Sustainable Entrepreneurship for Commercialising Radical Clean Technologies

A Means to Enable Carbon Dioxide Utilisation?

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"In fact, even if producing CO_2 was good for the environment, given that we're going to run out of hydrocarbons, we need to find some sustainable means of operating."

– Elon Musk, 2013[1]

[1] https://www.ted.com/talks/elon_musk_the_mind_behind_tesla_spacex_solarcity/transcript. Accessed on June 24, 2018

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LIST OF ABBREVIATIONS

ARPA-E ....Advanced Research Projects Agency – Energy

CCS ....carbon capture and storage/sequestration

Cleantech..........clean technology or cleaner technology

BMBF ....Federal Ministry of Education and Research, German: Bundesministerium für Bildung und Forschung

CO_2..........carbon dioxide

COP ....Conference of the Parties

DoE ....Department of Energy

EEA ....European Economic Area

EEG..................Renewable Energy Sources Act, German: Erneuerbare-Energien-Gesetz

EIT ....European Institute of Innovation and Technology

EnCO$_2$re ....enabling CO_2 re-use

EU ....European Union

EUR..................euro

G7.....................Group of Seven

IP ....intellectual property

IPCC.................Intergovernmental Panel on Climate Change

KIC...................Knowledge and Innovation Community

KPI ....key performance indicator

LCA..................life-cycle assessment

MLP ....multi-level perspective

PPP...................public-private partnership

R&D ....research and development

SBIR.................Small Business Innovation Research

SDG..................Sustainable Development Goal

SE ....sustainable entrepreneurship

SOI ....sustainability-oriented innovation

STTR................Small Business Technology Transfer

TEA ....techno-economic analysis or assessment

TRL ....technology readiness level

UNFCCC..........United Nations Framework Convention on Climate Change

USA..................United States of America

USD..................United States dollar

VC ....venture capital

EXECUTIVE SUMMARY

The purpose of this research is to increase our understanding of how sustainable entrepreneurship (SE) can enable the commercialisation of radical clean technologies (cleantech). The aim is to realise more sustainability-oriented innovation (SOI) in order to move towards an economy with closed carbon loops and an efficient (re-)use of resources.

Previous research focussed on drivers, barriers, and success factors for SE and identified sustainability-specific characteristics that could be added to findings of conventional innovation and entrepreneurship studies. Hence, new cleantech ventures face barriers related to SOI (e.g., path dependencies, regulatory dependencies or absence of business cases) and entrepreneurship-related hurdles in general. In particular, the interplay of the dimensions sustainability effect and market impact has been discussed in the light of SE's capabilities to contribute to a sustainability transition. Furthermore, risk capital in the form of venture capital (VC) has been acknowledged to play an important role in the commercialisation of cleantech via SE. Recent research suggests facilitating SE with dedicated systems that address these specifics and help to coordinate both dimensions.

Three management problems are reflected in this research and discussed in the doctoral thesis. First, specific barriers of new radical cleantech ventures on multiple levels (internal, external, hybrid) have not been examined in light of overcoming these hurdles with dedicated support systems. Second, the financial supply from private actors for these ventures in an early stage of their development is scarce due to unfavourable risk-return ratios. Hence, strategies that increase the capital supply by decreasing risk and increasing returns are necessary. Lastly, although previous research has examined different roles and activities that support system actors such as intermediaries should carry out, little is known about the evolution of these roles and activities or the evolution and survival of intermediary actors themselves.

The empirical setting of this PhD project is directed at niche, intermediary and system actors in the radical cleantech field with a focus on carbon dioxide (CO_2) utilisation. This research draws from 78 interviews with individuals from new ventures, large incumbents and infrastructure provider, investors, investment experts, and innovation intermediaries primarily in Europe, North America, and Australia.

Methodology applied in this research is a set of qualitative and semi-quantitative methods. Data from semi-structured interviews and documentation are analysed using Atlas.ti software and are combined with semi-quantitative evaluations from recorded interview data and collected survey data in case-study and "mixed-methods" approaches.

Results from these analyses are manifold. First, cross-linkage barriers – bridging internal and external barrier dimensions – occur in addition to barriers within the internal organisation and external stakeholders and complete the barrier framework for new CO_2 utilisation ventures. Second, commercialising the technologies of these ventures confirms the tensions between the dimensions of sustainability effect and market impact and thereby supports the notion of increased complexity in comparison to conventional new technology ventures. Third, 27 strategies are identified that potentially affect the investor's decision-making for early-stage, hardware-, material- or chemical-based cleantech venture investments by either increasing expected returns (archetypes a and b) or decreasing risks (archetypes c and d). Fourth, the potential, relevance and implementation complexity of these strategies are determined, and on this basis, strategy clusters for recommendations to bridge the valley of death are developed

for investors, ventures, service providers and public authorities. Fifth, the dynamics of innovation intermediaries over time are revealed and described based on their characteristics, scope, objectives, and roles and activities. Lastly, four dimensions are identified that influence the survival of coordinating innovation intermediaries: neutrality (independence from public administration or politics in terms of funding or technological orientation), technological context (interplay of market, policy, and technology), shared consensus (alignment and shared vision of stakeholders), and internal value creation (financial and non-financial values to sustain operations).

Contribution to theory is the advancement of a barrier framework for new hardware-, material- or chemical-based cleantech ventures with an emphasis on the contextual relationships between internal and external dimensions. Moreover, both dynamic capabilities and stakeholder synergies are confirmed to be appropriate theories to describe internal and external barriers. In addition, the valley of death is used to describe the effect of strategies on the risk-return ratio of early-stage radical cleantech investments. Lastly, static typologies of characteristics, scope, objectives, and roles and activities are complemented by dynamic considerations about the evolution and survival of innovation intermediaries that are influenced by internal and external dimensions. In summary, all articles acknowledge internal (organisation) dimensions and external (stakeholder) dimensions across either the niche, intermediary or system (regime) level and confirm – in an overall framework – the notion to use innovation intermediaries as a connector between niche- and regime-level activities.

Managerial implications are derived from this research for relevant stakeholders alongside the innovation process of new radical cleantech. First, four critical aspects of a dedicated support system (actors, resources, institutional settings, and the coordination of support systems) are used to provide recommendations to new ventures, policy makers and intermediary third parties about how to facilitate a successful commercialisation from CO_2 utilisation ventures. Second, hands-on strategies within five areas of recommendation sensitise stakeholders (investors, new ventures, service provers and public authorities) beyond policy makers only of their stake in bridging the valley of death for new early-stage and hardware-, material- or chemical-based cleantech ventures. Third, innovation intermediation process is enriched by recommendations to acknowledge the technology-specific requirements of SOI for initiators (e.g., policy makers) and operators (innovation intermediaries) of this process.

1 EDITORIAL

1.1 Motivation, Purpose and Relevance

Dealing with (global) societal challenges such as resource depletion and climate change is an increasing focus of attention in industry, research, and policy due to global agreements such as the COP21 (UNFCCC 2015) or the Sustainable Development Goals (SDGs) (United Nations 2015). There is wide agreement that societies must transition to more sustainable states of production and consumption as soon as possible (e.g., Geels 2002; Rockström et al. 2009; Griggs et al. 2013).

Research approaches the multifaceted challenges around sustainability on multiple levels: several academic disciplines have recognised their mandate to broaden and share the present state of scientific knowledge with scholars from other disciplines (see, e.g., Hirsch Hadorn et al. 2006 for transdisciplinarity in sustainability research), and stakeholders from industry and policy (see, e.g., Brandt et al. 2013 for a call for action to tackle real-world problems). Thus, environmental problems (e.g., resource depletion, environmental degradation, global warming) have become increasingly popular in the (management) realm of entrepreneurship, innovation management, and technology development (e.g., Dean and McMullen 2007; Schaltegger and Wagner 2011; Erzurumlu and Erzurumlu 2013; Klewitz and Hansen 2014; Adams et al. 2016; Gast et al. 2017).

Contributing to this interdisciplinary stream of research on sustainability, this PhD project combines research from *entrepreneurship*, *innovation management*, and *technology development* to explore the means to enable new *radical solutions* for this urgently required *transition* to more sustainable social, economic and ecological systems. More specifically, the focus lies at the intersection of sustainable entrepreneurship (esp. new technology ventures and investors), sustainability-oriented innovation (esp. commercialisation and technology diffusion) and clean technology development (esp. CO_2 utilisation and hardware-, material-, or chemical-based technologies), as shown in Figure 1-1.

