al., 2020; Van Geenhuizen and Nejabat, 2023).

Furthermore, it is worth investigating the extent to which actors within the entrepreneurial ecosystem can effectively support and encourage small high-tech startups in developing and introducing new solutions for energy transition in newly established innovation hubs embedded in relevant networks. Such comprehensive examination will contribute to a more nuanced understanding of the dynamics involved in bringing innovative solutions to the market, especially in the context of energy transition.

Appendixes

Appendix 5.1 Cities involved in the study

Table 5.3 Cities involved in the study

Norway	Oslo metro area; Trondheim, Stavanger, Tromsø
Sweden	Stockholm (incl. Uppsala) metro area; Umea, Lund-Malmø, Gothenburg, Linkoping, Sundsvall
Finland	Helsinki metro area; Tampere, Lappeenranta, Joensuu, Kuopio, Mikkeli
Denmark	Copenhagen metro area: Aarhus, Odense, Aalborg, Hedensted, Herning
The Netherlands	North-Randstad (Amsterdam, Utrecht) and South-Randstad (Delft) (metro area): Breda, Eindhoven, Zwolle, Groningen, Wageningen, Nijmegen

Appendix 5.2 Universities involved.

Table 5.4 Universities involved in the study.

University name	Number of spin-offs	Type of university
Aalborg University	1	General university
Aalto University	1	General university
Aarhus University	2	General university
Danish Technological Institute	1	Technical university
KTH Royal Institute of Technology	5	Technical university
Linköping University	2	General university
Lund University	6	General university
Mid Sweden University	1	General university
NTNU Norwegian Uni of Science & Tech*	16	General university
Radboud University Nijmegen	2	General university
Stockholm University	1	General university
TU Delft	20	Technical university
TU Denmark	10	Technical university
TU Eindhoven	4	Technical university
TU Helsinki	1	Technical university
TU Lappeenranta	6	Technical university
TU Tampere	1	Technical university
Umeå University	1	General university
University of Amsterdam	2	General university
University of Copenhagen	2	General university
University of Eastern Finland	1	General university
University of Gothenburg	2	General university
University of Groningen	1	General university
University of Oslo	2	General university
University of Oulu	1	General university
University of Southern Denmark	1	General university
University of Stavanger	1	General university
University of Tampere	1	General university
Uppsala University	9	General university
Utrecht University	1	General university
Wageningen University	1	Technical (agricultural) university

* The Norwegian University of Science & Technology was established in 1996 through the merger of six institutions in Trondheim. It offers a wide range of disciplines, including engineering, medicine, psychology, social sciences, teacher education, architecture, and fine art. In this study, therefore, it is categorized as general university.

Appendix 5.3 Correlation matrix

Table 5.5 Correlation matrix of all variables of the study

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.Period (Year of establishment)	1													
2. Business model	.12	1												
3. Innovation radicalness	-.18	.24	1											
4. Newness of market	-.00	.20	.06	1										
5.Business diversification	.07	.13	.00	.20	1									
6. Size of founding team	-.01	-.02	-.09	-.07	.00	1								
7. Founding team education	.17	-.20	.00	.13	-.03	.20	1							
8. Founding team business experience	-.10	-.14	.02	-.10	.08	.32	-.11	1						
9. Age at first collaboration	.01	.00	-.09	-.09	.00	-.03	.04	-.28	1					
10. Age at first investment	-.04	-.05	-.11	-.05	.04	.03	-.04	.08	.31	1				
11. Age at joining first marketing staff	-.14	-.02	-.10	-.16	.01	-.07	-.10	-.00	.37	.45	1			
12. Quality of NIS	-.19	-.04	-.18	-.11	-.01	.09	-.13	-.20	.14	-.04	.11	1		
13.Metropolitan type Location	-.09	.00	-.22	-.11	.10	.08	.09	.03	-.02	.09	.09	.00	1	
14.Type of incubating university	-.15	.43	-.16	.00	-.07	.01	.23	-.00	.-18	.02	-.19	-21	.04	1

Appendix 5.4 Cox proportional-hazards assumption test

Table 5.6 Cox proportional-hazards assumption test

Variable	*Rho*	*Chi^2*	*Df*	*p-value*
Period (Year of establishment)	-0.12	1.28	1	0.38
Business model	0.145	1.60	1	0.20
Newness of market	0.08	0.46	1	0.49
Business diversification	-0.154	1.77	1	0.18
Founding team size	0.031	0.11	1	0.74
Highest education of founders	-0.050	0.20	1	0.65
Business experience of founders	-0.105	0.62	1	0.29
Joining of marketing staff	-0.14	1.56	1	0.21
Time to first collaboration	-0.07	0.68	1	0.41
Time to first investment	-0.046	0.14	1	0.70
Quality of NIS	0.09	0.62	1	0.43
Location	-0.06	0.34	1	0.56
Type of University	0.19	0.53	1	0.51
Global test	8.34	14	1	0.78

Chapter 6.
Survival of High-Tech University Spin-off Firms in the Sustainable Energy Sector

6.1 Introduction

Many startups face significant challenges and often fail within the first few years, imposing a burden not only on the founders but also on their investors and the economy (Headd, 2003; Wiklund et al., 2010). High-tech startups face even greater challenges for their survival, especially when they are operating in a complex socio-technical system, such as the energy system, characterized by the involvement and interactions of several powerful agents such as established energy companies and governments. To navigate the complexity and difficulties of changes in the energy system, supportive policies and governmental assistance are often implemented to safeguard and stimulate startup firms active in this domain. Consequently, the failure of high-tech startups in sustainable energy, after investing considerable efforts, creates significant damage and is not a desired outcome. The aim of this chapter is to understand the factors that tend to prevent firm failure and contribute to the survival of high-tech startups in sustainable energy sector.

Josefy et al. (2017) provide an overview of studies that highlight the significant challenges that startups, in general, face compared to established firms in terms of survival. Startups typically struggle with the absence of an established reputation, customer base, and resources that established firms enjoy. In addition, the dynamic nature of the sustainable energy market poses unique hurdles for innovative startups. These startups face dual challenges stemming from introducing new technologies, or products, that align with sustainability goals, while also navigating evolving consumer preferences, changing market demands, and a shifting institutional environment. Furthermore, the existing path dependency and lock-in of consumers and investors in the traditional energy system complicate market entry and, consequently, endanger the survival of such innovative startups

(Schöpper et al., 2024). To avoid negative development, by selecting adequate innovation strategies by the firms, like small diversification with services and timely accessing external resources and competences, and by creating supportive environmental conditions by local policy actors, like places for testing the new product, and national government regulations and policies, all these may play a strong role to propel the firms forward (Meijer et al., 2019). Understanding how these factors influence firm survival becomes crucial for stakeholders and policymakers seeking to promote sustainable energy initiatives. Accordingly, this chapter aims to provide a comprehensive understanding of survival among startups in sustainable energy by incorporating the theories of liability of newness, the theory of firms' resources and capabilities, while also considering the implication of entrepreneurial ecosystem theory (Khurana et al., 2022).

This chapter intends to make three significant contributions to the existing literature on firm survival. First, it exclusively focuses on the sustainable energy sector, which encompasses renewable energy and energy efficiency technologies. This approach enables a thorough exploration of the distinctive challenges and opportunities that startup firms in the sustainable energy sector face. Second, in addition to the conventional Cox regression survival analysis, this study uses competing risk regression analysis to differentiate between two types of firm closure: firms that go bankrupt or are acquired by other firms. While the conventional view regards firm closure as a negative and undesirable outcome, it is crucial to recognize that firms may opt for a merger or acquisition to facilitate resource and market expansion through integration with a larger firm. This perspective suggests that such firm closures can contribute to technology scaling and broader dissemination, which some startup managers may consider a success. Therefore, distinguishing between firms that are acquired and those that go bankrupt might reveal some previously unexplored insights, even though the number of firms involved in the current sample is small (see Section 6.3 and Appendix 6.2). Third, in addition to examining firm characteristics, strategies and resources and capabilities, this study considers the impact of intermediate events throughout a firm's lifecycle on its survival prospects. Analysing specific intermediate events such as first market introduction, initial formal collaborations, and the receipt of substantial initial financial investment, the study aims to elucidate how these events shape the trajectory of firm survival in the sustainable energy sector (Section 6.4). Understanding the implications of these events can offer valuable insights for both entrepreneurs and policymakers, guiding the formulation of effective strategies and policies to enhance firm survival.

Through empirical analysis of a sample of 106 university spin-off firms in sustainable energy markets, this study aims to address the following research questions:

1) What are the dynamics of firm survival among the sample of university spin-off firms with regard to time of survival, and influencing factors?

2) In which ways do factors related to entrepreneurial orientation and firm's strategies regarding risk-taking/avoiding and risk mitigation, influence the survival of university spin-off firms?

3) How do firm-owned competences influence the survival of university spin-off firms? What is the impact of the timing of resource access and capability acquisition on the survival of university spin-off firms? What is the impact of early market introduction on firm survival?

4) How does a supportive entrepreneurial ecosystem affect the survival of university spin-off firms in the sustainable energy market?

The subsequent sections of this chapter are structured as follows: Section 6.2 outlines the theoretical background and hypotheses that underpin this study. Section 6.3 explains the methodology employed in this research and this is continued by a description of the database with regard to dynamics of survival/closure over time. Moving forward, Section 6.4 offers a detailed explanatory analysis of survival and its corresponding results, namely Cox regression analysis and related hypotheses testing, and Competing risk analysis. Finally, Section 6.5 concludes the chapter by summarizing the key findings and drawing conclusions based on the study's insights. Additionally, it suggests potential research streams for future studies, aiming to further explore and expand upon the implications and unanswered questions arising from the current research.

6.2 Theoretical Perspective and Hypotheses Development

This section presents a series of hypotheses related to the factors that are assumed to influence startup survival. Similar to the previous analysis on time to market introduction, this study is grounded in the main theories of Entrepreneurial Orientation (EO) (innovation and risks) and the Resource-Based View (RBV) of the firm, while also integrating the concept of the Entrepreneurial Ecosystem (EES). Additionally, by emphasizing the firm's life cycle, the theory of Liability of Newness (LN) has been incorporated into this study. The literature related to these main theories is discussed in Chapter 1, Section 1.5, and the application of these theories for assessing time to market is elaborated in Chapter 5, Section 5.2. In the current chapter, the application of these theories is on firm survival, along with more detail on the theory of Liability of Newness.

6.2.1 Entrepreneurial Orientation and Strategic Choice

Given that this study focuses on high-tech university spin-off firms involved in sustainable energy, the firm's strategy to manage innovations and leverage them for benefits is a crucial determinant of the firm’s success, in addition to the initial access to resources. Building on Schumpeter's theory of innovation (1934), which underscores the economic value created by innovation, several studies have explored firms' innovation strategies as potential sources of competitive advantage (e.g., McGrath et al., 1996; Chandy and Tellis, 2000; Zhou et al., 2005; Hana, 2013; Anning-Dorson, 2018). This perspective echoes Wiklund and Shepherd's view, highlighting that a firm's entrepreneurial strategy is a crucial knowledge source for generating competitive advantage and enhancing a longer firm survival (Wiklund and Shepherd, 2003). In the subsequent sections, the role of specific innovation strategies is hypothesised in firm survival.

Innovation radicalness

Previous empirical studies, that examine the effect of radical innovation on firm success, show diverse outcomes (see, Evanschitzky et al., 2012). Some studies argue that a firm may enjoy a competitive advantage and experience longer survival if it exploits radical innovation with a broad scope of patents. It can prevent other firms from imitating them in a short period (Zhou et al., 2005). Alternatively, other studies suggest that if firms combine radical innovations with strategies to reduce risks and uncertainties involved, they may survive longer. For instance, Nerkar and Shane (2003) examined the influence of product radicalness on the survival of university spin-offs and discovered that this correlation depends on the risk levels within the industry. Consequently, they argue that risk-averse or risk-mitigating strategies should be carefully considered, especially by small high-tech startups.

Risk-taking is substantially stronger and comprehensive in radical innovation compared to incremental innovation. Radical innovations are defined as novel technologies that offer substantially different core technology from existing technologies. In contrast, incremental innovation refers to minor changes or line extensions of the existing technology in order to improve its performance or efficiency (Zhou et al., 2005; Bessant et al., 2014). Drawing upon entrepreneurial orientation theory and the existing literature on avoiding risks and uncertainty and its effect on overall success of high-tech startups, the first hypothesis is formulated as follows:

Hypothesis 6.1: USOs in sustainable energy, that have adopted an incremental innovation strategy, survive longer compared to USOs that have adopted a radical innovation strategy.

Newness of market

With regard to newness of markets, some innovation studies distinguish between product-based innovation and market-based innovation, proposing that the latter gives access to new customer segments and, subsequently, new markets. Conversely, product-based innovations, even if they entail radical innovation, may not necessarily lead to the creation of new markets (Zhou et al., 2005; Sainio et al., 2012). For example, home energy management systems encompass devices or software applications that enable households to monitor, control, and optimize their energy consumption. While these systems may not be inherently considered radical innovations, they possess the potential to give rise to new markets that previously did not exist. In contrast, LED technology is classified as a radical innovation, due to its substantial enhancement in lighting efficiency; however, it did not give rise to a new market.

The creation of a new market or the development of a new customer segment offers a notable competitive edge, particularly providing advantage for startups, over established firms (Chandy and Tellis, 2000; King and Tucci, 2002). However, despite the potential benefits it offers to startups, the process of establishing new customer segments or markets is characterised by its inherent complexity, stemming from the challenge of evaluating customer reactions and acceptance, and risk of not passing the “Valley of death” (Markham et al., 2010; Mohr et al., 2013).

In the present study, the young high-tech university spin-off firms, are categorized based on the type of market they entered. One category includes those that create or enter a new/emerging market, while the other encompasses spin-offs entering an existing market. Following arguments on preference for risk avoiding strategies for survival of high-tech startups (Mohr et al., 2013) the second hypothesis is formulated as follows:

Hypothesis 6.2: USOs in sustainable energy, that enter established markets, survive longer compared to USOs that enter new markets.

Diversification in product or market

Diversification in product or market is a recognized strategy aimed at enhancing a firm's performance by mitigating risks through expanding its market and sales, increasing cash flow, and enabling self-investment in R&D (Rumelt, 1982; Garcia-Vega, 2006; Van Mieghem, 2007; Mohr et al. 2013). However, when applied to innovative startups, the literature approaches this topic from different perspectives. In one meta study, Palich and others summarised the results of past studies, showing the disagreements on the relationship between diversification strategy and firm performance (Palich et al., 2000). Accordingly, while some studies suggest that diversification strategy can potentially yield superior performance in comparison to a focused strategy, certain other studies highlight the adverse effects associated with diversification strategy, citing hurdles that top managers may encounter in managing diversified products or markets. For startup firms, diversification means spreading resources and focus across multiple areas, rather than concentrating all efforts and resources into a single area where success would depend solely on it. The diversification then helps to reduce risk and to increase the chances of success (Khurana and Farhat, 2021). Drawing on the existing literature and considering the uncertainties and risks involved in sustainable energy sector, the third hypothesis is formulated as follows:

Hypothesis 6.3. USOs in sustainable energy, that adopt a diversification strategy in product or market, survive longer compared to USOs adopting a focussed strategy.

6.2.2 Resources and Capabilities

Following the Resource-Based Theory (Barney, 1991) the firm resources and capabilities were discussed in this thesis in Chapter 1. The present chapter links the resource-based view to firm survival, considering that firms' ownership of and access to resources and capabilities, can help a firm to adapt to changing competitive environments (Esteve-Pérez and Mañez-Castillejo, 2008). Specific attention will be given to the characteristics of the founding team and its competences. These encompass team size, educational degrees, and pre-start business experience, as potential sources of firms' advantages or disadvantages in survival.

Founding Team Characteristics

In entrepreneurship literature, the characteristics of the founding team are recognized as a critical factor for the success of a startup (Scholten, 2006; Hambrick, 2007; Criaco et al., 2013). This significance is even more pronounced in the context of university spin-offs, given their unique nature that requires a delicate balance between scientific orientation and business orientation (Visintin and Pittino, 2014). Furthermore, assuming that the diversity and amalgamation of different experiences within the founding team enhance team capabilities, it becomes conceivable that a larger founding team size translates into a more diverse composition of both tangible and intangible resources for the firm. Consequently, this could lead to added value for the firm (Scholten, 2006; Huynh et al., 2017). However, various studies also point to potential dangers of large and more diverse founding teams, namely the rise of fault-lines between team-members that may delay effective decision-making (e.g. Aspelund et al., 2005; Yan et al., 2021). Inspired by the first perspective, the next hypothesis is formulated as follows:

Hypothesis 6.4: USOs in sustainable energy, when founded by a larger team, survive longer compared to USOs founded by a smaller team.

A scientific orientation of university spin-off firms is crucial for innovative technology development and is considered a competitive advantage. However, the presence of business orientation, often poorly developed at firm start, is emphasized as necessary for effective product/service commercialization and the overall survival of the firm (Huynh et al., 2017). Some previous studies suggest that individuals holding a Master degree are often more practical and can run businesses more successfully than their counterparts holding a PhD degree (e.g., Clough and Vissa, 2022). Additionally, having pre-business experience among the founders may empower the business orientation of the firm from the beginning and count as an advantage, particularly among university spin-off firms which suffer more from lack of business orientation in their early stages of development (De Cleyn et al., 2015). Following this perspective of founding team advantages for high-tech university spin-off firms, the following two hypotheses are formulated:

Hypothesis 6.5: USOs in sustainable energy, with a founding team that have a Master as highest education, survive longer compared to USOs with a PhD degree among the founding team.

Hypothesis 6.6: USOs in sustainable energy, which involve a founding team member with pre-business experience, survive longer compared to USOs without involvement of a founding team member with pre-business experience.

6.2.3 Liability of Newness

The concept of liability of newness was introduced by Stinchcombe in 1965 and since then has received considerable attention from scholars and practitioners. The concept states that the risk of business failure for a new firm, particularly a new innovative firm, is highest during its initial stages and gradually diminishes over time as the firm ages. The liability of newness underscores resource constraints and capability gaps that distinguish new startups from established firms (Thornhill and Amit, 2003; Fackler et al., 2013; Yang and Aldrich, 2017; Gimenez-Fernandez et al., 2020). This notion encompasses both internal organizational challenges and external obstacles that influence a firm's resource acquisition. Utilizing the liability of newness theory, this study develops hypotheses that focus on the timing of external resource and capability acquisition. Recognizing the resource constraints commonly faced by nascent startups in their initial stages (Thornhill and Amit, 2003), the rational guiding the formulation of hypotheses in this section is that early resource acquisition might mitigate the innate vulnerability of new firms and boost their ability to withstand the obstacles associated with the liability of newness. In the following section the hypotheses are developed and explained in more detail.

Early-Stage Resource Acquisition

In a study focused on bankrupted firms, Thornhill and Amit (2003) explained the concept of a firm's liability of newness through the lens of the resource-based view. The authors illustrated that despite a pronounced correlation between a firm's age and its eventual failure, age itself does not stand as the primary cause of a firm's failure. Instead, age acts as a proxy standing for insufficiencies in resources and capabilities. Accordingly, in contrast to older firms that have gradually accrued valuable resources and capabilities over time, the failure of young firms may stem from inadequacies in resources and capabilities.

Following this line of thinking, this chapter contends that an early acquisition of resources and capabilities can mitigate the vulnerability associated with a firm's newness and enhance its chances of survival. Business studies have defined a wide array of both tangible and intangible resources and capabilities, each carrying varying degrees of importance. Missing capabilities in the first years tend to include skills on markets and marketing, capabilities in management and networking, and capabilities to access investment capital (Van Geenhuizen and Soetanto, 2009; Fackler et al., 2013).

The situation becomes different when through market introduction and sales, cash flow is being generated enabling the firms to return previous loans and to do investment by themselves, e.g. to further improve the product and develop a sales organization. The next hypothesis is formulated as follows:

Hypothesis 6.7: USOs in sustainable energy that have experienced early market introduction, survive longer compared to USOs experiencing relatively late or no market introduction.

Seeking collaboration in networks is seen as vital for young high-tech firms in accessing external capabilities and resources (e.g. Lavie, 2006; Walter et al., 2006; Hayter, 2016; Engel et al., 2017; Eveleens et al., 2017; Wechtler et al., 2023). Being active in more diverse (larger) networks also prevents path-dependency by 'keeping horizons open' (e.g. Scholten et al., 2015; De Silva and Rossi, 2017). Since networks can be enriched over time, this is one of the areas in which startups mainly remain behind compared with older firms, unless individual creativity or specific connections work highly effective. The sooner the startup can establish a collaboration with larger firms, customers, or governments, the more advantages they could gain. These arguments lead us to formulate the following hypothesis:

Hypothesis 6.8: USOs in sustainable energy that develop collaboration with large firms early after start, survive longer compared to USOs that develop collaboration later or not at all.

Access to investment capital is crucial for innovative high-tech startups to improve the inventions and bring them to the market (Hall and Lerner, 2010; Nanda and Rhodes-Kropf, 2013; Bertoni et al., 2011). Although often initial investments can be afforded by startups through subsidies for starting a business or seed money, later on substantial amounts of investment capital may be needed, particularly if the invention is more radical and additional pilots or other testing are required which often happens in the sustainable energy sector. Hypothesis 6.9 phrases this statement as follows:

Hypothesis 6.9: USOs in sustainable energy that gain substantial financial investment early after start survive longer, compared to USOs that gain substantial financial investment later or not at all.

Overall, based on literature it can be concluded that the liability of newness is triggered mainly by lack of firms resources and their disability in gaining them. Such development happens because the managing team needs time to develop the necessary knowledge about customers (segments), competitors, competing value propositions, market structure, etc. (Gaskill et al., 1993; Mohr et al., 2013). Hiring market staff at early age may help the new startup to cover this shortage smoothly, suggesting the following hypothesis:

Hypothesis 6.10: USOs in sustainable energy that own market knowledge or attract marketing staff early after start, survive longer compared to USOs that attract marketing staff later or not at all.

6.2.4 Entrepreneurial Ecosystem

In the mid-20th century, entrepreneurship expanded beyond individual and firm-level considerations to encompass regional, temporal, and social dimensions (Cavallo et al., 2019). This expansion led to the recognition of the relationships between entrepreneurs (small and large ones) and their local economic and social environments, adding a new dimension to previous considerations. Consequently, alongside the traditional focus on individual and firm-level, a systemic perspective on entrepreneurship emerged and developed in the 21st century, giving rise to the concept of the Entrepreneurial Ecosystem. While contextual and environmental factors and their influences were already explored in earlier entrepreneurial studies (e.g. Pennings, 1982; Ritsilä, 1999; Sorenson and Audia, 2000), the new concept of Entrepreneurial Ecosystems consolidated fragmented ideas, underlining the substantial impact that the community and cultural environment of a given area can exert on entrepreneurship (Isenberg, 2010; Zahra et al., 2014; Stam and Spigel, 2016; Audretsch et al., 2021). The entrepreneurial ecosystem underscores the role of social, political, and cultural elements embedded within a specific region, fostering the development and growth of innovative startups (Spigel, 2017). The definition of an entrepreneurial ecosystem emphasizes a geographical viewpoint, highlighting the effect of dynamic interacting cultures, institutions, actors and networks that have built up within a region over time at different levels, like city and university (Stam and Spigel, 2016). Stam and Van der Ven (2021) made an attempt to quantify the quality of entrepreneurial ecosystems and define them by elements required to sustain entrepreneurship in a particular territory.

Drawing upon the concept of entrepreneurial ecosystems, this chapter attempts to explore the potential influence of national and regional factors on the viability of sustainable energy university spin-off firms. To achieve this, the analysis incorporates the National Innovation System (NIS) scores from each respective country into the model. Furthermore, distances and city-size in ecosystems, where these startups are established, will be considered due to the potential advantages of proximity and density of information flows and networks, enabling face-to-face meetings and serendipity (McCann and Shefer, 2004). The scope of the entrepreneurial ecosystem narrows down further in the current study and considers the incubating university, ensuring a thorough assessment of regional advantages or disadvantages. The subsequent subsections detail the formulation of the corresponding hypotheses.

National Innovation System

A systemic approach to studying innovation actors and country-level specificities was initially pioneered by Freeman and Lundvall in the 1980s. These concepts and relationships gained traction and evolved into the notion of the National Innovation System (NIS) as indicated by subsequent works (e.g., Lundvall, 1992; Nelson, 1993; Freeman, 1995). In this framework, innovation actors and institutions are seen as directly interacting and contributing to the generation, diffusion, and appropriation of technological innovation. Thus, it can be expected that countries with high ranks on NIS scores tend to foster strong collaboration between academia, industry, and government, creating a conducive environment for knowledge exchange and technology transfer, alongside financial incentives for firms involved (Acs et al., 2017).

Moreover, the presence of a well-developed NIS indicates that countries have better innovation infrastructures, and better support for new startups to survive the first years and find an entry into the market. This support stems from subsidies for research, incubation and acceleration facilities, governmental policies that favour innovation-driven startups and firms. Such support, in turn, makes the country more attractive for entrepreneurs, also because countries with robust NIS frameworks tend to prioritize education and skills development among the population, ensuring a steady supply of highly skilled workforce capable of driving innovation and technological advancements. This rationale leads to the formulation of hypothesis 6.11:

Hypothesis 6.11: USOs in sustainable energy located in countries that rank high in the national innovation system, survive longer compared to USOs located in countries with a lower rank in this system.

Metropolitan area

In the elaboration of agglomeration theories in the 1950s (Hoover, 1948; McCann and Ortega-Argilés, 2013), there was a notable emphasis on the significance of knowledge spillovers within and across regions. It is widely acknowledged today that the accumulation of knowledge and knowledge networking within specific larger metropolitan areas foster innovation leading to a more pronounced increase in returns in these areas (Anselin et al., 1997; Fotopoulos and Louri, 2000; Acs et al., 2013; McCann and Ortega-Argilés, 2013). This situation is expected to also hold true for the presence of a more specialized labour market, supply of specialized services, and presence of cheap incubation sites in metropolitan areas. Consequently, the characteristics of metropolitan cities can significantly influence the performance of startup firms. In addition, cities are increasingly viewed as agglomerations of organizational and institutional entities with socio-technical, socio-economic, and socio-political goals (Simmie, 2003). If metropolitan policymakers have converging priorities and expectations, they can further enhance policies fostering entrepreneurship and innovation, like municipalities acting as launching customer, and building (local) networks between important stakeholders, including strategic and financial advisors and investors (Van Geenhuizen and Nejabat, 2023). The next hypothesis builds on this observation as follows:

Hypothesis 6.12: USOs in sustainable energy that operate in a metropolitan area, survive longer compared to USOs that operate in small cities, or at far distance from a metropolitan area.

Type of incubating university

There is a global trend towards reshaping academic institutions, including teaching colleges, research universities, and polytechnics, into entrepreneurial universities (Etzkowitz, 2003; Guerrero and Urbano, 2012; Miller and Acs, 2017). An entrepreneurial university is an extension of teaching and research activities, encompassing the internalization of technology transfer capabilities and the commercialization of knowledge. Such entrepreneurial universities are recognized as independent actors within the broader entrepreneurial ecosystem, working in conjunction with other stakeholders, like large firms and financial investors (Nkusi et al., 2020).

The concept of entrepreneurial universities has been primarily developed within the framework of well-established institutional structures in developed economies (Audretsch and Belitski, 2017). Yet not every university within these economies aligns uniformly with the entrepreneurial model. As one of the first, Rasmussen and Sørheim (2006) have drawn attention to different types of university context that influence new entrepreneurial processes and knowledge commercialization by staff and students. Some universities prioritize teaching or fundamental research and may not actively engage in commercializing discoveries or participating in initiatives for societal improvement. In this vein, Guerrero and Urbano (2012) have differentiated between the entrepreneurial characteristics of technical universities and general universities, asserting that technical universities derive their main advantages from knowledge commercialization and strong industry relationships, whereas general universities leverage a multidisciplinary approach to exploit various areas, or they elaborate fundamental research. Moreover, technical universities have installed technology transfer offices that intend to commercialize the IP that is generated at the university. When it comes to university spin-off firms, these technical universities use more often a support or incubator model (Clarysse et al., 2011) to safeguard that their IP, which is in the spin-off or in one of the spin-off owners, is used appropriately. However, such differences may have been reduced, more recently. Building on the distinction and the retrospective analysis, the following hypothesis is proposed:

Hypothesis 6.13: USOs in sustainable energy that originate from technical universities, survive longer compared to USOs that originate from general universities.

In the following sections, the hypotheses are empirically tested, and the trends will be discussed.

6.3 Research Methodology

The focus of the present chapter is on survival of sustainable energy university spin-offs established between 1998 and 2016 in the Netherlands and four Nordic countries. The detailed information about the data and the data collection are provided in Chapter 3, Section 3.2. Given the nature of the data and the objectives of the study, Cox regression and Competing risk regression modelling are employed, including a multi-state modelling approach, both of which are recognized extensions of survival analysis (Meira-Machado et al., 2009; Wolbers et al., 2014). The details about the variables used in this study are available in Section 3.3 of Chapter 3. It should be noted that the variable measurements of the present study are consistent with what has been used in the analysis of Chapter 5 and explained in Section 3.3.3 of Chapter 3. Thus, the frequency of variables among the sample are similar to Table 5.1, except for firm survival which is the distinctive dependent variable of this study. The descriptive analysis of the sample regarding firm survival using the Kaplan-Meier method is presented in Section 4.4.3 of Chapter 4, and the Log-rank test explores the primary relationships of factors under study with firm survival, presented in Section 4.4.2 of Chapter 4.