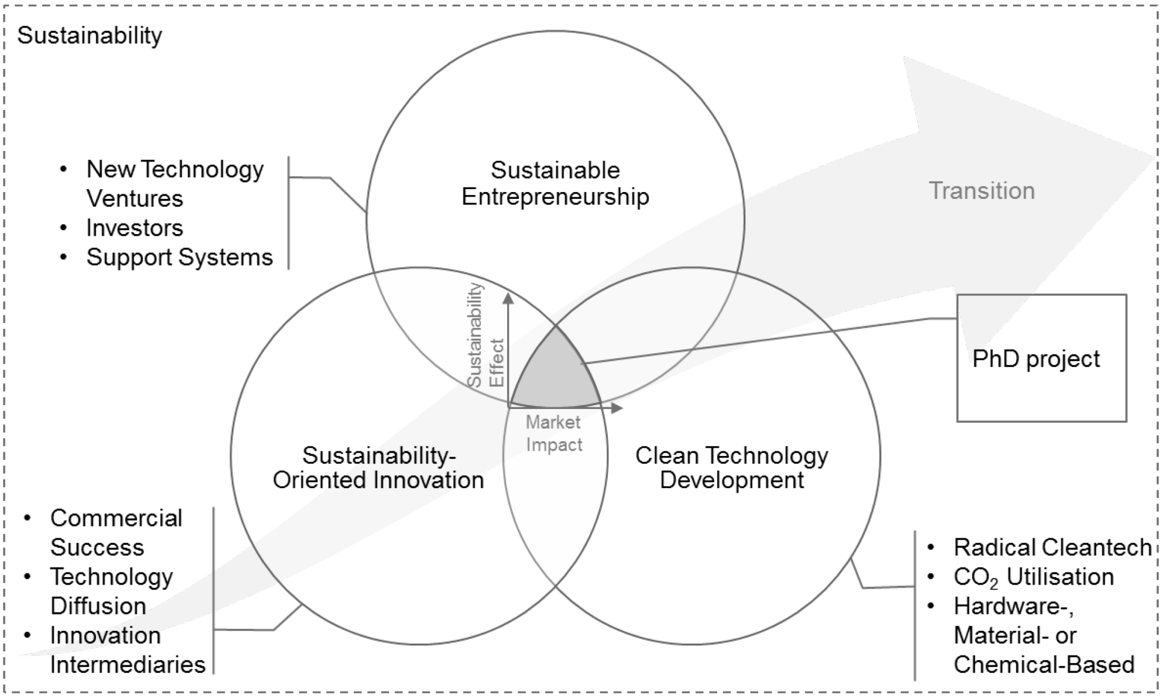

Figure 1-1: Research dimensions

This thesis argues that sustainability-oriented innovation (SOI) is realised by sustainable entrepreneurship (SE) and that this realisation process goes in tandem with providing benefits for society (cf. Schaltegger and Wagner 2008) that could potentially spark a transition towards a more sustainable society (cf. Hall et al. 2010). SE thereby enables the commercialisation of cleantech that could lead to transitional change. Two dimensions modulate this change: on the one hand, the effect on the sustainability (mainly environmental and social performance) of these technologies, and on the other hand, the impact on the market (addressing niche vs mass markets) of these technologies (e.g., Hockerts and Wüstenhagen 2010; Hörisch 2016; Schaltegger et al. 2016). The sustainability effect thereby expresses its qualitative nature (more quality in environmental and social performance), while the market impact follows a rather quantitative approach (more quantity on the market).

Furthermore, radical rather than incremental technologies, innovations or solutions are acknowledge to lead towards a sustainability transition (e.g., Milne et al. 2006; Roome 2012; Klewitz and Hansen 2014). Hellström (2007) argues that radical innovation in the context of SOI embodies the aforementioned sustainability effect, as these innovations reduce negative environmental and/or social impacts (sustainability effects). Moreover, this reduction is achieved by either replacing the critical components of a product or production process, or by creating completely new products and processes (ibid.). Incremental innovation, on the other hand, increases the eco-efficiencies of existing processes (often software-based) by, for example, reducing waste from production or establishing systems that reuse water (ibid.). Thus, the sustainability effect per production unit of a radical innovation tends to be greater than the effect of an incremental innovation. Moreover, the global greenhouse gas abatement potential of efficiency improvements is limited (cf. Nauclér and Enkvist 2009). Radical cleantech ventures may therefore also be considered as strong sustainability-oriented ventures (see Article 1).

Making a general statement about the market impact appears to be more difficult. Commodity markets such as bulk chemicals and fuels are dominated by large incumbents that mainly engage in incremental innovation to increase eco-efficiencies or to result in more corporate social responsibility initiatives (cf. Schaltegger 2002; Markides and Geroski 2004; Hockerts and Wüstenhagen 2010). Under this assumption, the market impact of incremental innovation tends to be greater than the impact of radical innovation – not least because of often negative greenhouse gas abatement costs (cf. Nauclér and Enkvist 2009) and higher associated risks.

A radical innovation as defined in this PhD project is the commercialisation of a new product or (sub-)process that incorporates a substantially different core technology to provide a positive sustainability effect. Scholars such as Hockerts and Wüstenhagen (2010) and Schaltegger et al. (2008; 2016) explicitly assign to SE a high sustainability effect and an (increasing) market impact, and Wüstenhagen et al. (2008) argue that SOI are in many cases radical innovations.

Some scholar point out that radicality is an attribute of innovation (radical vs incremental) rather than an effect of innovation on stakeholders and markets, such as disruptive or sustaining (cf. Sood and Tellis 2005; Govindarajan and Kopalle 2006a, 2006b; Govindarajan et al. 2011; Christensen 2016), and that new technologies or new products are described as radical in comparison to current technologies or ways of thinking (cf. Slocum 2008). However, radical and disruptive innovation have also been used interchangeably in the management literature, and radical innovation has often been measured as the introduction of products/services to a newly created market (e.g., Markides and Geroski 2004; Allen et al. 2011), describing merely the effect of the innovation (market creation/disruption) (cf. Sood and Tellis 2005). Researchers thereby risk making assertions that are true by definition when predicting market outcomes (e.g., new cleantech venture displaces a large incumbent with disruptive technology) (ibid.). Hence, this research distinguishes between the effects (disruptive vs sustaining) and the attributes (radical vs incremental) of innovation.

Moreover, radical innovation can disrupt or sustain industries (Christensen 2016). Sustaining an industry might even be more desirable for some radical solution to be able to acquire customers or establish partnerships in (conservative) industries, and thus to increase the market impact (see Chapter 2, Article 1). Hence, the compatibility of the modified or new processes or products (attribute of innovation, cf. Hellström 2007) with the existing infrastructure of the customer (effect of innovation) can affect both the sustainability effect and the market impact. This PhD project focusses on the commercialisation of radical cleantech or on radical SOI with (high) sustainability effects and (increasing) market impact, as these innovations appear to have a greater impact on sustainability transition (e.g., Berchicci 2008; Hockerts and Wüstenhagen 2010; Roome 2012; Bidmon and Knab 2018). Cleantech is used as an umbrella term for a broad range of technologies (e.g., Kuehr 2007; Markusson 2011), and this focus on radical innovation helps to narrow down cleantech to hardware-, material- or chemical-based technologies that imply its radical nature (see Section 1.4).

1.2 Managerial Problem Statements

> *"Just to give you an idea, in the chemical industry, 97% of all projects die. They don't go to the market. […] And these are guys who know their stuff."* (Industry-initiated innovation intermediary in the field of carbon dioxide (CO_2) utilisation – see Table 4-6 in Appendix 4.11.4 of Article 3)

The crucial issue of (radical) SOI from a managerial point of view is that they are not being realised by SE due to missing business cases and economic viability (e.g., Bocken et al. 2014). New radical cleantech ventures in particular struggle to cross from the mainly publicly funded development and first-demonstration phases to the stage of (early) successful commercialisation, as they are research- and capital-intensive and are associated with high risks[2] and long development times (cf. Grubb 2004). This occurrence is known as the 'valley of death' (cf. Murphy and Edwards 2003; Grubb 2004; Markham et al. 2010). In this PhD project, the valley of death will be addressed at three levels: (i) capital demand, (ii) capital supply, and (iii) intermediation.

The (i) capital demand is characterised by new (radical) cleantech ventures. These ventures face barriers related to SOI and entrepreneurship in general (Foxon and Pearson 2008; Hockerts and Wüstenhagen 2010). The ventures must manage the interplay of sustainability effect and market impact (Hörisch 2016; Hockerts and Wüstenhagen 2010) and integrate environmental and social issues into core business objectives (Schaltegger and Wagner 2008).

The (ii) capital supply is defined by different types of investors. Wüstenhagen and Teppo (2006) show that venture capital (VC) investors invest into "good industries" such as renewable energy technologies to some extent depending on the class of risk. However, private investments especially, in the early stage of (radical) cleantech ventures, have almost completely dried out due to a poor risk-return ratio compared to that of other investment opportunities in the cleantech space, e.g., more software-based ones (Gaddy et al. 2017).