The following sub-section 6.3.1 provides a concise overview of the database and elucidates the dynamics of firm survival/closure over the observation period.

6.3.1 Dynamics of Firm Survival/Closure

The age of a firm at closure is defined as the time between firm establishment and the official announcement of firm's exit from business operations. As previously indicated, the closing of a university spin-off firm can be classified into two types: closure through bankruptcy, and through acquisition. During the observation period (1999-2018) 36 (34 percent) spin-off firms closed, either following acquisition (13 percent) or following bankruptcy (21 percent), whereas 66 percent survived. The observed survival rate is consistent with the results of recent studies on firm survival undertaken by Rannikko et al. (2019), which estimated 72 percent survival rate for high-tech startups founded in 2006 in Sweden in a time period of 8 years.

The average age of all university spin-off firms measured at the end of the observation period is 8.4 years. Among the survived university spin-off firms, the average age is 9.2 years, while for non-survived ones, it is 7.1 years. Some previous studies have reported a younger average age, around 3 years, for startup survival (e.g., Cantamessa et al., 2018; Kalyanasundaram et al., 2021). However, research focused on high-tech startups has indicated that about half of the startups in the high-tech industry manage to survive beyond 5 years (Tsvetkova et al., 2014). This finding aligns with the results of the current study, showing both survived and non-survived university spin-off firms exceed the age of 5 years.

Table 6.1 illustrates the dynamics of the sample over time, specifically the number of firms exiting the business through bankruptcy and acquisition, alongside the firms' age. The highest frequency of exits occurs for firms in the range between age four and six, indicating this period as critical for high-tech startups. Additionally, Figure 6.1 in Appendix 6.1 displaying non-parametric smoothed hazard rate of firms' exit over time, visually illustrates the highest possibility of firm closure between the age of four and six years.

Table 6.1 Distribution of firms' age at closure through Bankruptcy and Acquisition

Age of firms	Abs. No. of survived firms	Abs. No. of Bankruptcy	Abs. No. of Acquisition	Total Number of Exits
2	105	1	0	1
3	103	1	1	2
4	98	3	2	5
5	92	5	1	6
6	86	4	2	6
7	85	0	1	1
8	80	4	1	5
9	78	0	2	2
10	76	1	1	2
11	72	3	1	4
12	72	0	0	0
13	71	0	1	1
14	70	0	1	1
Total No. of firms	70	22	14	36

The subsequent section provides detailed insights into the multivariate regression analyses utilized in this study, specifically Cox regression and Competing risk regression analysis. These analyses aim to assess the influence of each variable on the likelihood of firm exit in Cox regression modelling. Additionally, the effects of these variables specifically on firms' bankruptcy will be assessed separately through the implementation of Competing risk analysis.

6.4 Analysis of Firm survival

The explanatory analysis in this chapter assumes that different routes of firm exit may be caused by different factors. The analysis starts with Cox proportional hazard regression to assess the factors contributing to overall firm failure. Then, it distinguishes between firm closure through bankruptcy and acquisition, utilizing Competing risks regression analysis. However, due to the limited number of firms exiting through acquisition in the sample (n=14), the analysis primarily focuses on factors connected to firm bankruptcy which occurs somewhat more often (n=22). The results regarding firm acquisition are reported in Appendix 6.2. It is important to note that while a certain relationship between competing events might be perceived (such as firms being acquired just before they would have otherwise failed), due to the lack of available data to test such a relationship in this study, separate and independent hazards for bankruptcy and acquisition have been considered.

Detailed explanations and mathematical background on Cox regression and Competing risk regression analysis are available in Chapter 3, Section 3.4.3 and 3.4.4, respectively. The subsequent section provides the results of empirical analysis conducted in this chapter.

6.4.1 Firm Survival Analysis and the Result of Cox Regression

The sample analysed consists of 106 university spin-off firms within the observation period spanning from 1998 to 2018. The panel is unbalanced due to the varying founding years of the firms between 1998 and 2014, and their potential exit from the business at different stages. Additional details about the data and sample can be found in Chapter 3, Section 3.2. The closure of firms encompasses all exit paths, including bankruptcy, liquidation, and plain acquisition (while acquisition following bankruptcy is also possible, but falls beyond the study). The data have been tested for specification errors using the test of the proportionality assumption, and the null hypothesis that the hazard rates are proportional, cannot be rejected at a 5 percent significance level. The test results are provided in Appendix 6. 4.

This study follows the argument of some previous research suggesting that the causal processes leading to firm bankruptcy or acquisition differ (e.g., Esteve-Pérez et al., 2010). To investigate this, we employ two regression analyses: Cox regression and Competing risk regression. The models obtained from these analyses, presented in Tables 6.2 and 6.3, respectively, aim to identify the influencing factors on firm closure overall and firm bankruptcy in particular. In Table 6.2, all non-surviving firms are grouped together, regardless of their method of closure, and Cox regression analysis is conducted using a stepwise approach to select the best model for the data. Table 6.3 presents the results of stepwise modelling using Competing risk analysis, focusing specifically on firms exiting the business through bankruptcy. While firms closing solely through acquisition are also considered, the limited number of such events (14 acquisitions) leads us to present this analysis as an experimental model in Appendix 6. 2.

In order to test the 13 hypotheses, which were developed in Section 6.2, 13 independent variables were included in the models. A stepwise method is employed to acquire an optimal model fit for the data in both models, see Table 6.2 and Table 6.3. The measurements and descriptive statistics of these variables are identical to those used in Chapter 5 and are explained in Chapter 3, Section 3.3.3. In addition to the 13 explanatory variables, two control variables are inserted to the models (similar to the modelling in Chapter 5, Section 5.3.2). First, to account for potential impact of macroeconomic conditions on firm survival, a control variable is used on whether the time of firm's establishment was during the global economic crises from 2007 till 2010, or beyond. Furthermore, the analysis is also controlled for the distinction between service business models and manufacturing-oriented business models. Thus, the models are exploring the thirteen hypotheses, addressed in Section 6.2, and 2 control variables (the table of variables and measurements is identical to Table 5.1, except for time-to-market introduction, which is addressed in Hypothesis 6.7).

Before initiating the model estimation process, the ratio of sample size to variables was carefully evaluated. Given the relatively large number of variables compared to the sample size, a stepwise modelling approach was chosen to be conducted. It's worth noting that this study follows the guideline proposed by Vittinghoff and McCulloch (2007), which suggests that logistic and Cox regression models can be employed with fewer events per variables without compromising result robustness. By adhering to this guideline and conducting stepwise modelling, the study aims to mitigate sampling error and ensure the robustness of the analysis.

Cox regression analysis

All the statistical calculations and modelling in this Chapter were implemented using the statistical software Stata 16, which supports survival data analysis very well. Through stepwise modelling, four sets of variables, along with control variables, will be systematically considered, and all possible combinations will be explored. The final model selection will be based on comparison of p-values, Log-likelihood, and the Akaike Information Criterion (AIC) of the obtained models. All possible models for firm survival using Cox regression are presented in Table 6.2.

The first model in Table 6.2 serves as a control model, incorporating the two control variables. This control model shows a relative weak outcome, as neither the model nor the variables demonstrate a significant effect on firm survival. In Models 1 to 4, the controlling variables are added with each set of variables, thereby constructing new one-dimensional models. The hazard ratio results are reported in Table 6.2. A hazard ratio less than 1 indicates a decrease in hazard, whereas a hazard ratio greater than 1 is associated with higher hazards. Among the four models, only Model 1 which includes Entrepreneurial Orientation of firms, proves to be significant, with one influential factor (business diversification). Although Models 2 to 4 demonstrate some factors with relatively strong influence on survival, e.g. size of founding team, the models themselves are not significant. Concluding from this step, it has been decided to eliminate the control model and keep the sets of variables related to Entrepreneurial Orientation. Subsequently, the combinations of the remaining three sets of variables with Entrepreneurial Orientation factors were explored.

Models 5 to 7 in Table 6.2 present the two-dimensional models in which Entrepreneurial Orientation is consistently included. These sets of models exhibit large improvements in terms of both model significance ($p< .010$) and the number of significant variables. Building upon these significant variables, the next step involves adding the variables from the other categories while maintaining Entrepreneurial Orientation in all models. Model 8 to 10 in Table 6.2 provide the outcomes of these estimations.

Comparing the models based on their p-values, log-likelihood, and the AIC, Models 8, 9, and 10 exhibit almost identical improvements, with no substantial differences (p-values are in the same range, and the AIC differs by less than 2). Despite the attempt to avoid inclusion of all 13 explanatory variables due to the relatively small sample size-to-variables ratio, stepwise Cox regression modelling indicates *significant* improvements for three-dimensional models while assigning equal value to each set of variables (based on the results of Model 8, 9, and 10). Therefore, the decision was made to continue with Model 11 by incorporating all factors from Models 8, 9, and 10 into one model. Model 11 demonstrates a significant improvement in model features (the p-value of the model improved by one thousandth, and the AIC number decreased by at least 4 and proved to fit the database the most. Thus, Model 11 in Table 6.2 has been selected for interpretation and assessment of the hypotheses.

Table 6.2 Cox regression analysis on firm survival

Explanatory variables (hypotheses in brackets)	*Control model*	*Model 1* HR(s.e.)	*Model 2* HR (s.e.)	*Model 3* HR (s.e.)	*Model 4* HR(s.e.)	*Model 5* HR (s. e.)	*Model 6* HR(s.e.)	*Model 7* HR (s.e.)	*Model 8* HR(s.e.)	*Model 9* HR (s.e.)	*Model 10* HR(s.e.)	*Model 11* HR(s.e.)
Control variables												
Period (Year of establishment)	1.15(.40)	1.29 (.46)	1.12(.40)	.80(.31)	1.22(.43)							
Business model	1.76 (.79)	1.46 (.69)	1.81(.84)	1.07(.64)	1.96(.90)							
Entrepreneurial orientation												
Innovation radicalness (H6.1)		.80(.29)				.74(.28)	.60(.23)	.91(.33)	.54(.22)	.80(.33)	.61(.24)	.63(.27)
Newness of market (H6.2)		1.22(.33)				1.39(.38)	1.14(.32)	1.20(.33)	1.26(.38)	1.3(.37)	.96(.29)	.99(.33)
Business diversification (H6.3)		.33 (.11)***				28(.11)***	.31(.12)***	.24(.09)***	.24(.10)***	.23(.10)***	.22(.09)	.19(.09)***
Resources/capabilities in Founding team												
Size of founding team (H6.4)			.63(.14)**			.55(.12)***			.49(.12)***	.56(.13)***		.49(.12)***
Found. team education (H6.5)			.95 (.39)			.76(.33)			.51(.24)	1.02(.46)		.70(.33)
Found. team business exp. (H6.6)			1.25(.46)			.81(.31)			1.01(.46)	1.11(.45)		.74(.35)
Accessed Resources/capabilities												
Age at first market introduction (H6.7)				1.00(.004)**			1.00(.004)**		1.00(.004)**		1.01(.004)***	1.05(.004)***
Age at first collaboration (H6.8)				.99(.004)			.99(.004)		.99(.005)		.99(.004)	.99(.005)
Age at first investment (H6.9)				1.00(.004)			.99(.003)		.99(.004)		1.00(.003)	.99(.004)
Age at joining first marketing staff (H6.10)				1.00 (.003)			1.00(.004)		1.00(.003)		1.00(003)	1.00(.004)
Entrepreneurial ecosystem												
Quality of NIS (H6.11)					1.46(.49)			1.90(.67)**		1.96(.72)*	.67(.22)	1.89(.72)*
Metropolitan type Location (H6.12)					1.04(.22)			.83 (.18)		.89(.70)	1.04(.14)	.85 (.19)
Type of incubating university (H6.13)					.53(.19)*			.53(.20)		.55(.21)	.53(.19)*	.34(.15)**
No. of USOs	106	106	106	106	106	106	106	106	106	106	106	106
LR Chi-square	1.85	13.02	8.52	7.72	6.27	19.15	18.34	19.5	28.34	26.73	27.84	39.06
Log likelihood	-147.58	-142.00	-144.25	-144.65	-145.37	-138.93	-139.34	-138.75	-134.34	-135.14	-134.59	-128.98
P value	.39	.023	.13	.25	.29	.0039	.010	.0028	.0016	.0015	.0019	.0002
AIC	299	294	298	301	300	289	292	289	288	287	289	283

***p<0.1 **p<0.05 ***p<0.01**

Model 11 in Table 6.2 reveals five variables that significantly influence the closure of university spin-offs operating in sustainable energy. It should be remembered that interpretation of the results always needs to be done considering the reference category of each variable coded by 1 in Table 5.1. Business diversification demonstrates the strongest significance ($p < 0.01$; $HR = 0.19$). This indicates that employing a diversification strategy tends to diminish the hazard rate significantly compared to those with a focus strategy, thus Hypothesis 6.3 of the study is confirmed. The size of the founding team tends also to play a crucial role, with firms having one person in their founding team experiencing a significantly lower hazard rate of closure compared to those with more than two persons in founding team. This result confirms the effects of size of founding team on survival of university spin-offs, however the result are in the *opposite* direction of Hypothesis 6.4 ($p < 0.01$; $HR = 0.49$). Additionally, the age at which a university spin-off firm enters its product to the market, tends to influence the likelihood of closure, indicating that for each year increase in the age of firm at first market introduction, the hazard rate of closure increases; thus Hypothesis 6.7 is supported by this result ($p < 0.01$; $HR = 1.05$). With regard to networking and environmental support, the quality of the National Innovation System (NIS) in a country is also a key influence, with university spin-offs operating in countries with a low-quality NIS facing higher likelihood of closure than those in countries with a high-quality NIS, confirming Hypothesis 6.11 ($p < 0.1$; $HR = 1.89$). Furthermore, the type of university tends to be a significant factor, with spin-offs from general universities facing a lower hazard rate of closure compared to those from technical universities ($p < 0.05$; $HR = 0.34$). This result is in *opposite* direction of Hypothesis 6.13. In this hypothesis a higher likelihood of survival for firms from technical universities is assumed compared to general universities, which is not supported as hypothesized.

In the following section, the results of Cox regression and the hypotheses will be discussed. After the assessment of the hypotheses, the study extends its exploration by focusing on firms that exit the business through bankruptcy. This part of the analysis serves as an extension to the main study and aims to address the question of the importance of different routes of firm exit when investigating firm survival. This exploratory analysis will be conducted using Competing risk regression analysis on the same database. Comparing the results of both analyses will enrich the literature on firm survival and provide insights into appropriate approaches.

6.4.2 Cox Regression Results and Discussion of the Hypotheses

This empirical study examined 13 hypotheses by incorporating 13 explanatory variables and 2 control variables. Model 11 in Table 6.2 as the full model excluding non-significant control variables, emerged as the best fit for our data and was utilized to assess these pre-developed hypotheses. With a p-value of .0002, this model demonstrates the influence of all variables and identifies 5 variables with a statistically significant influence on firm survival. The subsequent section discusses the obtained results and presents a detailed examination of the hypotheses.