A support system for SE could help to overcome barriers on the supply and demand side by managing "[…] all actors, institutional settings and resources that help entrepreneurs in innovating successfully" (Fichter et al. 2016, p. 5). The management of such a system could be described via an (iii) intermediation process where an innovation intermediary "[…] acts [as] an agent or broker in any aspect of the innovation process between two or more parties" (Howells 2006, p. 720). These innovation intermediaries are therefore recognised as vital actors in the innovation process (Howells 2006; Boon et al. 2011) and contributors to SE (Gliedt et al. 2018). However, innovation intermediaries also face barriers and must adapt to external influences (e.g., Hakkarainen and Hyysalo 2016).

[2] These ventures often compete against large incumbents with conventional technologies that do not account for their impact on the environment (e.g., Stern 2008).

Figure 1-2 depicts the valley of death (adapted from Murphy and Edwards 2003) – including the associated risk – along the temporal dimensions of the capital supply and demand: the cumulated cashflow of the venture (capital demand) is thereby negative, with a peak in the demonstration and early commercialisation phase, and the perceived risk for the investor (capital supply) decreases the later the investment stage. Furthermore, the figure indicates the actor-specific barriers in the innovation process, the interference of support systems and the scope of the three articles in this doctoral thesis.

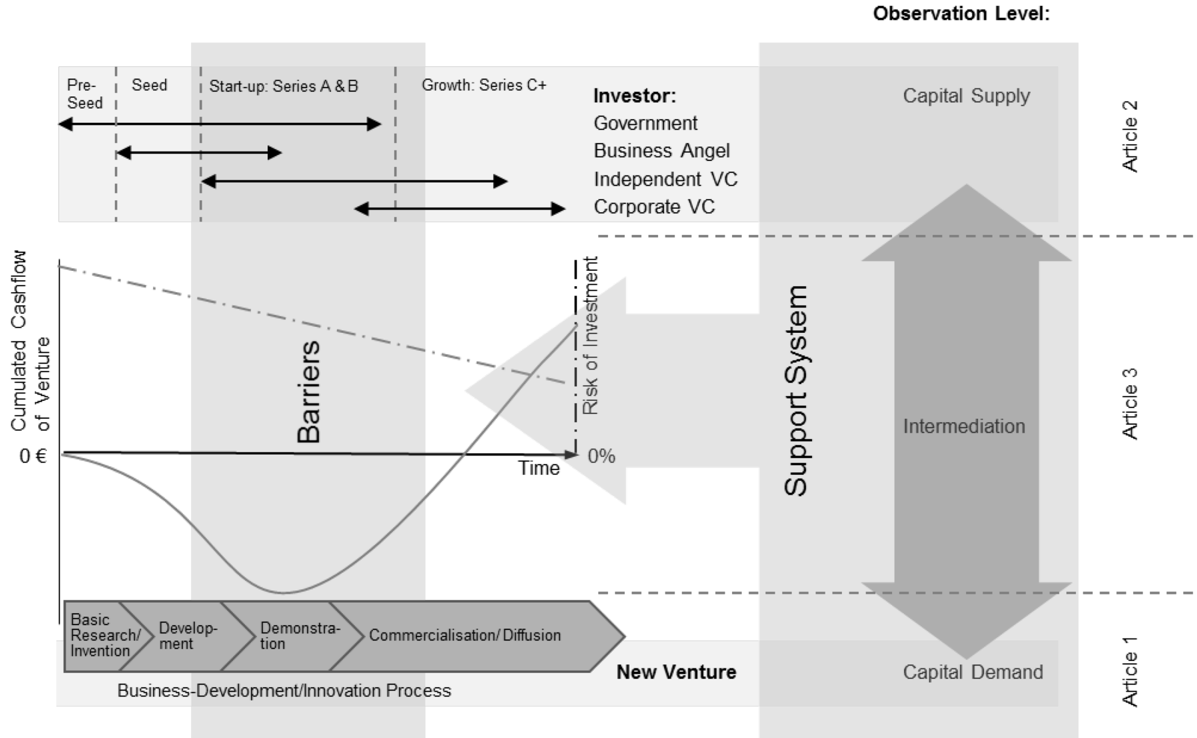

Figure 1-2: Addressing the valley of death (adapted from Murphy and Edwards 2003)

1.3 Research Questions and Designs

In the following section, the articles' scope and methods are briefly described, and the corresponding research questions are listed:

Article 1 focusses on the explicit barriers and drivers of new technology ventures that are in the demonstration and early commercialisation phase with their radical cleantech to gain an understanding of the venture's demand for dedicated support systems (see lower part of Figure 1-2). The research question was answered using a qualitative approach by analysing 25 interviews with new ventures, large incumbents, and infrastructure providers.

> Research Question 1: *What are the barriers and drivers for the successful commercialisation of strong sustainability-oriented new technology ventures?*
>
> Title of Article 1: *Overcoming Barriers to Successfully Commercialising Carbon Dioxide Utilisation*

Article 2 examines the investor's supply of capital as part of support systems. It investigates strategies to improve the risk-return ratio of early-stage investments (see seed until series B/C) into new radical cleantech ventures to draw more private capital into this sector (upper part of Figure 1-2). The method used to respond to the research question would be best characterised as a mixed-methods approach, assessing interview and survey data from 45 investors and investment experts.

> Research Question 2: *What strategies can improve or have successfully improved the risk-return ratio of early-stage hardware-, material- or chemical-based cleantech venture investments? What is their potential effect and who are the players involved in their implementation?*

> Title of Article 2: *Strategies to Bridge the Valley of Death!? How to Improve the Risk-Return Ratio of Hardware-, Material- or Chemical-Based, Early-Stage Cleantech Venture Investments*

The last article, Article 3, deals with the evolution and survival of innovation intermediaries to successfully coordinate a support system for SOI (see right-hand side of Figure 1-2). In a case study with a comparative setting, interviews and documentation data of four innovation intermediaries were analysed to approach the research question.

> Research Question 3: *How do innovation intermediaries evolve over time, and what are the survival factors in that evolution?*

> Title of Article 3: *Innovation Intermediaries: What Does it Take to Evolve and Survive Over Time?*

1.4 **Empirical Setting**

The PhD project was part of a holistic European innovation programme that was funded by the European Institute of Innovation and Technology (EIT), with an annual budget of around three million euros between 2015 and 2017. The programme focussed on CO_2 utilisation by using a multidisciplinary approach taking value chains (sinks and sources of CO_2), technology development, technology assessment (economic, ecological, and social), and market and business development into consideration in various joint projects. Partner organisations in this programme came from research (university and research institutes) and industry (large corporations) of seven European countries (Germany, Sweden, Denmark, the UK, Netherlands, Belgium). The research for the PhD project was mainly conducted within the market and business development scope and the duration of the innovation programme. However, the empirical samples of this research are based on *actors* in the fields of technology that combine the overall requirements of radicality with sustainability effect and market impact. Whereas Article 1 focusses on *CO_2 utilisation actors* in the European Economic Area (EEA), Canada and the USA, Article 2 takes a broader perspective on *actors in the field hardware-, material- or chemical-based cleantech* that includes CO_2 utilisation[3] in Europe and the USA. Article 3 focuses on *intermediary actors in CO_2 utilisation but also on the field of carbon capture and storage (CCS)* as forms of radical cleantech in the EU, the USA, and Australia.

The following section describes the rationale of the empirical sampling and puts the sampling into context with the overall research purpose: first, the technological background will be given by introducing the observed forms of cleantech that incorporate radical innovation; and second, the geographical context will be touched upon by comparing observations in the EU and the USA. With more than 80 actors participating in this research, contributions to theory and practice can draw from rich empirical data.

1.4.1 Technological Background

1.4.1.1 CO_2 and its Utilisation

CO_2 is the most common anthropogenic greenhouse gas emission, in terms of both quantity emitted and impact on global warming (accumulated global warming potential: quantity times global warming potential) (IPCC 2014). Entire trading schemes are being based on CO_2 and its equivalents (e.g., Kuik and Mulder 2004). However, CO_2 can also be a source for other value-adding molecules and converting CO_2 into organic or inorganic compounds is understandably not a novel process. Photosynthesis in nature has been doing it for billions of years (cf. Hoashi et al. 2009), and even the chemical industry has been using processes such as the Bosch–Meiser urea process to convert CO_2 to urea at a full industrial scale[4] for decades (cf. Bosch and Meiser 1922).

However, novel processes to turn CO_2 into other value-added chemicals are still under development or not (yet) commercialised (e.g., Zimmermann and Schomäcker 2017). CO_2 is a rather inert molecule, and its transformation is kinetically and thermodynamically unfavourable. Hence, most organic reactions rely on efficient and selective catalysts that are being researched by industry and academia (e.g., Dibenedetto et al. 2014).

Figure 1-3 shows the circle of capturing CO_2, using CO_2 to create new products and emitting CO_2 during the entire product lifecycle (e.g., energy input during production, combustion of CO_2-based fuels or thermal recovery of other CO_2-based products). However, the scope of CO_2-based products is broad and utilising CO_2 can be carried out using a range of technologies (e.g., Styring et al. 2015a).

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[3] At least five out of 34 investors invested in CO_2 utilisation ventures.

[4] With a global production of 170 million tonnes (metric) in 2017 (International Fertilizer Association 2017), urea production is by far the largest chemical utilisation of CO_2 (Quadrelli et al. 2015).

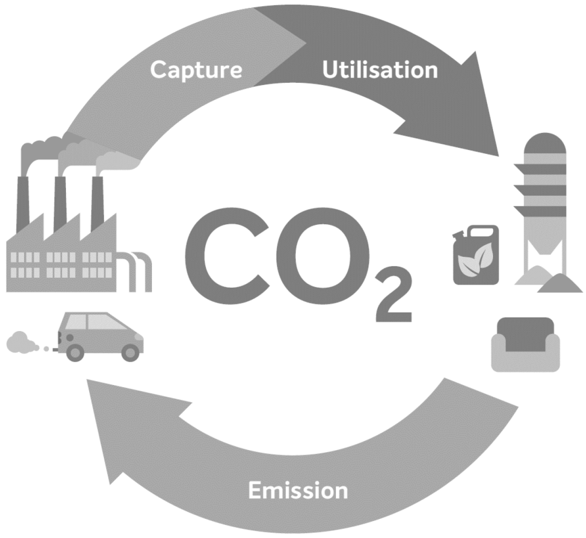

Figure 1-3: CO_2 as a raw material (Zimmermann and Kant 2017)

Nevertheless, all of these CO_2 utilisation technologies use CO_2 to either substitute energy-intensive fossil raw materials and thereby replace critical components, accelerate/improve (more efficient) naturally occurring processes (accelerated weathering, synthetic photosynthesis) via novel processes, or create other (direct) routes/processes for novel CO_2-based products (Styring et al. 2015a; Sternberg et al. 2017). Hence, CO_2 utilisation can be acknowledged as a radical innovation by definition in this thesis (cf. Hellström 2007). Moreover, the effects of these technologies vary along the value chain; hence, assessing the effects of CO_2 utilisation innovation is a matter of perspective (cf. Markard and Truffer 2006 for a grading of "radicality" along the value chain)[5]. Article 1 discusses these effects of disruption or sustainment on a potential customer.

Sustainability effect and market impact are also reflected in CO_2 utilisation. CO_2-based products address mostly niche markets, but there have been efforts to find applications in wider markets as well (cf. Styring et al. 2015a; Aresta et al. 2013). The sustainability effect of CO_2 utilisation is assessed at the environmental, economic, and social levels (e.g., Zimmermann and Kant 2017). Several studies have applied instruments such as life-cycle analysis (LCA), techno-economic assessment (TEA), and social acceptance studies (e.g., Assen and Bardow 2014; Hoppe et al. 2018; Duraccio et al. 2015; Zimmermann and Schomäcker 2017; Jones et al. 2017), thereby covering all sustainability dimensions (cf. Elkington 1998). Performing some of these assessments is even mandatory in order to receive public funding (BMBF 2015). LCAs in particular allow for a better understanding of the potential of CO_2 utilisation with respect to overcoming the aforementioned societal challenges such as climate change and resource depletion.

Even though CO_2 utilisation reduces the climate effects of CO_2, its climate change mitigation potential is limited in scale and rate of utilising CO_2[6] as well as in the storage time of CO_2 in products (e.g., Mac Dowell et al. 2017). The potential is rather in the replacement of energy-intensive fossil-based feedstock and the closure of resource cycles (Assen and Bardow 2014; Naims 2016; Armstrong and Styring 2015). Furthermore, CO_2 utilisation can reduce the

[5] Markard and Truffer (2006) use the term "radicality" to describe the effect of an innovation and thereby use the words radical and disruptive interchangeably. Hence, their "radicality" outlines for this thesis whether an innovation disrupts or sustains a value chain.

[6] To put this into perspective, the global annual urea production – currently the largest CO_2 utilisation – accounts for approximately 127 million tonnes of CO_2 being used as feedstock (calculation based on Alper and Yuksel Orhan 2017), whereas the current total global anthropogenic emissions of CO_2 is approximately 35.5 billion tonnes (metric) (Mac Dowell et al. 2017).

complexity of existing processes and may lead to more efficient (less resource- and energy-intensive) direct routes in the chemical industry (cf. Sternberg et al. 2017). The production of synthetic fuels (e.g., oxymethylene ether) in combination with available renewable energy could be another means of closing carbon loops (cf. Sternberg and Bardow 2015; Deutz et al. 2018; Thenert et al. 2016) and looking beyond CO_2 reduction to the reduction of other emissions such as nitrogen oxides and soot with CO_2-based diesel-fuel-substitutes (Deutz et al. 2018). Thus, CO_2 as raw material can increase resource efficiency and security, and counteract resource depletion rather than mitigate climate change (cf. also Bruhn et al. 2016). This potential has been recognised by research, governments and industry: between 2010 and 2016, for example, approximately 150 million euros from the German government and industry were granted to and invested in CO_2 utilisation and efficiency measures for the chemical industry (Mennicken et al. 2016). Furthermore, CO_2 utilisation has been discussed in light of the SDGs[7] (United Nations 2015), although analyses in this regard are still ongoing (e.g. Olfe-Kraeutlein et al. 2016).

1.4.1.2 Radical Cleantech in General and in Other Forms (CCS)

The technology scope was extended for Article 2 to ensure a sufficiently large population to draw from. Not all CO_2 utilisation ventures were backed by investors, further narrowing the population of N=48 (see Article 1). Hence, this thesis's focus also includes a more general field of technologies that shares relevant characteristics of CO_2 utilisation technologies: radicality and novelty in terms of early-stage technology development or demonstration. This broader field is referred to as early-stage hardware-, material- or chemical-based cleantech: early-stage links to the development/demonstration stage. Moreover, hardware-, material- or chemical-based meets this thesis's definition of radical innovations (cf. Hellström 2007) within the wide spectrum of cleantech (cf. Kuehr 2007; Markusson 2011) because new processes or process steps are used to develop (new) products (hardware, material or chemical) that significantly improve environmental performance relative to other technologies (cf. Slocum 2008).

In addition to CO_2 utilisation, CO_2 can also be stored in geological foundations for thousands of years (e.g., Haszeldine 2009). The process of capturing and storing/sequestering CO_2 is known as CCS. Similar to CO_2 utilisation, CCS technologies may be considered radical by definition in this thesis (cf. Hellström 2007) in terms of some capture (cf. Rennings et al. 2013) or novel storage processes (Matter et al. 2016). Unlike CO_2 utilisation, CCS's potential lies in the reduction of CO_2 and therefore in the mitigation of climate change (e.g., Bui et al. 2018; Styring and Jansen 2011; Bruhn et al. 2016; IPCC 2014). Furthermore, CCS must manoeuvre in a similar tension between sustainability effect and market impact, not least because it is currently the most costly technology to abate CO_2 emissions (Nauclér and Enkvist 2009). The effect of CCS on the environment, economy and society has been assessed in various studies (e.g., Dütschke et al. 2016; Cuéllar-Franca and Azapagic 2015; Kraeusel and Möst 2012; Koelbl et al. 2014). Similar to CO_2 utilisation, the common methods are LCAs, TEAs, and social acceptance studies.

Even though CCS is a more mature technology than CO_2 utilisation, it has not yet been deployed (Bui et al. 2018). This difference in technological maturity was another reason to compare CCS to CO_2 utilisation in Article 3.

Overall, three forms of radical cleantech are considered in this doctoral thesis: CO_2 utilisation, hardware-, material-, or chemical-based cleantech, and CCS. Whereas not all radical cleantech ventures are CO_2 utilisation technologies or CCS, the reverse case for the three forms does apply. Furthermore, the terms of these forms and radical cleantech are used interchangeably in some articles, the editorial or in the overall conclusion. Nevertheless, generalisations stemming

[7] In particular, SDG 8, 9, 11, 12, and 13 may be affected by CO_2 utilisation.

from the analyses of this doctoral thesis remain challenging and will be subject of the overall conclusion (see Section 5.2).

1.4.2 Geographical Context

The geographical setting of this doctoral thesis is dominated by a focus on the USA and the EU. As all three articles analyse actors in both regions, it was deemed appropriate to compare the two geographic contexts in more depth throughout the articles. However, this PhD research is mainly of a qualitative nature, with sample sizes of 6-18 and regional sub-samples of 2-10[8]. Thus, this section presents observations as food-for-thought for future research, rather claiming to provide statistically sound explanations.
Article 1 shows that the barriers to and drivers for the successful commercialisation of CO_2 utilisation are perceived quite homogeneously across new ventures in Canada, the USA and the EEA. However, the perception of some barrier categories and of Song et al.'s (2008) success factors differ, as Article 1 discusses. In Canada and the USA, the entrepreneurial team is perceived as more important than in the EEA, while strategic and organisational fit is perceived as more important in the EEA than in Canada and the USA (see Article 1). *Risk-related* barriers, such as requirements of warranties from the ventures or uncertainties in the global economy, and barriers related to *society*, such as the acceptance of certain technologies, appear to be more relevant for new ventures in the EEA than in Canada and the USA. Hence, the following section will explore the risk perception and the relevance of societal acceptance in those two geographical locations (EU and USA) in more depth on the basis of the observations in Articles 2 and 3.