Control variables

No significant effects were observed when controlling for the year of establishment, particularly in the context of initiating operations during an economic crisis. This outcome could be attributed to the simultaneously heightened emphasis on energy transition towards sustainability, spearheaded by the Kyoto Protocol in 2008 and further reinforced by the Paris Agreement in 2015. These international agreements have prompted policy shifts that prioritize, and support firms engaged in sustainable energy practices, thereby mitigating the influence of economic crises. In other words, the impact of the global economic crisis on sustainable energy firms may have been offset by this increased focus on sustainability-related initiatives.

Regarding the control variable of the business model for university spin-off firms, comparing services and manufacturing-oriented businesses, once again, no significant influences were detected, despite the expectation that manufacturing-oriented firms would experience more failures. This unexpected result may also be explained by the aforementioned recent emphasis on sustainability, which anticipated and encouraged changes in energy industries. Consequently, manufacturing firms might have received more support to prevent failure. Another reason may be that manufacturing-oriented business in general have invested a lot more in equipment, instruments and other costly physical facilities compared to service firms, and as a result may quit the business less easy.

Entrepreneurial orientation

Among the three factors related to the entrepreneurial orientation of the firms, i.e. innovation radicalness, newness of market, and business diversification, the business diversification strategy is shown to have a significant effect on firm survival, confirming Hypothesis 6.3 of this study. The result indicates that university spin-off firms adopting a focused strategy exhibit a significantly higher probability of closure compared to those that choose to have a diversified product or market. This finding suggests that small high-tech university spin-offs in sustainable energy need more flexibility to integrate the risks and uncertainties involved. Therefore, those with a more concentrated focus face increased vulnerability in terms of closure. Accordingly, Hypothesis 6.3 is supported in the predicted direction by the result, while Hypotheses 6.1 and 6.2 are not supported.

Competences in founding team

Among the three factors representing the differences in founding team competences, i.e. size of founding team, education of founding team, and pre-business experience of founding team, the size of the founding team emerges to have a significant effect. Surprisingly, the observed direction *contradicts* Hypothesis 6.4. The results indicate that university spin-off firms with smaller founding teams possess a lower probability of closure, as compared to those with larger founding teams. This unexpected outcome challenges the study's premise, which posited that a larger founding team, with its potential for increased diversity in knowledge and capabilities, network, and resource access, would contribute to a lower probability of closure. One plausible explanation may lie in the unique characteristics of university spin-off firm’s founding team and the diverse backgrounds of their founders (Visintin and Pittino, 2014; Huynh et al., 2017), which could lead to more conflict. Founders of university spin-off firms often possess strong academic backgrounds but may lack familiarity with the business environment and team dynamics. It is also conceivable that larger founding teams experience heightened internal conflicts, potentially contributing to the observed higher probability of closure for firms with bigger founding teams. While the size of the founding team appears to influence a firm survival, its role in augmenting a firm’s resources and capabilities is not straightforward. Inspired by some previous studies in the same domain (e.g., Shane and Stuart, 2002, Scholten, 2006; Taheri, 2013), it could be concluded that to establish a more meaningful connection between team size and a firm’s resources and capabilities, other characteristics of the founding team, such as their diversity in knowledge and networks, and prior friendships or partnerships within the team, should be incorporated alongside the team size. The same holds for additional strategies following a small team size, like a Lean Model, e.g., by outsourcing various team activities to external advisors (Bocken and Snihur, 2020). ‘Balancing’ of weak starting teams, e.g. through adding competences or outsourcing team activities in, is receiving increased attention today (Van Geenhuizen and Taheri, 2024), but such later changes have remained unknown in the current study.

While Hypothesis 6.4 is supported but in the opposite direction, Hypotheses 6.5 and 6.6 are not supported due to weak influence.

Access to resources/capabilities

Hypotheses 6.7, 6.8, 6.9, and 6.10 explore the influence of the timing of having access to certain resources and capabilities, claiming that acquiring resources earlier would increase the probability of firms' longer survival. The primary focus of these hypotheses is on timing, assuming that earlier access would increase the probability of firm survival. Based on the results, early market introduction seems to be a factor positively influencing the probability of firm survival. However, early access to other resources, such as collaboration with large firms, financial investment, and hiring marketing staff, tends not to be influential regarding survival. The last results are not matching some previous studies that confirmed positive effects of access to the mentioned resources on the survival of the firm. For instance, Park et al. (2010) and Sungur (2015) in their studies found a significant relationship between firms' collaboration and their survival. Similarly, Musso and Schiavo (2008), and Bridges and Guariglia (2008), emphasized the role of access to substantial financial investment in the survival of the firms. However, the *timing* of access to the resources was not considered in any of the previous studies. The unexpected result might also be explained by specificities of the sample, namely university spin-off firms in sustainable energy sectors. Since the acceleration of energy transition towards sustainability aligns with global and national policies in recent decades (overlapping with the observation period of the study), it can be imagined that if the sustainable energy innovation introduced by the university spin-offs appears promising, missing access or missing early access to networks and financial investment wouldn’t be a major obstacle. Therefore, it is a doubtful step to compare the obtained results with previous studies beyond the energy sector and its’ changing policy context.

For university spin-off firms in sustainable energy, in many cases, the main uncertainty starts with the innovation and its technology readiness level. Access to investment capital or collaboration with large firms, is a necessary step to demonstrate or pilot a project, but it does not guarantee the survival of the firm. This might be the reason why the expected relationships do not appear in the results. In addition to that, it should be considered that some roles, such as marketing personnel advice or collaboration with other firms, are covered by the support of incubating universities for university spin-offs; thus, results for non-university spin-off firms might be different.

Overall, Hypothesis 6.7 is supported by this study, confirming that university spin-off firms with an early market introduction face a higher likelihood to survive longer, while Hypotheses 6.8, 6.9, and 6.10 are not supported by empirical results of the study.

Entrepreneurial Ecosystem

The quality of the National Innovation System (NIS) is another set of influencing factors on survival of the firms in the context of high-tech university spin-off firms active in sustainable energy. The findings reveal a significant relationship indicating that firms operating in countries with lower NIS rankings may face a considerably higher probability to fail, as compared to their counterparts in countries with higher NIS rankings. This finding suggests that firms operating in countries with well-established innovation systems are more likely to benefit from a supportive entrepreneurial ecosystem that encourages research and development, collaboration, and the adoption of new technologies. In addition to that, such countries may strongly encourage activities related to energy transition, like financing national research programs and providing subsidies to university spin-off firms elaborating solutions. Thus, Hypothesis 6.11 is supported by results of the study.

The type of university shows also to be a significant factor influencing firm closure, but these findings *contradict* our initial proposition and Hypothesis 6.13, which posited that technical universities might offer a more conducive environment for high-tech university spin-off firms due to their connections with industry and investors. And finally in contrast with assumptions, Hypothesis 6.12 on positive influence of a metropolitan eco-system location, is not supported by the results, suggesting that rural areas have developed compensation mechanism, e.g. within learning activities of university spin-off firms and most probably also incubators (Flåten et al., 2015). In addition, those areas may benefit from technology specialization derived from nearby natural resources. What may also occur is that influence of metropolitan entrepreneurial ecosystems is neutral due to emerging harmful influence of ‘agglomeration diseconomies’, like increase of real-estate prices, pressure on traffic infrastructure, relatively high wage-level and decreasing quality of life in large cities (Richardson, 1995; Zengh, 2001).

6.4.3 Competing Risk Regression Analysis

As mentioned previously, Cox regression survival analysis primarily focuses on determining the presence or absence of a specific event, such as the survival or non-survival of a firm. However, in certain situations, additional events may act as competing risks, potentially influencing the outcome under investigation. For instance, when a firm is acquired, it no longer faces the risk of bankruptcy as it ceases to exist after integration. Competing risk regression analysis is well-suited for handling such ‘scenarios’. In this section, after distinguishing between firm exits through bankruptcy and acquisition, firm survival was analysed using competing risk regression. More detailed explanation of competing risk regression is provided in Section 3.4.4 of Chapter 3. This analysis enriches our understanding of firm survival by exploring the impact of different closure routes on the final result. Due to the limited number of firms exiting through acquisition in the sample, the analysis reports firm bankruptcies in the main text (Table 6.3), while the (less robust) results of firm acquisitions are presented in Appendix 6.2 (Table 6.4).

Similar to the Cox regression analysis, a stepwise approach was employed in the Competing risk regression analysis to determine the best model fit for the database. This involved testing a series of models by progressively adding sets of variables. Table 6.3 presents the results of the influencing factors on firm bankruptcy. Initially, control variables were included in a model, which showed no significant effect. Models 1 to 4 were then formed by adding one set of variables to the control variables. Among these, Model 3, incorporating control variables and variables related to resource access/capability, proved to be significant. Consequently, Model 3 was kept, and other possibilities were explored by adding additional sets of variables to this model. Models 5 to 10 in Table 6.3 represent all possible combinations and the specifications of the obtained models. While all Models 5 to 10 showed significance with a p-value of $p < .0000$, Model 9 demonstrated a significant improvement when comparing the AIC values and Log-likelihood. Given the relatively small ratio of sample size (106) to the number of variables, as argued in Cox regression analysis, the study attempts to avoid including all 13 explanatory variables and two control variables in one single model. Therefore, unlike Cox regression analysis of the study, here, the significant improvement observed in the Model 9 compared to the other models justifies our decision not to pursue modelling that includes all variables in one model. Accordingly, Model 9 in Table 6.3 was identified as the best fit for the data and can confidently be selected as the optimal model for interpreting the competing risk analysis of firm bankruptcies. Model 9 involves ten explanatory variables plus two control variables and excludes the set of variables related to resources/capabilities in founding teams. Among the 10 independent factors included in Model 9, six factors demonstrate a significant effect on firms’ likelihood of experiencing bankruptcy. It is important to emphasize again that for the interpretation of the hazard ratio, the reference group, indicated and coded as 1 in Table 5.1, should always be considered. For instance, the business model, as a control variable, exhibited a statistically significant effect ($p < 0.01$; HR = 0.06). Referring to Table 5.1 indicates that service-oriented firms are coded as 1 and serve as the reference category. Thus, the result suggests that moving from the reference category (service-oriented university spin-off firms) to the next category (manufacturing-oriented university spin-off firms) is associated with a reduced risk of bankruptcy (hazard ratio less than 1). This means that spin-offs operating with a manufacturing-oriented business model tended to have a significantly lower risk of bankruptcy compared to those in the service sector.

Table 6.3 Competing risk regression analysis on firm bankruptcy

Explanatory variables	*Control model*	*Model 1* $HR(s.e.)$	*Model 2* $HR\ (s.e.)$	*Model 3* $HR\ (s.e.)$	*Model 4* $HR(s.e.)$	*Model 5* $HR\ (s.e.)$	*Model 6* $HR(s.e.)$	*Model 7* $HR\ (s.e.)$	*Model 8* $HR(s.e.)$	*Model 9* $HR\ (s.e.)$	*Model 10* $HR(s.e.)$
Control variables											
Period (Year of establishment)	1.19(.47)	1.04 (.43)	1.22(.51)	.74(.29)	1.23(.51)	.73(.27)	.75(.30)	.78(.34)	.69(27)	.75(.40)	.93(.38)
Business model	.92 (.46)	.66 (.33)	1.13(.57)	.20(.12)***	1.07(.58)	.19(.10)***	.18(.14)**	.11(.07)***	.10(.08)***	.06(.04)***	.11(10)**
Entrepreneurial orientation											
Innovation radicalness (H6.1)		1.65(.75)				.97(.45)			1.21(.64)	1.29(.61)	
Newness of market (H6.2)		1.28(.35)				1.10(.40)			.97(.43)	.85(.45)	
Business diversification (H6.3)		.34 (.15)**				43(.18)**			.30(.15)***	.24(.11)***	
Resources/capabilities in Founding team											
Size of founding team (H6.4)											
Found. team education (H6.5)			.69(.17)				.63(.18)		.48(.15)**		.59(.17)*
Found. team business exp. (H6.6)			.77 (.36)				.63(.34)		.61(.32)		.85(.50)
			1.02(.52)				1.00(.43)		.86(.41)		1.46(.66)
Accessed Resources/capabilities											
Age at first market introduction (H6.7)				1.02(.006)***		1.02(.006)***	1.02(.007)***	1.03(.006)***	1.02(.006)***	1.03(.006)***	1.03(.008)***
Age at first collaboration (H6.8)				1.00(.004)		1.00(.004)	1.00(.004)	1.00(.004)	1.00(.004)	1.01(.004)*	1.00(.004)
Age at first investment (H6.9)				1.00(.004)		1.00(.004)	1.00(.005)	1.00(.005)	.99(.006)	.99(.004)	1.00(.005)
Age at joining first marketing staff (H6.10)				1.00 (.003)		1.00 (.003)	1.00(.005)	.99(.005)	1.00(.005)	.99(.004)	1.00(005)
Entrepreneurial ecosystem											
Quality of NIS (H6.11)					1.78(.75)			2.56(1.02)**		4.03(1.8)***	.42(.19) *
Metropolitan Location (H6.12)					.72(.22)			.74 (.15)		.48(.16)**	.77(.16)
Type of incubating university (H6.13)					.91(.41)			.80(.37)		.71(.38)	.56(.31)
No. of USOs	106	106	106	106	106	106	106	106	106	106	106
LR Chi-square	.16	9.05	2.66	21.57	4.43	39.95	35.90	47.86	57.90	97.18	55.46
Log likelihood	-98.96	-95.08	-98.07	-88.02	-97.60	-86.38	-86.77	-84.59	-84.15	-80.89	-82.93
P value	.92	.10	.75	.0014	.48	.0000	.0000	.0000	.0000	.0000	.0000
AIC	201	200	206	188	205	190	191	187	192	184	189

$* p < 0.1 \quad ** p < 0.05 \quad *** p < 0.01$

Further, Business diversification strategy tends to play a pivotal role in firms bankruptcy ($p < 0.01$; $HR = .24$). This result indicates that university spin-off firms pursuing a focus strategy faced a significantly higher likelihood of bankruptcy, as compared to firms with diversification strategy. Further, the age at first market introduction demonstrated to be an influential factor with ($p < 0.01$; $HR = 1.03$) suggesting a slight increase in the hazard with each year increase in the age at first market introduction. Similarly, age at making first collaboration increases the hazards of bankruptcy when it increases by one year ($p < 0.1$; $HR = 1.01$). With regard to Entrepreneurial Ecosystem, the quality of the National Innovation System (NIS) showed to be very influential ($p < 0.01$; $HR = 4.03$). The trend indicates that firms in countries with a lower-quality NIS have about 4 times higher hazard of bankruptcy, as compared to those in countries with a higher-quality of NIS. Finally, the urban location variable had a substantial effect ($p < 0.05$; $HR = 0.48$) for firms in metropolitan areas compared to small cities, indicating that firms located in smaller and far cities tended to have a lower hazard of bankruptcy. The next section seeks to uncover the potential insights that could be gained from comparing the obtained results from Cox regression analysis with those from Competing risk analysis.