1.4.2.1 Risk Perception

Different risk perceptions are also observed in Article 2: cleantech investors in the USA subsample are more likely to invest in early-stage, radical cleantech ventures – that face greater *risk* than typical VC investments (cf. Ghosh and Nanda 2010; Cumming et al. 2016) – than investors in the EU subsample (see Figure 1-4). Similarly, the investment focus of the USA subsample tends to lean towards more hardware-, material-, and chemical-based cleantech ventures than software alternatives. Investors in the EU subsample, however, either make no difference between software, and hardware-, material- and chemical-based cleantech ventures, or prefer to invest in more software-based start-ups (see Figure 1-5).

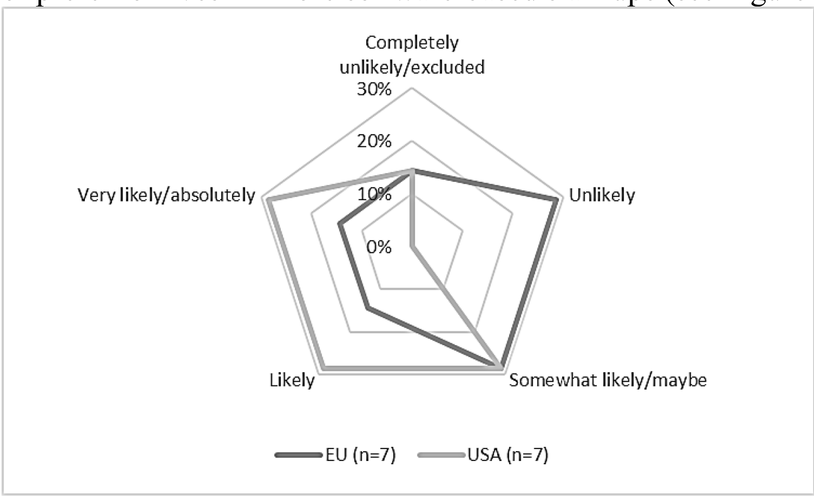

Figure 1-4: Investment preference (likelihood to invest in early-stage, hardware-, material- or chemical-based cleantech, in %): EU vs USA

[8] Article 1: n=18, n_{EEA}=8, $n_{Canada\&USA}$=10. Article 2: n=14, n_{EU}=7, n_{USA}=7. Article 3: n=6, n_{EU}=4, n_{USA}=2

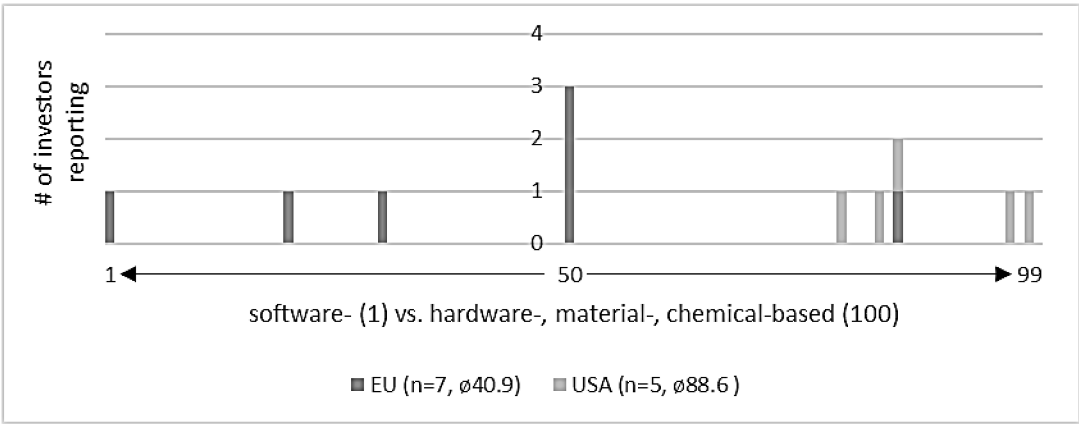

Figure 1-5: Investment preference on a scale from 1 to 100: software (1) vs hardware-, material- or chemical-based (100)

Similar comparisons between the two subsamples are made regarding investment focus. Overall, the average focus (100%) of our sample (n=12) is evenly distributed in the successive investment phases, from pre-seed (19%) and seed (20%) to series A (24%), B (19%), and C (18%). However, when divided into subsamples, the investment focus differs: Whereas pre-seed investments, both in terms of focus and maximum investment sum, dominate in the USA subsample, the EU subsample favours later-stage investments, such as series A and B for the investment focus and series B and C for the maximum investment sum (see Figure 1-6 and Figure 1-7).

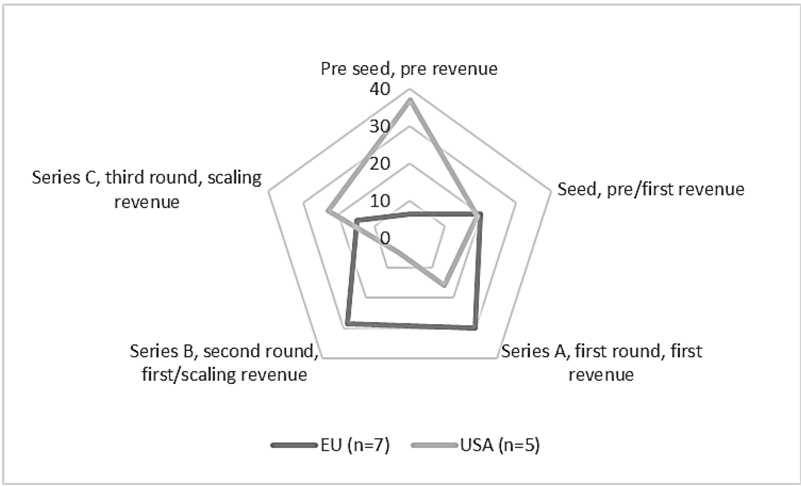

Figure 1-6: Investment focus (average shares of investment phase in overall investment activity, adding up to 100): EU vs USA

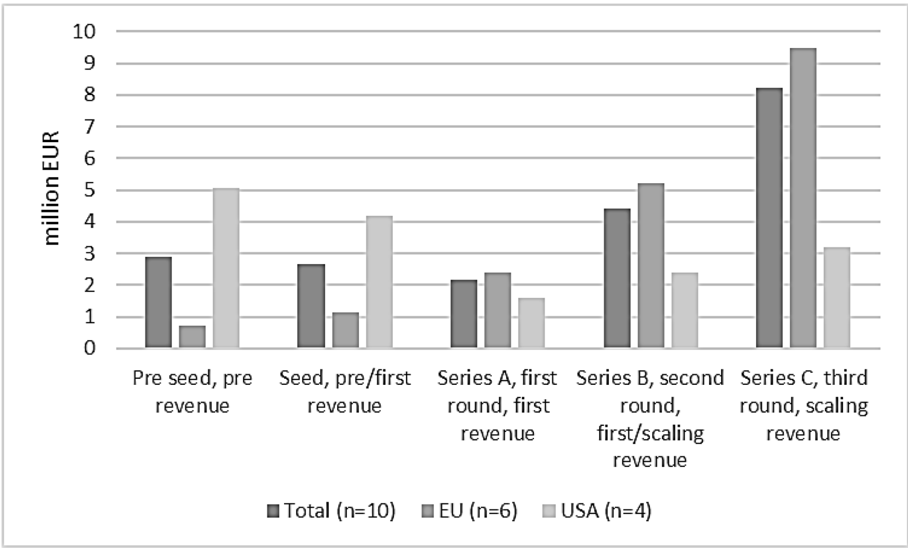

Figure 1-7: Maximum investment sum per phase, averaged

In the sample, investors in the USA are more likely to invest in early stage hardware-, material- or chemical-based new cleantech ventures in terms of investment phase, investment type, maximum investment sum, and likelihood to invest. Thus, the risk emphasis appears more pronounced in the EU subsample.

1.4.2.2 Social Acceptance

The emphasis on *society* in Article 1's EU subsample is also observed in Article 3's case of a government-initiated innovation intermediary in the EU. This intermediary was designed in a triple helix setting with participation of stakeholders from governments (as society's representatives), industry and academia. The innovation intermediary in the USA, on the other hand, was initiated by industry. Further comparisons are difficult because of the different depths of analysis and ages of the intermediaries. However, Figure 1-8 indicates that the industry-initiated intermediary in the USA has a more pronounced emphasis on standardisation measures than its government-initiated counterpart in the EU. Industry-wide agreements on, for example, how to assess radical cleantech may spur the development via (free) market dynamics for these technologies, rather than government interventions via policy measures. Nevertheless, societal acceptance is crucial in either approach, whether in the EU or in the USA (see, e.g., Kraeusel and Möst 2012 for public acceptance of CCS in Germany; see, e.g., Palmgren et al. 2004 for public acceptance in the USA).