6.4.4 Comparison of Cox Regression Model and Competing Risk Regression Model

In this study, Cox regression analysis explores factors contributing to firm closure or hindering their long-term survival, while Competing risk regression analysis specifically focuses on firms that close through bankruptcy and identifies the factors influencing this outcome. The results of both analyses are presented in Tables 6. 2 and 6. 3 respectively, with the best model for each analysis determined (Model 11 in Table 6. 2 and Model 9 in Table 6.3). By comparing these two models, we can gain insight into the impact of applying different methods when studying firm survival.

It's important to note that due to the relatively small number of exited firms in the sample (36 out of 106 USOs), and subsequently, an even smaller portion of bankrupted firms (22 out of 106 USOs), the results of the competing risk regression analysis alone should be regarded as *tentative*. However, comparing the results of both analyses can still offer valuable insights.

Analysing all closed firms as one group revealed five influential factors, while focusing solely on bankrupted firms identified six influential factors affecting the duration of firm survival. Notably, three factors were found to be *overlapped* between the results of the two analyses, highlighting their significant influence on shortening firm survival: business diversification, age at first market introduction, and the quality of the National Innovation System (NIS). Thus, it can be confidently concluded that regardless of the routes of firm closure, firms employing a focused strategy in their product and market are more vulnerable to facing closure. Similarly, it indicates that a later market introduction increases the chance of firm closure. And firms located in countries with higher-ranked National Innovation Systems (NIS) are less likely to face closure compared to their counterparts in countries with lower-ranked NIS.

Additionally, using Cox regression analysis it was found that the size of the founding team and the type of university are among the factors influencing firm survival. The results of competing risk regression also showed the effect of being active in the service sector, first collaboration at a later age, and firm' location in metropolitan areas on increasing the probability of firm bankruptcy. However, the most significant insight derived from this comparison arises from the overlap in results, emphasizing the importance of these identified factors. Despite disparities, the overlap in influential factors identified by both analyses underscores their critical role in influencing firm survival regardless of the closure route. This suggests that strategic decisions related to diversification, timing of market entry, and institutional environment significantly impact a firm's ability to survive in the long term. However, the identification of additional influencing factors by each analysis indicates that making distinction between the routes of closure using a larger sample and higher closure rates, may lead to more accurate results which is worth to be considered.

The hypotheses developed in Section 6. 2 did not distinguish between routes of exit, primarily due to the small number of firms exiting in our sample (36 out of 106). Thus, the study focuses solely on testing the developed hypotheses without distinguishing between the paths of exit for the firms that did not survive as indicated by Cox regression analysis.

6.5 Conclusion

The central question of entrepreneurship and business research revolves around understanding why some young firms survive longer while others fail. Consequently, firm survival has become one of the most intensively researched events in the organizational literature (see, for instance, Josefy et al., 2017). While few studies have specifically explored the survival of university spin-off firms (see Rodeiro-Pazos et al., 2021), the limited number of research endeavours and the diversity in the scope of analysis have prevented the establishment of a consensus on influencing factors leading to the survival of university spin-offs. The findings of this study contribute to this narrow body of literature on the survival of university spin-offs by empirically analysing 106 university spin-off firms active in sustainable energy technologies.

A major contribution of this study is the significance of the diversification strategy, which is identified as the most influential factor preventing firms from failure. By incorporating risk-avoidance strategies such as reducing the radicalness of innovation and entering established markets, alongside risk-mitigating strategies in the form of product or market diversification, the study explicitly pointed out the advantage of risk-mitigating strategies over risk-avoidance strategies for ensuring firm survival. Accordingly, the results suggest that in sustainable energy industry, risk-avoidance strategies such as choosing more incremental innovation or entering established market do not have a significant relationship with longer survival of small high-tech university spin-offs. Instead, the study highlights the impact of risk-mitigating strategies, such as securing early access to revenues through limited diversification and early market introduction.

In detail, among early access to all resources considered in this study, early market introduction proves pivotal for firm survival. This result confirms that, for small high-tech university spin-off firms, proof of product may open new doors and provide access to more resources and networks. Thus, entrepreneurs and university spin-off founders need to pay special attention to finding the optimal time for firm establishment, considering the product readiness level, to avoid late market introduction after firm establishment, which would increase the risk of firm failure.

In terms of the quality of the founding team, the results indicate that a smaller size of the founding team is more desirable for firm survival. This emphasizes the importance of agility and a faster decision-making process for the survival of university spin-off firms. Further, as one might imagine, a supportive environment plays a crucial role in the survival of high-tech university spin-off firms. The results suggest that university spin-off firms) located in countries with a higher level of National Innovation System benefit more from their supportive ecosystems and experience a longer survival period. Furthermore, university spin-off firms originating from general universities tend to survive longer, a phenomenon that requires further exploration.

This study contributes to the literature on early firm survival by clarifying the differences in methods of firm survival analysis by employing two distinct approaches and comparing their results. Previous research on firm survival has predominantly relied on Cox regression survival analysis, often overlooking the impacts that different routes of firm closure may have. However, certain other research endeavours, such as those by Köke (2002), He et al. (2010), Esteve-Pérez et al. (2010), and Grashuis and Franken (2020), have advocated for a clear differentiation between various exit routes from business, especially distinguishing between bankruptcy-induced exits and exits via acquisition. This differentiation is crucial because in the case of acquisition, the novel product and economic activities of the business often continue to exist under new (and possibly stronger) ownership and management, which can be viewed as a success for the spin-off firm. Therefore, treating firm acquisition as a form of failure in the analysis may lead to misleading results. However, for small sample sizes like the one used in this study, the division of non-survived firms into two groups can result in smaller groups with lower incidence rates. In case of this study, the group of acquired firms was particularly small, impacting the validity of the results, reason why it has been removed from the modelling table and just reported in the Appendix as an experimental study. Nevertheless, this distinction is found to be useful and is recommended when sufficient data are available.

Future studies in the field of entrepreneurial research could benefit from addressing two important avenues. Firstly, as suggested by previous research (e.g. Moog and Soost, 2022), exploring the indirect and non-linear effects of founding team characteristics on firm survival would provide valuable insights into the nuanced dynamics of start-up success. Investigating the effect of the involvement of star-scientists, as some studies have mentioned (e.g. Thomas et al., 2020), and the existence of surrogate entrepreneurship in university spin-off founding teams (Franklin et al, 2001) could shed light on the diverse influences shaping firm outcomes. Secondly, despite efforts to make Entrepreneurial ecosystems measurable, there remains a need for more accurate and applicable indicators for the measurement of such ecosystems.

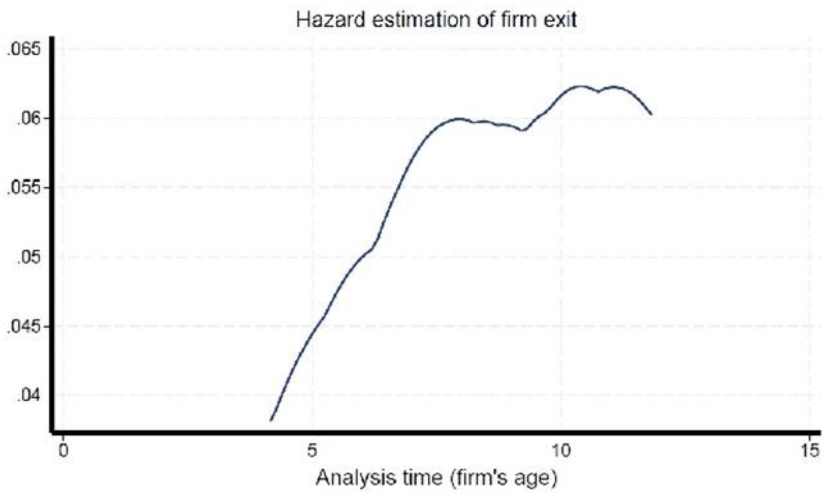
Developing comprehensive frameworks and reliable metrics for assessing the various dimensions of Entrepreneurial ecosystems would enable more robust comparisons across different geographic contexts and facilitate the identification of effective policy strategies for ecosystem development and support.

Appendix

Appendix 6.1 Non-parametric smoothed hazard rate

Figure 6.1 displays non-parametric smoothed hazard rate of firms' exit over time. The hazard rate shows the probability that a firm exits the market in a specific year, given that it has survived until the beginning of that year. This function is derived from the number of exit firms at time t_j divided by the number of firms still at risk of exit (i.e. the firms that have survived until time t_j) for any given time across the observation period. Since the graph represents a smoothed hazard rate, the primary focus is on the trend of the hazard. The graph indicates that the hazard of exit will increase until around age 7, and between ages 7 and 9, the slope of the hazard decreases. From age 9 to 11, the hazard increases again and becomes decreasing once more after age 11. Figure 6.1 illustrates an increasing trend in the hazard of exit for firms during the initial years, followed by a decrease after age 8. This pattern aligns with the results presented in Table 6.1 and is consistent with findings from some prior studies (e.g., Fackler et al., 2013). This observation suggests the implementation of the log-logistic distribution in the analysis, as it accommodates an initially increasing and subsequently decreasing hazard.

Figure 6.1 Non-parametric hazard function



Appendix 6.2 Influencing factors on acquisition of the firm; an experimental model

The study's hypothesis encompasses the closure of firms as a whole. This comprehensive approach is chosen due to the relatively small proportion of firms closing during the observation period, rendering it impractical to divide them into multiple groups. However, through the application of competing risk analysis, two closure types—bankruptcy and acquisition could be distinguished while not separating them into two groups. In this analysis, subgroups of acquired firms are treated as firms no longer exposed to the risk of bankruptcy, despite being inactive in business. The analysis in Section 6.4.2 then proceeds to compare bankrupt firms with those that have survived. Similar analysis could be applied to acquired firms. However, given that only 14 university spin-offs were acquired among our sample, the results may exhibit reduced statistical power. Consequently, these findings are presented separately in this appendix as an experimental model. Despite the limitation of applying such analysis to the sample, this result might provide some insights and preliminarily information for further studies.

Table 6.2 influencing factors on time to firms acquisition

Explanatory variables	*HR (SD)* *Acquisition*
(Period)Year of establishment	1.7 (.73)
Business model	7.5(6.8)**
Innovation radicalness	.21 (.20)
Newness of market	1.8 (.93)
Business diversification	7.9 (4.1)***
Size of founding team	.39(.17)**
Founding team education	.59(.65)
Founding team business exp.	1.6(1.3)
Age at first market introduction	.97 (.01)*
Age at first collaboration	.90(.07)
Age at first investment	.97 (.009)***
Age at joining of first marketing staff	1.02 (.008)**
Quality of NIS of countries	.42(.30)
Location	2.00 (.55)**
Type of incubating university	.56 (.31)
No. of USOs	106
No. of events	14
Wald test	88.60
Log pseudolikelihood	-45.98
P value	.0000

The result of analysis presented in Table 6.4 focuses on the significant factors influencing the likelihood of firm acquisition. Firstly, the business model emerged as a substantial determinant ($P < 0.05;\ HR = 7.5$). It indicates that USOs operating with a manufacturing business model exhibited a 7.5 times higher hazard of being acquired compared to their service-oriented counterparts. Additionally, diversification strategy shows to have significant impact ($p < 0.01;\ HR = 7.9$). It means firms pursuing a focus strategy faced a 7.9 times higher probability of being acquired compared to those with diversified strategy. The size of the founding team was also identified as a crucial factor, ($P < 0.05;\ HR = 0.39$). Firms with one person founding team had a substantially lower hazard of acquisition compared to those with two persons or more people in founding team. The temporal aspects of a firm's development also played a role, with the age of the firm at first market introduction, the age at receiving the first investment, and the age at the joint of the first marketing expert all demonstrating influences. However, these effects appear to be weak when each year increase in age is taking into account. The age of the firm at first market introduction and receiving the first investment both had HR values of 0.97, suggesting a slight decrease in the hazard with each unit increase in age. On the other hand, the age of the firm at the joint of the first marketing expert showed a slightly increased hazard with a HR of 1.04. Lastly, the location variable exhibited a significant impact, with a HR of 2 for firms located in far and smaller cities compared to metropolitan areas and adjacent ($P < 0.05;\ HR = 2$). This indicates that firms in small cities faced a two times higher acquisition likelihood.

The obtained result presented in Table 6.4 shows two influential factors which appear only to be significant in case of firm acquisition: age at first investment, and age of firms at joining first marketing staff. Regarding the firms age at receiving first investment, the result indicates that longer duration to secure initial investment diminishes the probability of acquisition. This suggests that a prompt infusion of capital may enhance the attractiveness of the firm for potential acquirers. Conversely, the age of the firm when the first marketing expert joins the team proves to be an influential factor, indicating that a longer time taken to hire a marketing expert increases the likelihood of acquisition. This counterintuitive finding challenges expectations, suggesting that delaying the addition of marketing expertise might paradoxically enhance the appeal of the firm for acquisition. One plausible explanation for this unexpected outcome could be rooted in the strategic intentions of firms. Those that opt to hire a marketing expert earlier in their trajectory may aim to have greater commitment to independently sustaining and growing their business, potentially making them less inclined to pursue acquisition.

Appendix 6.3 Test of proportional hazards assumption

The proportional hazards (PH) assumption can be assessed through statistical tests based on scaled Schoenfeld residuals. These residuals are assumed to be time-independent. The test for each covariate correlates the respective set of scaled Schoenfeld residuals with time to examine independence between residuals and time. Additionally, a global test evaluates the entire model. A non-significant relationship between residuals and time supports the null hypothesis, signifying the proportionality of hazards. P-values greater than 0.05 for each covariate, indicates no significant deviation from the proportional hazards assumption. Table 6.5 demonstrates that the test is not statistically significant for each covariate, and the global test is also non-significant. Consequently, it can be asserted that the proportional hazards assumption remains unviolated in the data and modelling of this study.

Table 6.3 Cox proportional-hazards assumption test (firm survival)

Variable	***Rho***	***Chi²***	***Df***	***p-value***
Period (Year of establishment)	- 0.14	.71	1	0.39
Business model	0.22	2.47	1	0.11
Newness of market	-0.02	0.01	1	0.95
Business diversification	-0.01	0.01	1	0.93
Founding team size	0.12	0.61	1	0.41
Highest education of founders	-0.06	0.18	1	0.67
Business experience of founders	-0.02	0.02	1	0.89
Time of first market introduction	0.17	1.20	1	0.27
Time to first collaboration	0.18	1.5	1	0.22
Time to first investment	-0.18	1.43	1	0.23
Joining of marketing staff	-0.21	1.82	1	0.17
Quality of NIS	-0.06	0.15	1	0.69
Location	-0.01	0.02	1	0.94
Type of University	-0.20	0.20	1	0.15
Global test		12.31	15	0.65

Chapter 7. Summary, Discussion, and Reflection

7.1 Overview of the Summary, Discussion and Reflection Chapter

This thesis aimed to empirically investigate the development of university spin-off firms in the sustainable energy sector. In the context of contribution of new small high-tech firms to sustainable energy transition, two crucial aspects in the lifecycle of specifically university spin-off firms had a primary focus: first, the time to market introduction, and second, the firm survival. The background to this investigation is the recognition that sustainable energy transition requires radical innovations to transform the energy system to a more sustainable one. For that purpose, governments have initiated support programs to accelerate the contribution of university spin-off firms in the sustainable energy transition. Given that university spin-off firms constitute small and vulnerable startups, the focus in this investigation is on differences in time-to-market and in survival dynamics. The analyses draw on a sample of university spin-off firms in the Netherlands and the Nordic countries, because these countries have been known to spearhead the development of new and innovative sustainable energy companies. In these countries, the university spin-off firms favour a combination of government incentives, university programmes, and *socio-economic* circumstances, which have facilitated the founding of such companies. However, in several years, government support in Norway and the Netherlands has remained behind as compared to Denmark, Finland, and Sweden, causing some differentiation within the sample.

Aimed at fulfilling a longitudinal study, the data collection proved to be one of the most time-intensive phases of the research. The dedication invested in this endeavour yielded a valuable and precise database of 106 university spin-off firms in retrospection over the years 1998 to

2018, justifying the duration of this research phase. The thesis is theoretically anchored in the foundational concepts of the firm's entrepreneurial orientation (mostly regarding risk-taking and -mitigation), its resources (Barney, 1991), coupled with the theory of dynamic capabilities (Teece and Pisano, 2003), and insights from the entrepreneurial ecosystem theory (Stam, 2015; Stam and Van de Ven, 2021). Within this framework, the market introduction and survival of a university spin-off firm is considered to be influenced by its entrepreneurial orientation, its resources at start and those accessed after start through collaboration and through benefits in the entrepreneurial ecosystem in which the USO operates. Furthermore, the timely acquisition of resources is identified as a crucial factor in enhancing a firm's overall time to market introduction and chance of survival. This theoretical underpinning emphasizes the imperative consideration of external conditions and the broader entrepreneurial environment, particularly for small university spin-offs. The integration of the above theories resulted in four sets of hypotheses, based on entrepreneurial orientation, resources and capabilities, time of starting networking, and the quality of the entrepreneurial ecosystem, to explore their role in time to market introduction (Chapter 5) and firm survival (Chapter 6).

- The thesis is structured around four empirical analyses, as presented in Chapters 2, 4, 5, and 6. The initial phase of the thesis involved a pilot study conducted on a small subset of university spin-off firms. This preliminary investigation using Rough Set Analysis aimed to test key data's availability, like time of first market introduction, to refine measurement approaches, and to initially explore relationships. Chapter 2 presents the results of this pilot study, which focused on fast market introduction as a binary variable. Acknowledging the limitations of a small sample size and the inherent fuzziness of the data, Rough Set Analysis was chosen as the method for initial exploration. Encouraged by the insights gleaned from the pilot study, a more extensive data collection initiative was launched, setting the stage for two substantial studies conducted on this expanded dataset, i.e. on market introduction and on survival. However, before starting the comprehensive analyses in Chapters 5 and 6, Chapter 4 offers a descriptive analysis of the data, furnishing valuable information by highlighting preliminary evidence. Employing Kaplan-Meier and Log-rank test analyses, this chapter elucidates basic relationships within the sample, providing a foundational understanding for the subsequent in-depth examinations. Chapter 5 develops and examines hypotheses on factors influencing early market introduction by employing Cox regression analysis. Following this, Chapter 6 entails the development and testing of hypotheses on firm survival, utilizing both Cox regression and Competing Risk analyses.

In this concluding Chapter 7, the empirical results, theoretical contributions, policy recommendations, reflections and limitations of the study will be discussed and finally a set of potential future research avenues based on the findings and shortcomings of this study, will be recommended.

7.2 Insights on Theoretical and Empirical Relationship within Four Streams of Theory

Two empirical studies systematically tested hypotheses pertaining to two primary domains: the time to market introduction and the survival of university spin-off firms. In Chapter 5, the first study tested 12 hypotheses to scrutinize the factors influencing the time required for market introduction, whereas Chapter 6 expanded on the second study to test 13 hypotheses that examined the factors affecting firm survival, including time to market introduction. The hypotheses were developed based on four streams of theory. First, using arguments of entrepreneurial orientation (Wiklund and Shepherd, 2005) of university spin-off firms, three hypotheses were tested in each study to assess its impact on fast market introduction and firm survival. Second, the hypotheses considered founding teams' resources and capabilities and followed the Resource-based view (Barney 1991). Third, taking a nuanced approach, hypotheses were developed based on the dynamic capabilities view (Teece et al., 1997) to assess the effects of time taken to acquire and develop specific resources and capabilities, not owned at firm start, on fast market introduction and firm survival. And finally fourth, the environmental influence based on the theory of the entrepreneurial ecosystem (Prokop, 2021; Stam and Van de Ven, 2021; Huggins et al., 2024) was leveraged to formulate the effect of three hypotheses, namely, concerning quality of NIS, location in metropolitan area and the type of university on fast market introduction and firm survival. The focus of attention now moves to assessing these four categories of hypotheses for both studies, facilitating a comprehensive comparison of the obtained results.

7.2.1 Entrepreneurial Orientation

In this thesis, the entrepreneurial orientation of university spin-off firms was evaluated based on the radicalness of energy technology, the novelty of the market, and the choice of diversification in product or market. The results pertaining to the hypotheses regarding time to market introduction and survival are presented in Table 7.1. The hypotheses in the table are numbered accordingly, with those related to Chapter 5 distinguished by H5. and those related to Chapter 6 distinguished by H6.

Table 7.1 Hypotheses on USOs' entrepreneurial orientation (risk-taking), time to market and survival

Hypotheses related to Time to Market Introduction (CH5)		
H5.1	USOs in sustainable energy, that have adopted an incremental innovation strategy, have earlier market introduction compared to USOs that have adopted a radical innovation strategy.	Supported
H5.2	USOs in sustainable energy, that enter established markets have earlier market introduction compared to USOs that enter new markets.	Supported
H5.3	USOs in sustainable energy, that have adopted a diversification strategy in product or market, have earlier market introduction compared to USOs adopting a focussed strategy.	Not supported
Hypotheses related to Survival (CH6)		
H6.1	USOs in sustainable energy, that have adopted an incremental innovation strategy, survive longer compared to USOs that have adopted a radical innovation strategy.	Not supported
H6.2	USOs in sustainable energy, that enter established markets survive longer, compared to USOs that enter new markets.	Not supported
H6.3	USOs in sustainable energy, that have adopted a diversification strategy in product or market, survive longer compared to USOs adopting a focussed strategy.	Supported

The results from the two analyses indicate that university spin-off firms adopting incremental innovation strategies (H5.1) experience earlier market introduction. However, this factor does not show any influence on the survival of the university spin-off firms in the sustainable energy sector (H6.1 not supported). For the newness of the market, the results show that USOs entering an established market have earlier market introduction (H5.2), however, this effect was not found to influence the survival of university spin-off firms (H6.2 not supported). Further, the findings for the diversification strategy demonstrate no significant effect on early market introduction for university spin-off firms that adopt a diversification strategy (H5.3 not supported), however the findings show that they tend to survive longer (H6.3 supported).

The previous comparisons suggest that while strategies focused on risk avoidance through a relatively low level of product and market innovativeness, may accelerate market introduction, they do not contribute to a longer survival of university spin-off firms. In contrast, employing a risk-mitigating strategy by diversifying revenue sources enhances the probability of firm survival without impacting the time to market introduction. This implies that the goals of fast market introduction and longer survival cannot be covered by a single risk avoiding/mitigating strategy. Firms aspiring for both a faster market entry and prolonged survival must carefully navigate a nuanced balance in their risk-taking, risk-avoiding and mitigating strategies to optimize their approach for achieving both objectives.

7.2.2 Founding Team Resources and Capabilities

The composition of the founding team is thought to play a crucial role in shaping the trajectory of startups in general, and university spin-offs in particular (e.g. Aspelund et al., 2005; Bjørnåli et al., 2016; Fiorentino et al., 2022). Accordingly, founding team dimensions are influencing spin-offs' ability to respond to the challenges such as early market introduction and ensuring sustained survival in competitive markets. In this context, hypotheses related to team resources and capabilities, including team size, educational backgrounds, and pre-business experience, were developed, which are presented in Table 7. 2.

Table 7.2 Hypotheses on founding team characteristics, time to market and survival

Hypotheses related to Time to Market Introduction (CH5)		
H5.4	USOs in sustainable energy, when founded by a larger team have earlier market introduction compared to USOs founded by a smaller team.	Not Supported
H5.5	USOs in sustainable energy, with founding team that have a Master as highest education, have earlier market introduction compared to USOs with a PhD degree among the founding team.	Not Supported
H5.6	USOs in sustainable energy, which involve a founding team member with pre-business experience, have earlier market introduction compared to USOs without involvement of a founding team member with pre-business experience.	Not Supported
Hypotheses related to Survival (CH6)		
H6.4	USOs in sustainable energy, when founded by a larger team, survive longer compared to USOs founded by a smaller team.	Supported with *reverse* effect
H6.5	USOs in sustainable energy, with a founding team that have a Master as highest education, survive longer compared to USOs with a PhD degree among the founding team.	Not Supported
H6.6	USOs in sustainable energy, which involve a founding team member with pre-business experience, survive longer compared to USOs without involvement of a founding team member with pre-business experience.	Not Supported

Regarding the size of founding teams, Hypothesis 5.4 in Table 7.2 suggests that larger founding teams of university spin-offs in sustainable energy are associated with a higher probability of early market introduction. However, this assumption is not supported by the analysis. Shifting the focus to firm survival, Hypothesis 6.4 in Table 7.2 indicates that similar university spin-off firms with a larger founding team have a higher probability of longer survival, which however, is intriguingly supported in the *reverse* direction. This opposing result emphasizes the fact that survival of startups may be easily affected by the emergence of team fractures (fault lines) in large teams, certainly if there are also age-differences between team members (Valls et al., 2021). In addition, fault lines might happen more when the team is not familiar with the business environment, such as the case of university spin-offs.

Hypothesis 5.5 suggests that when the highest education of the startup team is at Master degree level, the university spin-off firms have a faster market introduction. This argues for more practical approaches for business management that individuals holding Master's degrees might offer compared to those with PhDs. This hypothesis was not supported by results of the study. With the same argument, Hypothesis 6.5 claims more probability of longer survival for university spin-off firms involving individuals with a Master degree in the founding team, which is also not supported by the results. Furthermore, the findings for Hypotheses H5.6 and H6.6 did not align with the anticipated advantage of having a team member with pre-business experience, as suggested for achieving faster market introduction and longer survival. The results do not support these hypotheses.

Unexpectedly, the hypotheses about founding team characteristics didn’t receive support, one hypothesis yielded even a contrary result. These results indicate no positive significant effect of founding team characteristics on faster market introduction, and only one effect on firm survival. This unexpected outcome may be explained by the substantial support that university spin-off firms, particularly those in sustainable energy, receive from universities, incubating organizations, and national support programs, blurring influence from characteristics of founding teams. In other words, these support initiatives, designed to address gaps in business knowledge and skills within founding teams, might overshadow the direct impact of founding team characteristics on firm performance. Furthermore, the founding team may have been adapted substantially since start, e.g. by adding experienced managers in the case of small (lean) founding teams. Therefore, it is suggested that future investigations not only include a range of static characteristics of the founding team, such as diversity, existing network, and any prior or subsequent friendships or partnerships among the founding team, but also consider the dynamics of change in founding team characteristics, such as participation in business-related courses and involvement of advisors, eventually of an advisory board (Bjørnåli et al., 2024). This approach will contribute to a more comprehensive understanding of the impact of founding team characteristics on university spin-off firms, also including non-linearities in influence and interaction with other spin-off characteristics and behaviour in the context of sustainable energy markets (Tagliazucchi et al. 2021; Moog and Soost, 2022).

7.2.3 Time to Acquiring External Resources and Capabilities

Introducing an innovative methodological approach, our analysis investigated the temporal dynamics of resource acquisition and its impact on both the time to market and the survival time of university spin-off firms in sustainable energy. This novel facet of our study adds a layer of complexity by scrutinizing the relationship between the timing of resource acquisition and its subsequent effects on market entry and firm survival. The underlying proposition posits that earlier resource acquisition enhances overall firm performance, contributing to both faster market introduction and extended survival. The hypotheses and corresponding results are detailed in Table 7.3. Recognizing actual market introduction as a crucial component of firm capabilities and as a source of turnover, the time to market introduction was integrated into the influential factors impacting firm survival. This incorporation leads to the introduction of Hypothesis 7 (H6.7) into the survival study, adding one more hypothesis to the examination of firm survival, thereby changing the existing similarity in the subsequent hypotheses in Chapter 5 and Chapter 6.

Table 7.3 Hypotheses on early acquisition of resources/capabilities, time to market and survival

Hypotheses related to Time to Market Introduction (CH5)		
H5.7	USOs in sustainable energy that develop collaboration with large firms early after start, have earlier market introduction compared to USOs that develop collaboration later or not at all.	Supported
H5.8	USOs in sustainable energy that gain substantial financial investment early after start, have earlier market introduction compared to USOs that gain financial investment later or not at all.	Supported
H5.9	USOs in sustainable energy that own market knowledge or attract marketing staff early after start, have earlier market introduction compared to USOs that attract marketing staff later or not at all.	Not supported
Hypotheses related to Survival (CH6)		
H6.7	USOs in sustainable energy, that have experienced early market introduction, survive longer compared to USOs experiencing relatively late or no market introduction.	Supported
H6.8	USOs in sustainable energy that develop collaboration with large firms early after start, survive longer compared to USOs that develop collaboration later or not at all.	Not supported
H6.9	USOs in sustainable energy that gain substantial financial investment early after start survive longer, compared to USOs that gain substantial financial investment later or not at all.	Not Supported
H6.10	USOs in sustainable energy that own market knowledge or attract marketing staff early after start, survive longer compared to USOs that attract marketing staff later or not at all.	Not supported

As a general trend, collaborations with large firms (H5.7) and early investments (H5.8) emerge as influential factors fostering early market introduction, aligning with the expected outcomes. However, in contrast to market introduction, for survival, the formal collaborations with large firms early on (H6.8) and receiving first investment early after start (H6.9) do not exhibit a significant impact on survival, highlighting the complexity of factors contributing to the long-term viability of university spin-off firms. With regard to time of first substantial investment, the expected positive impact may be disturbed by fast following rounds of substantial investment, making survival critical in some cases due to emerging payback issues, as observed in some Scandinavian countries (Van Geenhuizen and Nejabat, 2021; Hegeman and Sorheim, 2021).