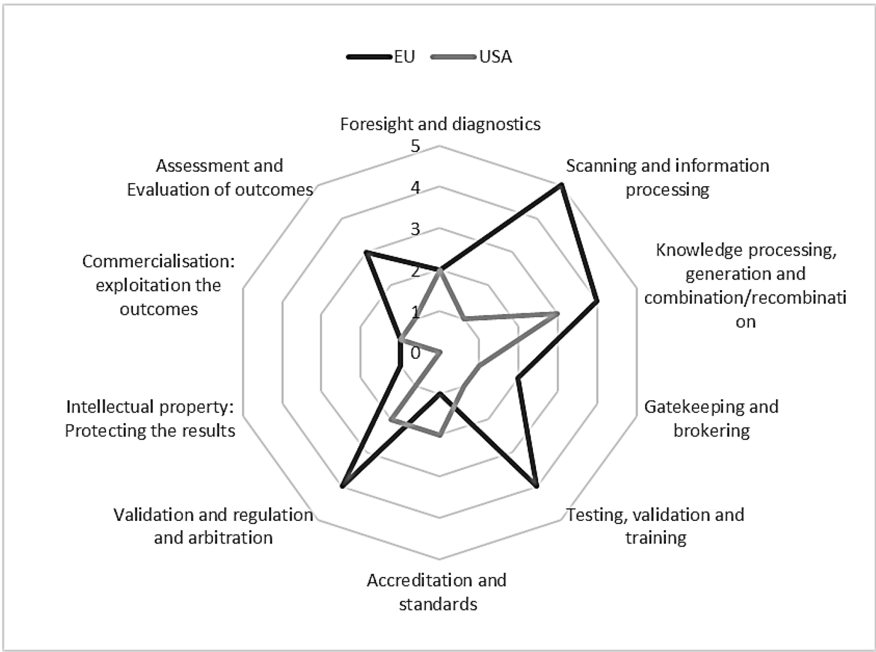

Figure 1-8: Activity mapping (number of reported activities) per region

1.5 Overall Conceptual Framework

This PhD project can be conceptualised along two different levels of analysis and corresponding recommendations: First, along the multi-level perspective (Geels 2011; Loorbach and Wijsman 2013) and second, along the internal or external dimension of the investigated actors. Figure 1-9 shows where the three research articles are situated.

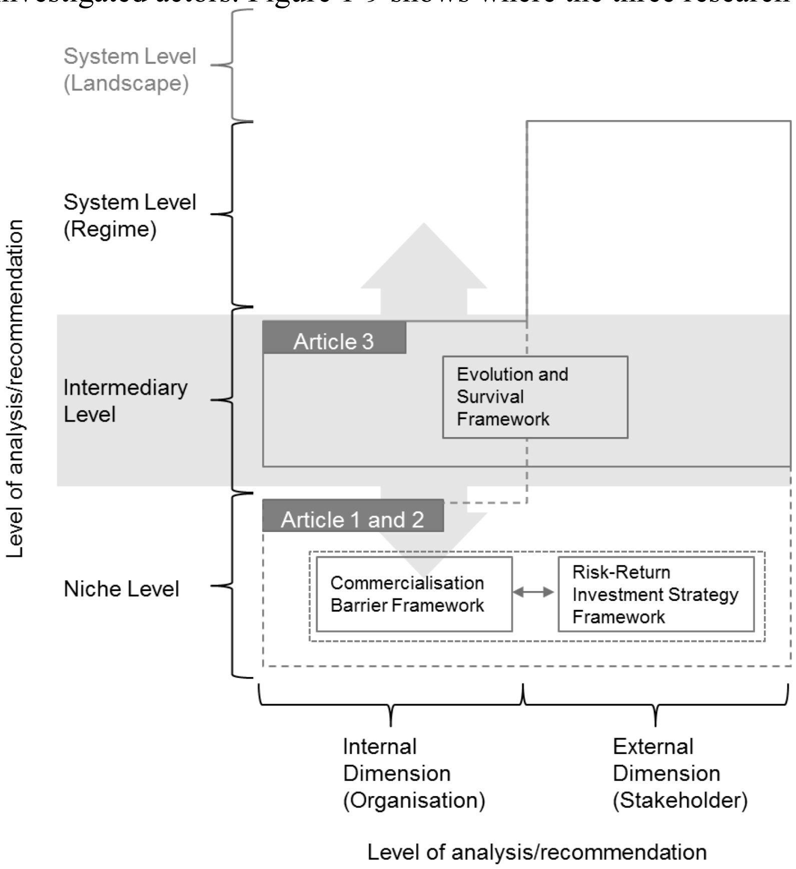

Figure 1-9: Overall conceptual framework

The multi-level perspective (MLP) is used to analyse socio-technical transitions to sustainability (cf. Geels 2011). The transition is thereby viewed as a non-linear process driven by three levels: niche, regime, and landscape (ibid.). Whereas the regime level defines the transition (shift from one regime to another), the niche and landscape levels are defined in relation to the regime level. Geels (2011) defines niches as "[…] practices or technologies that deviate substantially from the existing regime […]" (ibid., pp. 26f.) and landscape as the "[…] external environment that influences interactions between niche(s) and regime" (ibid., p. 27).
In this doctoral thesis, the focus is primarily on the niche and regime levels as push or pull factors for SOI (cf. Hörisch 2015). However, McCauley and Stephens (2012) identify innovation intermediary as a connector between niche-level activities and regime-level institutions and as a facilitator of niche technology diffusion (ibid.). Hence, a third level is added to position the different articles of this PhD project: the intermediary level (see Figure 1-9). Innovation intermediary not only brokers between different niche actors (see Figure 1-2 for coordination of support system supply and demand) but also between niche and regime actors (see Figure 1-9) (see also Howells 2006).
Article 1 describes the internal and external dimensions of actors in the context of barrier and driver identification. The internal dimension thereby covers the internal organisation of the actor: its internal resources and its capabilities to purposefully adapt its resource base to external influences (cf. Teece et al. 1997; Barney 2001). The external dimension includes all stakeholders that interact with the actor to create shared value simultaneously (cf. Tantalo and Priem 2016). Although only mentioned explicitly in Article 1's commercialisation barrier framework (adapted from Hueske and Guenther 2015), the internal-external dimensioning can also be applied to Articles 2 and 3. Both investors within the risk-return framework for radical cleantech (adapted from Tyebjee and Bruno 1984; Cochrane 2005; Guo and Whitelaw 2006) and innovation intermediaries within the evolution and survival framework (adapted from Howells 2006; Klerkx and Leeuwis 2009; Kivimaa 2014; Kanda 2017; Laur et al. 2012; Silva et al. 2018) encounter barriers and drivers (see Figure 1-2) that either occur at the internal or external dimension (e.g., see Section 4.6 of Article 3).
The level of recommendation is broader than the level of analysis in both actor specificity (see Section 1.4) and actor types. Recommendations can thereby not only be generalised but also derived for stakeholders that have been involved in the external dimension of the analysed actor's barriers and drivers. Table 1-1 provides an overview of this PhD project and summarises the editorial chapter.

Table 1-1: Overview of paper-based PhD

	Article 1 (see Chapter 2)	Article 2 (see Chapter 3)	Article 3 (see Chapter 4)
Title (see Section 1.3)	Overcoming Barriers to Successfully Commercialising Carbon Dioxide Utilisation	Strategies to bridge the valley of death!? How to Improve the Risk-Return Ratio of Hardware-, Material- or Chemical-Based, Early-Stage Cleantech Venture Investments	Innovation Intermediaries: What Does it Take to Evolve and Survive Over Time?
Research question (see Section 1.3)	What are the barriers and drivers for the successful commercialisation of strong sustainability-oriented new technology ventures?	What strategies can improve or have successfully improved the risk-return ratio of early-stage hardware-, material- or chemical-based cleantech venture investments? What is their potential effect and who are the players involved in their implementation?	How do innovation intermediaries evolve over time, and what are the survival factors in that evolution?
Design (see Section 1.3)	Qualitative interview study	Mixed-methods	Case studies
Level of analysis (see Section 1.4 and 1.4.2)	New CO_2 utilisation technology ventures and industry players	Early-stage chemical-, material- or hardware-based cleantech investors and experts	CO_2 utilisation and CCS innovation intermediaries
Level of recommendation (see Section 1.4 and 1.4.2)	New (radical) cleantech ventures, policy makers, support providers (intermediaries)	Early-stage chemical-, material- or hardware-based cleantech investors and ventures, policy makers	(Radical) cleantech innovation intermediaries, policy makers
Geographic focus (see Section 1.4)	EEA, USA and Canada	EU and USA	EU, USA, and Australia
Perspective of analysis (see Section 1.4.2)	Niche	Niche	Intermediary
Perspective of recommendation (see Section 1.4.2)	Niche, system (and intermediary)	Niche and system	Intermediary and system
Applied framework (see Section 1.4.2)	Commercialisation barrier framework (adapted from Hueske and Guenther 2015)	Risk-return framework for radical cleantech (adapted from Tyebjee and Bruno 1984; Cochrane 2005; Guo and Whitelaw 2006)	Evolution and survival framework (adapted from Howells 2006; Klerkx and Leeuwis 2009; Kivimaa 2014; Kanda 2017; Laur et al. 2012; Silva et al. 2018)

Article 1

Overcoming Barriers to Successfully Commercialising Carbon Dioxide Utilisation

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Keywords: sustainable entrepreneurship, sustainability transition, barriers to commercial success, CO_2 utilisation, new technology venture, commercialisation, sustainability-oriented innovation, support system

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Kant, Marvin (2017): Overcoming Barriers to Successfully Commercializing Carbon Dioxide Utilization. In *Front. Energy Res.* 5, p. 14. DOI: https://www.doi.org/10.3389/fenrg.2017.00022 (CC BY).