With regard to the assumed positive role of early marketing knowledge in teams on faster market introduction (H5.9), and on firm survival (H6.10), these effects could not be supported by the results. This unexpected outcome may be caused by a relatively large number of spin-offs that already own such knowledge in the founding team (see Table 5. 1 in Chapter 5). Turning to firm survival, the results confirm that early market introduction positively influences the likelihood of survival (H6.7).

7.2.4 Entrepreneurial Ecosystem

With regard to the influence of the entrepreneurial ecosystem at various levels, the investigation included national, regional, and local dimensions on time to market and firm survival. The investigation incorporated three indicators, i.e. the National Innovation System, the urban location of firms (metropolitan areas or smaller cities, and distances), and the type of universities from which the university spin-offs originated. The hypotheses related to these factors are outlined in Table 7.4, focusing on time to market introduction and firm survival.

Table 7.4 Hypotheses on entrepreneurial ecosystem, time to market and survival

Hypotheses related to Time to Market Introduction (CH5)		
H5.10	USOs in sustainable energy located in countries that rank high in the national innovation system, have earlier market introduction compared to USOs located in countries with a lower rank in this system.	Not Supported
H5.11	USOs in sustainable energy that operate in metropolitan area have earlier market introduction compared to USOs that operate in small cities, or at far distance from metropolitan area.	Not Supported
H5.12	USOs in sustainable energy that originate from a technical university, have earlier market introduction compared to USOs that originate from general universities.	Supported
Hypotheses related to Survival (CH6)		
H6.11	USOs in sustainable energy located in countries that rank high in the national innovation system, survive longer compared to USOs located in countries with a lower rank in this system.	Supported
H6.12	USOs in sustainable energy that operate in a metropolitan area, survive longer compared to USOs that operate in small cities, or at far distance from a metropolitan area.	Not supported
H6.13	USOs in sustainable energy that originate from technical universities, survive longer compared to USOs that originate from general universities.	Supported with *reverse* effect

Table 7. 4 indicates that the effects of the entrepreneurial ecosystem at the national and regional level are not significant for time to market introduction (H5.10 and H5.11). However, the local support (facilities) from technical universities tends to lead to faster market introduction (H5.12). Overall, the analysis suggests stronger effects for local supports compared to regional or national supports for faster market introduction.

The results on survival, however, tend to be different. In the comparison, the national level of support within the National Innovation System significantly impacts the survival of university spin-off firms (H6.11). However, no influential effect was found from the metropolitan area for firms located in such areas (H6.12). This situation may point to equally beneficial circumstances in large cities compared to small cities and distant rural areas, which may originate from specialization and specific supports connected with availability of place-based sustainable energy sources, like strong winds and coastal current, and local abundance of silicon sands or natural wood as raw materials. Further, at the local level, the type of university shows a significant effect but in a *reverse* direction (H6.13). The result indicates that firms originating from general universities had a higher probability of longer survival compared to their counterparts from technical universities. To interpret this result, it can be imagined that general universities usually have fewer spin-off firms, thus they might receive more support than university spin-off firms from technical universities. It is also possible that at general universities university spin-off firms act at higher level of fundamental research, and eventually remain integrated in university laboratories for a longer time under 'protected' conditions, making them survive longer.

In summary, the outcomes of the last category of hypotheses highlight the diverse effects of urban environmental influences on firm performance, indicating that varied environmental factors have varying effects on different facets of firm performance. This underscores the importance of careful and customised policy design and implementation to account for the intricacies of various performance indicators within the entrepreneurial landscape. In order to effectively foster the growth and sustainability of small high-tech firms in the sustainable energy market, policymakers should adopt a differentiated approach, recognizing the diversity of impacts that environmental factors can have on different firm behaviours.

7.3 Policy Recommendations

The findings of this thesis offer valuable insights with potential benefits for three key stakeholder groups: 1) entrepreneurs and startup managers aiming for success in fast market introduction and longer firm survival, 2) policymakers striving to achieve sustainability goals and stimulate economic growth through entrepreneurship, and 3) universities supporting the incubation of university spin-off firms and seeking to foster their entry to the market and scaling-up, as well as seeking to play important roles in sustainable energy R&D programs by themselves in which spin-off firms may also participate, or even lead, like in battery and hydrogen technology.

Such policy recommendations aim to translate the contributions of the thesis into actionable strategies for entrepreneurs (starting teams), policy makers at different spatial level concerning stimulating measures and supports, and universities concerning enhancing risk-taking entrepreneurship by students and staff. The tailored nature of these recommendations reflects the nuanced findings from the hypotheses testing, providing a foundation for informed and strategic decision-making in the context of university spin-off firms in the sustainable energy sector. Recommendations concerning the three stakeholder groups will be discussed in the next subsections.

7.3.1 Recommendations for Entrepreneurs

For entrepreneurs and startup managers, the study highlights certain points listed below.

a) *Importance of Entrepreneurial Orientation with Regard to Innovation Strategies*. Empirical evidence derived from this study suggests that risk-taking/avoiding and risk-mitigating strategies can impact firms' success in different ways, necessitating a careful selection of the appropriate strategy. The findings reveal that avoiding risk-taking strategies, such as reducing the radicalness of technology and the newness of the market, significantly accelerate the time to market introduction but have no discernible impact on firm survival. Conversely, risk-mitigating strategies, addressed through diversification in product or market, prove to affect firm survival without influencing the time to market introduction. Furthermore, the study emphasizes the substantial positive effects of faster market introduction on firm survival. In conclusion, entrepreneurs aiming for prolonged survival may choose to have a risk mitigation strategy of diversification to reduce innovation-related risks. Simultaneously, they might consider shortening the time to market introduction to secure longer survival, thus employing risk-avoidance strategies like reducing the radicalness of the product and the newness of the market, but also extending presence at university and participation in co-creation with universities as risk-mitigation. Since these two types of strategies, namely risk-taking/avoiding and risk-mitigating, are not mutually exclusive, it is advisable for university spin-off firms to incorporate both strategies in their innovation, striking a delicate balance. This approach empowers entrepreneurs with valuable insights into the market potential of diverse business propositions, enabling them to make informed choices for greater success. Such strategy may benefit from having strategic advisors or an *advisory board*, which increasingly happens if spin-offs' founding teams are small and may help to complement the team in connecting with external networks.

b) *Resources and Capabilities of Founding Teams*. The impact of a founding team on early market introduction of university spin-offs might not be immediately evident and could be overshadowed by the supplementary support gained through collaboration in the industry network or the entrepreneurial ecosystem. Surprisingly, the results indicate that a smaller founding team contributes to longer survival compared to a larger team. This suggests that larger founding teams, especially those from diverse backgrounds and lacking professional business experience, may encounter more conflicts during the decision-making process. This result underscores the importance of conflict avoidance and agility in decision-making for the survival of university spin-off firms. Consequently, it is crucial to advise entrepreneurs to start with a relatively small (lean) founding team and to actively seek skills enhancement programs via incubators or accelerators, and to seek collaboration, eventually co-creation, with university and/or existing firms, instead of starting with relatively large teams. Initiatives like mentorship programs, workshops, and training sessions can also enhance teamwork skills among the board and the team. In conclusion, for high-tech small university spin-off firms, prioritizing the quality of the founding team over its quantity is suggested. Therefore, the formation of the founding team should focus on selecting high-quality members from the outset and planning for ongoing improvement over time.

c) *Timely Engagement in Resource Acquisition*. The key outcome of this study confirms that a faster market introduction increases the probability of a firm's longer survival. Entrepreneurs, aiming for prolonged success, should definitely consider the factors influencing fast market introduction. Notably, the study reveals that early collaboration with large firms and securing substantial investments at an earlier stage would contribute to expediting and accelerating of market introduction. Entrepreneurs are advised to actively pursue partnerships with large firms from the inception of their businesses or even before that. Simultaneously, they should proactively engage with potential investors to secure financial support during the initial stages of development, all while at the same time avoiding the risk of rapid debt accumulation. In essence, the results of the study emphasize the critical role of '*time*' for entrepreneurs; whether through faster market introduction, early collaboration, or securing early investments.

7.3.2 Recommendations for Policymakers

The study's findings indicate a longer survival of university spin-off firms in countries with a better developed National Innovation System. This suggests the need to adopt a broader approach and focus efforts on national climate-related research and implementation programs, and empowering the entrepreneurial ecosystem, which currently tends to be fragmented and lacking coherence. National and local authorities may actively participate in accelerating energy transition by supporting high-tech startups, specifically spin-offs, in the field of sustainable energy.

a) *Suggestions for Local/Regional Level.* It is evident that achieving the goals of sustainability transition and net-zero emissions requires the development of more radical innovations. However, the results of this study suggest that firms may encounter delayed market introduction when they take the risk of pursuing radical innovations and entering new markets. This delay could, in turn, impact firm survival. Policymakers at both local and national levels, who are tasked with reaching scheduled sustainability goals, have an opportunity to intervene and assist firms in adopting radical innovations while expediting market entry. Policymakers at the municipal/regional level can enhance the market capabilities of university spin-offs by serving as a *launching customer for their radically new products*, and thereby decreasing the time to market introduction. The involved policymakers can also support in the creation and management of experimentation places in cities, e.g. to improve the use (charging) of electric vehicles. Additionally, they can influence financial circles to facilitate the provision of investment funds and incentivize regional providers of early-stage investment, including large firms (Van Geenhuizen and Nejabat, 2021). However, there are also limitations to consider. For instance, if regional networks become too tightly knitted and university spin-offs can easily access large amounts of venture capital, there is a risk among these firms of being unable to pay back the significant investments later on in time. On the regional level, a stronger pro-active behaviour may be developed and adopted by groups of municipalities, in which universities and their spin-off firms and related large firms may take a leading role in elaboration and market introduction of specific sustainability energy technologies, for example, concerning hydrogen applications, like in transport in the Netherlands (Helion-Siemens, 2023).

b) *Suggestions for National Level.* Given the challenges associated with radical innovation in both market and product domains, national governments could play a crucial role in actively encouraging and incentivizing high-tech startups, in particular university spin-offs, to adopt such approaches. This is already happening on a large scale, with universities utilizing financial resources for research and development obtained through European Horizon 2020 programs, and university spin-offs participating in program activities. Other forms of support from the national level may include tax incentives and streamlining regulatory processes tailored to university spin-offs and their radical innovation strategies. Furthermore, recognizing the potential benefits of (narrow) diversification as a risk mitigation strategy in certain contexts, policymakers are urged to acknowledge and support this approach, by using narrowly diversified university spin-offs as role models in national program reports. In a broader sense, tailored policy initiatives could be designed to provide university spin-offs with the necessary support to realize and pursue effective risk taking and risk mitigation strategies. A part of this could be directed towards creation of new investment capital modes (models) that better match the risk-full situation of radical innovation and new markets among university spin-off firms, by avoiding early payback schedules.

7.3.3 Recommendations for Universities

The strategic role of universities as drivers of regional economic growth through knowledge transfer is manifested among others through the establishment and support of university spin-off firms. In this study on sustainable energy, the type of university was shown to be influential for both fast market introduction and the longer survival of university spin-off firms, strengthening the notion that universities, as parent organizations, can significantly contribute to the success of their spin-offs. Below are several important suggestions for universities:

a) *Strengthening Entrepreneurial Support Programs.* In order to fulfil their third mission, universities should strengthen their entrepreneurial support programs. This may involve enhancing incubation and acceleration facilities, providing specialized mentorship for technical innovations, and fostering industry partnerships. Overall, universities should actively promote their unique role in shaping regional entrepreneurial ecosystems and establishing relationships with industry partners and offer comprehensive entrepreneurial education programs. These programs should go beyond traditional academic training, incorporating real-world business skills and market experiences to equip founders with the necessary competences for success in risk-taking in sustainable energy business environments.

b) Facilitating Industry Collaborations. In alignment with the importance of early collaboration with large firms, investors and industries providing important resources and capabilities for startups, universities should actively facilitate collaborations between academic researchers and industry partners. Establishing formal mechanisms for industry engagement, such as joint research initiatives and technology transfer programs, can provide university spin-off firms with valuable opportunities for early collaboration and resource access, and risk-mitigation.

c) Providing Marketing Support Services. In contrast to mainstream literature on the role of founding team characteristics in startup performance, this study on university spin-offs found that characteristics such as pre-business experience and level of education did not significantly influence fast market introduction and longer survival. This lack of influence may be attributed to the wide range of technologies that sustainable energy university spin-off firms are dealing with, ranging from solar and wind energy to tidal and wave energy (See Table 4. 1 in Chapter 4), many of which are largely new to the market. Consequently, the study recommends that universities continue and enhance their marketing support and create a better match with the practical needs of the industry. This entails a fixed position of high-technology marketing in curricula in business studies, technology policy studies and in knowledge transfer, but also providing specialized workshops, consulting services, and access to marketing experts who can assist university spin-off firms in designing effective marketing strategies. By offering such resources, universities can empower university spin-off firms to navigate the complexities of marketing without the need for a dedicated in-house marketing professional, thereby boosting their overall chances of success.

d) Bridging Borders Between Faculties Involved. Though not directly influencing performance of university spin-off firms, a closer collaboration between science faculties and ‘applied’ faculties at university (eventually also applied universities) is desirable. This would mean for example to enhance joint university staff meetings about entrepreneurship in the energy sector, and to increase joint application for national and international R&D programs aimed at improving and accelerating market introduction of new energy technology. Such endeavours may also include extension of possibilities at university for *co-creation* between faculties and spin-off firms, coming with important risk-reduction for these firms regarding investment in equipment and personnel, while at the same time anticipating a quick market-introduction.

7.4 Reflections

The research in this dissertation has sought to provide an in-depth understanding of the roles of high-tech startups, particularly university spin-offs, in sustainable energy transition, focusing on their success in fast market introduction and their dynamics of survival over time. The collection of a unique and retrospective database of university spin-offs in sustainable energy has yielded novel empirical results, not existing before. These results both align with certain aspects of existing literature and also prompt further clarification when they diverge from expectations. This section reflects on the journey of the research process, explaining how the research aim and objectives were achieved (sub-section 7.4.1), detailing the process of conducting the study (sub-section 7.4.2), and ultimately, extracting lessons from the obtained findings.

7.4.1 Reflection on Research Aim and Objectives

Nowadays, the growing body of literature on environmental entrepreneurship or sustainable entrepreneurship indicates the well-accepted role of startups in energy transition (for a review, see Piwowar-Sulej et al., 2021). Additionally, the latest reports from the International Energy Agency (IEA 2023) on World Energy Investments claim that venture capital investments in energy startups have been rising since 2018 and reached over USD 5 billion in 2020. Although when this thesis study began, it was not as clear as it is now, today, without a doubt, it could be claimed that, in addition to more general indicators for assessing energy transition such as sustainable energy production and consumption and reduction of CO2 emissions, *monitoring of energy startup activities* could serve to provide indicators to determine the success and impact of sustainable energy-transition policies (Singh et al., 2021).

As governments worldwide increasingly recognize the potential of startups in driving sustainable energy innovation, their policy measures have shifted towards providing direct support for startups (IEA 2021, How Governments Support Clean Energy Startups). This approach is driven by the understanding that although some key, large-scale, sustainable energy technologies may not emerge via the startup route, certain sustainable energy solutions tend to be developed and commercialized more efficiently by small startups, like university spin-off firms. This situation necessitates a more hands-on governmental role in nurturing these nascent businesses. The shift also reflects higher expectations and an urgent need for disruptive innovations to meet global climate goals.

Since the Kyoto Protocol, which came into force in 2005, and the Paris Agreement on climate change in 2015, followed by the Glasgow Climate Pact in 2021, there has been a notable surge in government initiatives aimed at helping startups bring new sustainable energy technologies to market. These measures are diverse and innovative and seek to tackle specific barriers unrelated to the quality of the underlying technology and employ both direct and indirect supports for startups (IEA 2021, How Governments Support Clean Energy Startups). This recent approach is very encouraging, as it addresses the unique challenges startups face, thereby accelerating the deployment of sustainable energy solutions and contributing significantly to local and global economic prosperity. The relatively high survival rate of sustainable energy university spin-off firms among the sample of this study, as demonstrated in Chapter 6, section 6.3.1 (79 percent survival rate when excluding acquired firms), confirms the special attention and support provided to sustainable energy startups, enabling them to achieve higher survival rates compared to regular startups (Gonzalez, 2017).

While this thesis did not directly measure and compare different policies and their effects on market introduction and survival of university spin-off firms, it did consider the entrepreneurial ecosystem as part of the modelling process. The entrepreneurial ecosystem reflects the overall (urban) environmental conditions surrounding startups (Stam, 2015). In this study, it was addressed by examining the quality of the National Innovation System (NIS) of countries, the favourable conditions in metropolitan areas, and the type of incubating universities.

7.4.2 Reflection on Research Process

This sub-section offers a retrospective evaluation of the process of data collection and variable measurements.

The longitudinal data collection and observation process is one of the most time-consuming aspects of this study. Tracking the progress and activities of university spin-off firms over time requires strong attention to detail and thorough documentation. The dynamic nature of the study involved measurements of firms over substantial time-periods, predominantly in a retrospective manner, which posed both advantages and challenges. Utilizing mixed data obtained from different sources, including company websites and their social media platforms, alongside regular data gathered from one-time interviews or surveys with firm founders, supplemented by publications of organisations involved, like investment consortia and national climate policy programs, present a comprehensive perspective for analysis. Such an approach is definitely recommended for picturing firm’s progress over time.

It is worth mentioning that the decision to start the study with a pilot study, employing a smaller sample size and rough variables, is a highlight of the research process. This approach is instrumental in overcoming several challenges that were encountered during the study, like the possibility to measure constructs in a valid way and to reveal sufficiently strong influences on market introduction and survival. The pilot study is a major step throughout the work, allowing for the assessment of data collection feasibility and refinement of variable measurements. The successful completion of the pilot study marks a significant milestone in the research process and underscores its importance for similar studies in the future.

From a methodological perspective, this study examines the influence of several events and developments in the firm life cycle, based on the occurrence of specific events: time-to-market introduction and firm survival. While previous studies have often explored time-to-event and survival analysis, this study introduces a *novel* approach by investigating how the occurrence of specific events influences subsequent important events, such as market entry and survival of the firm. This innovative methodology sheds new light on the complex dynamics of startup evolution and underscores the importance of considering temporal dependencies in empirical research.

At the end of this study, it can be confirmed that the effects of occurrence of some events on the other events should not be neglected in future researches. The results provide compelling evidence of the impact of market introduction on firm survival, further corroborating the significance of making initial collaborations, e.g. with large firms or investors, in facilitating market entry.

7.4.3 Reflection on Research Findings

Besides the interesting and fruitful findings discussed in Chapter 5 and Chapter 6, the main anomalous finding from both analyses on time to market introduction and survival, is the non-significant effect of founding team characteristics on the market introduction and survival of the university spin-off firms. Direct influence of founding team composition (education, business experience) on firm performance could not be confirmed in the current study, this in contrast to direct influence of early networking after firm establishment. Our study, however, could not investigate indirect influence of team characteristics through, for example, financial networking (like the structural model by Moog and Soost, 2022). Also, the current study did not take into account later changes in the team composition and networks ("balancing" the team), that may have influenced time to market and survival.

In fact, the current study examined direct relationships. However, the role of entrepreneurial orientation may be indirectly influencing time-to-market introduction. For instance, when university spin-off firms adopt an incremental innovation strategy, the application of the invention for the market may be more clear when these firms have marketeers in their teams at start or early after start, which leads to faster market introduction. In such a case, having a market team member early in time mediates the relationship between incremental innovation strategy and faster market introduction arguments. These type of indirect or mediation relationships have not been examined, in part due to the sample size, but can give more insight into the dynamics of time-to-market introduction and firm survival. In addition, it can be assumed that several starting team factors tend to influence performance (market introduction, survival) in a non-linear manner (Tagliazucchi et al. 2021), like size of the starting team. The current study however, in the final steps (Chapter 5 and Chapter 6), merely explored linear influence.

The main contribution of the modelling in Chapter 5 and Chapter 6 is first in its comprehensiveness (risk-taking strategy, owned and accessed resources and capabilities, and entrepreneurial ecosystems). Secondly, the unique contribution is specifically in the time-dimension of accessing networks with large firms/other organisations and accessing financial investment. This approach can be extended with other stakeholders, like universities where university spin-offs are involved in co-creation, and the time-aspects concerned. In addition, in Chapter 6 a unique contribution is also provided by including influence of time of market introduction to survival. Though prior innovation activity and survival have often been subject of investigation in literature (e.g. Ortiz-Villajos and Sotoca, 2018), the specific time-dimension - even in highly competitive sectors - has often been overlooked and deserves more attention.

7.5 Limitations of the Current Study and Suggestions for Future Research

Despite the valuable insights gained from this study, it is essential to acknowledge its limitations, which paves the way for future research endeavours to address remaining gaps and to further contribute to the field. Like most empirical studies, this research faces constraints related to data gathering and accordingly related to missing some key variables. Particularly, the study of time to market introduction should ideally incorporate the *readiness level* of *technology* as a crucial variable at firm start. Technology Readiness Levels (TRLs) is a globally accepted tool for measuring and understanding the technical maturity of the stage of the technology involved, and what development is needed to progress to next stage (Salvador-Carulla et al., 2024). Despite the initial intention to include this variable, data collection for it proved challenging, including validity issues in measurement. This can be explained as follows. In the retrospective study, technology developers were either absent during data collection or they lacked a precise evaluation of the technology readiness level at starting point of firm activities (memory bias). Consequently, this important variable had to be excluded from the study. Future studies should prioritize the collection of data from the inception of technologies to avoid losing this critical factor. Also, potential influence from strategic advisors or advisory boards has remained beyond the study. As the influence of advisors (boards) may increase when more teams are founded as lean teams, future studies preferably include them aside from founding teams. Another limitation of this study - in terms of opportunities for rigid statistical analysis - is the low incidence rate of bankruptcy and, particularly, of firm acquisition. In addition, data on important changes in team or board composition after start, other than marketing staff, are also missing. These may include attraction of experienced managers able to balance risk-related strategies or being familiar with accessing international markets. Constraints like these pose challenges in drawing robust conclusions and warrants caution in interpreting the results. Future studies could aim for larger sample sizes, in particular including more firms that are forced to close, enabling more robust statistical analyses and enhancing the reliability of the findings.

Drawing inspiration from the outcomes of the empirical analyses in this thesis, particularly the explanation of why some factors are significant while others are not, could offer valuable directions for future research.

One of the unexpected results of the empirical analyses in this thesis is the lack of a significant role for the founding team. This finding suggests the need for further and more in-depth investigation. Future studies could explore whether the composition or dynamics of founding teams, such as diversity of expertise or prior entrepreneurial experience, might play a more nuanced role that was not captured in the current analysis. Additionally, researchers could examine the impact of external factors, such as university/incubator supports or advisory board, on the effectiveness of founding teams in driving university spin-off success.

The results regarding NIS-related Entrepreneurial Ecosystems (EES) in the current study confirmed the positive influence of a strong NIS on survival of spin-off firms. The specific influence of local universities on firm survival was also confirmed, although the positive influence mainly occurs at general universities, rather than technical ones. However, the influence of city size and location (metropolitan area) could not be confirmed, most probably due to alternative favourable conditions in rural areas with abundant availability of sustainable energy sources and limiting influences in large cities which have remained 'under the radar' of this study. Accordingly, the results confirm some multilevel influence of both a national-level factor and a local factor in providing resource endowments and institutional arrangements. This includes qualities such as good-level intermediaries, talent, leadership, diverse knowledge, community and culture, and finance (Stam and Van der Ven, 2021; Huggins et al., 2024). Evidently, the precise contribution of the entrepreneurial ecosystem to the success of university spin-offs has been limited in this study, due to a restricted operationalization and measurement of the entrepreneurial ecosystem mentioned in the emerging literature on this topic (Stam and Van der Ven, 2021). Future research should focus on refining the operationalization and developing more robust methods for measuring the impact of entrepreneurial ecosystems to gain deeper insights into their role in fostering innovation and business success.

Future studies could further explore the impact of different types of universities on spin-off success by distinguishing between disciplines, such, or the impact of technical universities with specialized innovation outputs. Considering the outcome of the analysis in Chapter 6 which indicates a longer survival for university spin-offs from general universities, a deeper investigation about their support programs and when the support was offered can help to understand why the spin-offs from general universities survive longer.

Additionally, examining the role of city size and remoteness of location in more detail might uncover hidden factors influencing firm survival that this study did not capture, particularly in rural areas where local resources and community dynamics differ significantly from urban settings. Moreover, expanding the scope of entrepreneurial ecosystem components to include other dimensions, such as local policy frameworks, network strength, and the availability of mentorship and incubators, could provide a more comprehensive understanding of how various elements contribute to the success of university spin-offs.

It is important to note that since this study focuses specifically on the sustainable energy sector, generalization of the findings to other sectors should be cautiously done. Future research could investigate the applicability of the identified factors and strategies in several other industries, thereby providing a more comprehensive understanding of entrepreneurial dynamics. For example, hampering factors at the system level (regime factors) could be investigated as these may be different, like price-setting and regulation. Investigating the generalizability of these findings to other countries also offers a new direction for future studies. Understanding how contextual factors vary across different National Innovation Systems can provide valuable insights into the broader applicability of entrepreneurial insights gleaned from this research.

Another avenue for future research involves investigating the counterfactual effects of the support mechanisms provided to university spin-offs by considering a control group of non-university spin-off startups operating in the same sector. Such comparative analysis could shed light on whether university spin-offs exhibit distinct performance patterns compared to their non-university counterparts (corporate spin-offs; non-spin-off startups) within the same industry. Exploring such differences may provide a deeper understanding of the unique contributions and challenges faced by university spin-offs in the entrepreneurial landscape, producing valuable insights to both academia and (sustainability) policymakers. Additionally, the methods employed in this study primarily focus on investigating linear relationships, overlooking potential non-linear relationships, and the mediating effects of underlying factors, which may have significant implications. Exploring these non-linear relationships and mediating effects can serve as a starting point for more extensive investigations into various dimensions of university spinoffs' survival and time to market. However, conducting such analyses would require additional data collection beyond the scope of the current study. Therefore, future research endeavours could benefit from incorporating non-linear modelling techniques and exploring potential mediating factors to gain a deeper understanding of the dynamics influencing the survival and time to market of university spinoffs in the sustainable energy sector.

While this study predominantly relies on quantitative analysis, supplemented by mixed-methods techniques and descriptive analysis, the absence of in-depth case studies is noteworthy. The incorporation of in-depth case studies could serve to enhance our comprehension of the sustainability and start-up landscape, offering a more holistic understanding of the intricacies inherent in entrepreneurial decision-making, innovation strategies, and firm survival. Future research endeavours are encouraged to consider the inclusion of in-depth case studies, as they have the potential to provide a qualitative layer that complements and enriches the quantitative findings, offering a more nuanced perspective on the multifaceted aspects of university spin-offs in sustainable energy, in particular on operationalization and measurement of their resources and capabilities at start and also developed later on in their life.

In conclusion, this study is among the first to study time to market introduction and survival of university spin-off firms in the sustainable energy sector and contributes to our knowledge of the complexity in dynamics of early high-tech startup growth. This study lays the groundwork for future research endeavours to expand upon its findings, refine methodologies, and explore additional dimensions of entrepreneurial success and sustainability. By addressing its limitations and pursuing suggested research directions, this study provides the challenge that researchers can contribute to a more nuanced and comprehensive understanding of the multifaceted dynamics inherent in entrepreneurial ventures and market introduction of (technology) solutions to sustainability problems and challenges.

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Selected Publications

Journal papers

Nejabat R., & Van Geenhuizen M. (2019). Entrepreneurial Risk-Taking in Sustainable Energy: University Spin-Off Firms and Market Introduction in Northwest Europe, *Sustainability*, 11 (24).

Schöpper, Y., Digmayer, C., Bartusch, R., Ebrahim, O., Hermens, S., Nejabat, R., ... & Böschen, S. (2024). Towards niche readiness: Achieving socio-economic maturity in the bottom-up transition to DC power systems. *Environmental Innovation and Societal Transitions*, 51, 100831.

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Working Papers

Schöpper Y., Digmayer C., Bartusch R., Ebrahim O., Hermens S., Nejabat R., Steireif N., Wendorff J., Jakobs E.-M., Lohrberg F., Madlener R., Mütze-Niewöhner S., Reicher C., Böschen S. (2023). Developing a Niche Readiness Level Model to Assess Socio-Economic Maturity: The Case of DC Technologies in the Transition to Flexible Electrical Networks, *FCN Working Paper No. 11/2023, Institute for Future Energy Consumer Needs and Behaviour*, RWTH Aachen University, August 2023.

Book chapters

Nejabat R., Taheri M., Scholten V., & Van Geenhuizen M. (2018). University Spin-offs' Steps in Commercialization of Sustainable Energy Inventions in Northwest Europe, in: Van Geenhuizen

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Van Geenhuizen M., & Nejabat R. (2018). Market Introduction and Scaling-up of University Spin-offs in Sustainable Energy Innovation: No Birds of One Feather, Workshop 'From Start-up to Scale-up', October 29–30, 2018, Stockholm, Sweden.

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Van Geenhuizen M., & Nejabat R. (2022). Struggle or fast victory? A competence-based approach to spin-off firms active in energy innovations, with a focus on local university ecosystems, The 20th Triple Helix Conference, Florence, Italy.

Awards

Best Paper Award in the 20th Triple Helix Conference, Florence 27-29 June 2022, presented to Marina Van Geenhuizen and Razieh Nejabat, for the paper "Struggle or fast victory? A competence-based approach to spin-off firms active in energy innovations, with a focus on local university ecosystems".