2 ARTICLE 1
Overcoming Barriers to Successfully Commercialising Carbon Dioxide Utilisation

2.1 Abstract

The successful transition to a low-carbon economy hinges on innovative solutions and collaborative action on a global scale. Sustainable entrepreneurship is thereby recognised as a key driver in the creation and transformation of ecologically and socially sustainable economic systems. The purpose of this article is to contribute to this topic by understanding commercialisation barriers for strong sustainability-oriented new technology ventures and to derive recommendations to overcome them. A qualitative multi-level approach is applied to identify barriers and drivers within the internal dynamic capabilities of the organisation and within the organisation's external stakeholders. A model of barriers has been developed based on semi-structured interviews with new carbon dioxide utilisation ventures and associated industry players in Canada, the USA, and the European Economic Area. Resulting recommendations to facilitate the (re-)design of a dedicated support system are proposed on four levels: a) actors, b) resources, c) institutional settings, and d) the coordination of the support system.

2.2 Introduction

Paris's COP21 (UNFCCC 2015) and the G7 Summit (G7 Germany 2015) in 2015 emphasise the need for a transition to a low-carbon economy. Moreover, increasing amounts of money will be invested in clean technologies over the next decades (UNFCCC 2015), potentially boosting sustainable-oriented innovation. However, effective allocation and support systems to leverage the sustainability transition of entire industries are still relatively unexplored.

In recent years, sustainable entrepreneurship (SE) has been recognized as key in the creation and transformation of ecologically and socially sustainable economic systems (Pacheco et al. 2010) such as a low-carbon economy. Furthermore, SE is identified as an essential driving force in the sustainability-oriented innovation (SOI) process (Jay and Gerard 2015): the multi-directional sequence of inventing, developing and diffusing new sustainability-oriented technologies and ideas.

This work uses Schaltegger's and Wagner's definition of SE, because it ties SE and SOI together: "Sustainable entrepreneurship is in essence the realisation of sustainability[-oriented] innovations aimed at the mass market and providing benefit to the larger part of society." (Schaltegger and Wagner 2011, p. 225). The following section focuses on SE (realisation of SOI) and its role in the sustainability transition (environmental and social benefits to society, and market impact).

Literature increasingly deals with SE (cf. Schaefer et al. 2015), and entrepreneurship has been proposed as a solution to environmental problems (York and Venkataraman 2010). SE identifies market opportunities and addresses market failures by aligning environmental, social, and economic aspects of sustainability (Hall et al. 2010; Parrish 2010; Thompson et al. 2011; Cohen and Winn 2007). Elkington (1998) coined this alignment as the "triple bottom line" principle. Porter and Kramer (2011) put Elkington's triple bottom line in a business perspective, arguing that business should deal with society's environmental and social issues such as resource depletion and climate change to create a shared value. The participation of multiple stakeholders and actors in the innovation process is required to create such a shared value. Hence, the involvement of stakeholders outside the organisation becomes paramount for SOI and SE (Paech 2007). This leads to the multi-level perspective on all stakeholder along the innovation value-added chain of this study to realise SOI.

The sustainability-orientation of an innovation determines the provided benefits for society, the environment, and the economy. Scholars often distinguish the degree of sustainability in two to three ascending categories (Klewitz and Hansen 2014; Muñoz and Dimov 2015; Jay and Gerard 2015). The highest degree of sustainability may be achieved by radical (cf. Christensen 1997) rather than incremental change (Roome 2012). Therefore, this research focuses particularly on radical innovation which is either "(…) explicitly directed at a sustainability goal" or implicitly adhered to sustainability goals without having sustainability issues as a primary target (Blowfield et al. 2008, p. 2). Thus, strong sustainability-orientation and meaningful impact on sustainability transformation may be attained.

Although large incumbents struggle with radical innovation, incumbents seem key in diffusing sustainability innovations to mass markets because they have the necessary assets at their disposal (Schaltegger and Wagner 2011) and often directly sell to other businesses (Parker 2011). Hockerts and Wüstenhagen investigated the interplay of large incumbents and new technology ventures (Hockerts and Wüstenhagen 2010). Their work on "Greening Goliaths" and "Emerging Davids" describe the necessary interaction to attain sustainability transformations. Therefore, this study focuses on radical new technology ventures and their endeavour to bring sustainability-oriented products/services to the market whilst particularly acknowledging the interaction with external stakeholders such as large industry players.

The radical nature of an innovation is quite often best depicted in hardware-based technologies. The problem with hardware-based technologies is that a proof-of-concept on a technically relevant scale is essential when attracting external resources to sustain business operations and business growth. These proofs of a scale-up production for hardware-based sustainability-oriented technology applications range from demonstrators over pilot production facilities to large commercial plants and are mostly very capital-intensive (Bossink, Bart A. G. 2015). Capital intensity, in turn, greatly influence investment risks for sustainability-oriented technologies such as renewable energy (Tietjen et al. 2016).

In this regard, Bürer and Wüstenhagen (2009, based on Grubb 2004) refine Murphy's and Edwards' (2003) concept of the cash flow valley of death and describe this technology valley of death as the middle phase between publicly funded R&D and self-sustaining funding from (private) partners/customers, where a successful prototype needs to scale-up further to introduce a product/service to the market successfully . When this valley of death is not bridged, sustainability-oriented ventures are lacking and current societal challenges such as resource depletion and climate change are not being tackled through radical innovation.

Carbon dioxide (CO_2) utilisation technology ventures typically combine the underlying problem of high capital intensity and the preconditions for a sustainability transition due to a high level of technology radicalness for a strong sustainability-orientation and mass application potential. The author defines CO_2 utilisation as innovative approaches to convert CO_2 molecules to other molecules. This definition builds on Styring' and Jansen's definition (2011) by adding the innovation aspect of not being fully commercialised yet.

The sustainability effect of CO_2 utilisation is reflected by the fact that the use of CO_2 as a raw material may not only be a door-opener for large emission abatement technologies but may also be a potent resource efficiency technology because it feeds CO_2 back into the carbon-based economic system (Naims 2016; Styring et al. 2015b; Armstrong and Styring 2015). Furthermore, CO_2-based products such as CO_2-based fuel are about to reach larger markets (Aresta et al. 2013) and thereby gaining increasingly importance for sustainability transitions. However, a successful diffusion of a technology in society is crucial to have meaningful SOI (Boons and Lüdeke-Freund 2013; Hall and Clark 2003). Hence, this paper has a particular focus on the commercialisation phase (cf. Pellikka 2014) and looks at the critical process step between product development and commercialisation, as it is at this stage that most sustainable entrepreneurs fail.

Barriers, drivers and success factors of SE have already been drawn to the centre of attraction of business scholars (Pinkse and Dommisse 2009; Pinkse and Groot 2015; Kennedy et al. 2013; Walker et al. 2008; Bernauer et al. 2007). Pinkse and Groot (2015), for example, focus on market barriers, namely inefficiency, externalities and imperfect information, identifying SE as a possible way to overcome these barriers. They argue that market barriers, once overcome by entrepreneurs, who are involved in political collective activities via industry associations, can reveal entrepreneurial opportunity (ibid.). However, most of these research findings are adding sustainability-specific characteristics to findings from conventional innovation or entrepreneurship studies (Driessen et al. 2013; Jay and Gerard 2015; Walker et al. 2008)
This article contributes to the literature by addressing the following primary research question:

> *What are the barriers and drivers for successful commercialisation of strong sustainability-oriented new technology ventures?*

The aim of this work is twofold: first, to gain a better understanding of the internal and external barriers to the commercial success of new CO_2 utilisation technology ventures; and second, to use the identified barriers to derive hands-on recommendations to (re-)design a dedicated support system for these technologies. It brings together different research on SE in the light of sustainability transition to illustrate the complex and dynamic process to commercialise new sustainability-oriented technologies. By researching new CO_2 utilisation ventures in Canada, the USA, and the European Economic Area (EEA) a broad set of barriers and drivers have been identified. Subsequently, detailed recommendations for strong sustainability-oriented new technology ventures, policy makers, and support providers are derived to facilitate the implementation of strong SOI such as CO_2 utilisation.

2.3 Barrier Framework Methodology

Previous research noted that the commercialisation process of a small firm has both an internal (e.g., managerial actions and decision making) and an external (e.g., interaction with commercialisation environments) dimension of activities (c.f. Pellikka 2014). Especially, the dependency of small firms, such as new technology ventures on external resources, has been recognised (e.g., Oakey 2007). Pellikka's (2014) framework of the commercialisation process in small high-technology ventures sheds light on the interface between internal and external commercialisation dimensions and thus may help to discover how firms can receive these external resources.
Other scholars also acknowledge these internal and external dimensions. Walker et al. (2008), for example, performed a literature review on barriers and drivers of small and medium enterprises to engage in good environmental practice. They point out two perspectives how barriers are perceived: the firm perspective, representing the internal dimension and the government perspective, as one of the main representations of the external dimension (ibid.). Acknowledging such of a multi-level perspective can also help to better understand ambiguous findings such as barrier of company A is a driver for company B (Hueske and Guenther 2015). Hueske and Guenther (2015) propose a barrier framework that enables a more encompassing identification, on different level of analysis, of innovation barriers and draws from theory.
This work builds on a multi-level perspective from current relevant research (Hueske and Guenther 2015) to investigate all barriers to commercial success. A dynamic capabilities approach (Teece et al. 1997; Eisenhardt and Martin 2000), in combination with stakeholder theory (Freeman 2004; Tantalo and Priem 2016), was chosen to analyse both internal and external barriers that exist alongside the innovation value-added chain. Applying this analysis on multiple levels enables a focus on interactions of barriers within and across the levels of analysis. Furthermore, it acknowledges the specificity of context and thereby allows for a broad

set of recommendations (Hueske and Guenther 2015) and an increased contextual understanding. Both, the organisational and the external level define (cross-)barrier categories and sub-categories are set out within the different levels. Figure 2-1 pictures the applied barrier framework.

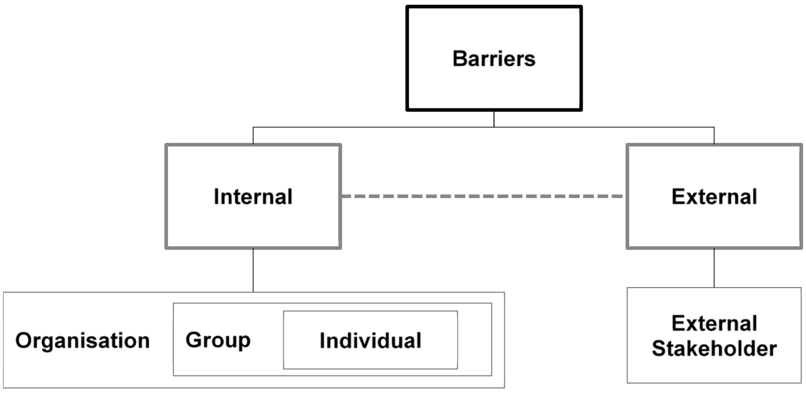

Figure 2-1: Applied barrier framework (adapted from Hueske and Guenther 2015)

Freeman et al. (2007; 2010) argue that stakeholders have competing goals when creating value that need to be addressed by managerial trade-off decision making. In contrast to Freeman's mind-set, the stakeholder synergy approach addresses how value can be created simultaneously for stakeholder groups that are essential for a firm (Tantalo and Priem 2016). This approach helps to identify value creation opportunities both within and across relevant stakeholder groups (ibid.). Seven key stakeholder groups can be observed: (1) investors, (2) future employees, (3) partners and suppliers in research, engineering and manufacturing, (4) competitors, (5) customers, (6) governments, and (7) society (Hueske and Guenther 2015).

Dynamic capabilities may be used to create new resource configuration and update the competitive position of an organisation. Furthermore, dynamic capabilities include processes such as collaboration and product development that may turn resources into value-creating strategies (Eisenhardt and Martin 2000).

An explorative qualitative interview study was used to investigate the new CO_2 utilisation venture landscape worldwide. This research approach is suitable for early stage research such as SE in CO_2 utilisation (Silverman 2013). Furthermore, the approach was chosen to enable the enfoldment of existing theory by analysing capability-driven, internal barriers and stakeholder-driven, external barriers (Eisenhardt 1989)

The empirical setting is carefully chosen and looks specifically on the EEA, and Canada and the USA. This choice was made to exclude too much variation due to differences between industries.

2.4 Sample and Data Collection

The author choses a theory-based purposeful sampling approach to identify and select information-rich interviews (Palinkas et al. 2015; Patton 2015). Experienced and knowledgeable individuals, which were available and willing to participate, have been identified to make an effective use of limited research resources (Palinkas et al. 2015). New CO_2 utilisation ventures were identified globally via (1) the author's participation at several events (such as conferences and workshops) with a CO_2 utilisation theme and (2) an extensive online desk research on past conferences, privately and publicly funded projects/programmes/prizes, and aggregated news platforms. A population of N=48 existing new CO_2 utilisation venture companies (as of October 2015) were identified with a great concentration in the EEA, Canada and the USA.

Smit et al. (2014) divide carbon utilisation into four sections: enhanced oil recovery, CO_2 to chemicals, CO_2 to fuels, and incorporating CO_2 into construction and building material. This categorisation is based on the output of the various CO_2 utilisation technologies (see also Styring and Jansen 2011; Hendriks et al. 2013; Peters et al. 2011). The author of this work adapted the categorisation by application class of CO_2 utilisation technologies, but included only those categories that are in line with the CO_2 utilisation definition of this paper. Incorporating CO_2 into construction and building material is mainly carried out by mineralisation of CO_2. Hence, the population and sample were divided into CO_2 to chemicals, CO_2 to fuels, or CO_2 mineralisation.

Typically, these categories contain various technologies that address different industry sectors:

- CO_2 mineralisation turns CO_2, minerals, and industrial waste mainly into aggregates or fillers for the building industry (Styring et al. 2015b).
- CO_2 to chemicals primarily cover applications such as intermediates, specialty chemicals or precursors such as polyols for the plastic production (ibid.).
- CO_2 to fuels include primary power-to-x technologies. Power-to-x processes – in the context of CO_2 utilisation – use electricity to transform CO_2 into liquid or gaseous fuels, e.g., for the transportation sector or as seasonal storage for the energy market (ibid.).

Other possible transformation pathways of power-to-x are chemicals with more complex molecular structure such as pharmaceuticals (ibid.). Hence, also a hybrid category of “CO_2 to chemicals” and “CO_2 to fuels” is possible. The use of microorganisms are another method to convert CO_2 into fuels and/or chemicals (Styring and Jansen 2011).

Within the population of N=48 companies, 19 initial interviews were conducted with 18 different ventures. The geographical distribution and the shares within the categories of the identified CO_2 utilisation ventures of the population were well reflected in the sample (cf. Figure 2-2). The interviewees’ position ranged from CEOs, CTOs, and CFOs to R&D managers, business developers, and operations and sales persons. Most of the interviewees were intentionally the (co-)founders of the company because they potentially have the best overview of the company and can share in-depth insight into business operations and strategies. 30- to 80-minute (Ø 45 minutes) interviews were conducted face-to-face and/or via telecommunication between October 2015 and April 2016. In addition to the initial 19 interviews, two more interviews with new CO_2 utilisation ventures were conducted in July and November 2016, adding up to n=20 companies with a total of 900 minutes of recording time. This enabled further insights and the ability to test propositions derived from previous interviews. All interviews were semi-structured and a semi-open questionnaire was adapted from interview studies on similar technology fields (e.g., Matus et al. 2012). The semiopenness allowed for an ongoing adjustment of the questionnaire in the course of the interview series; in combination with the sequenced interview process over several months, interviews were carried out until no new phenomenon were discovered and therefore theoretical saturation was reached (Strauss and Corbin 2015). In addition, a ranking of perceived success factor categories, which were identified in the literature, was carried out in twelve interviews. All initial interviews were recorded, transcribed, and send to the respective interviewee for validation prior to the anonymised data analysis process. The study was carried out in accordance with the German law. No ethics approval was required for this type of research as per German laws and regulations. In compliance with these laws and regulations, oral informed consent was obtained from all research participants. Their answers were anonymised and it is not possible to link the statements back to individual subjects. Figure 2-2 provides further aggregated information about the sample on the ordinate.

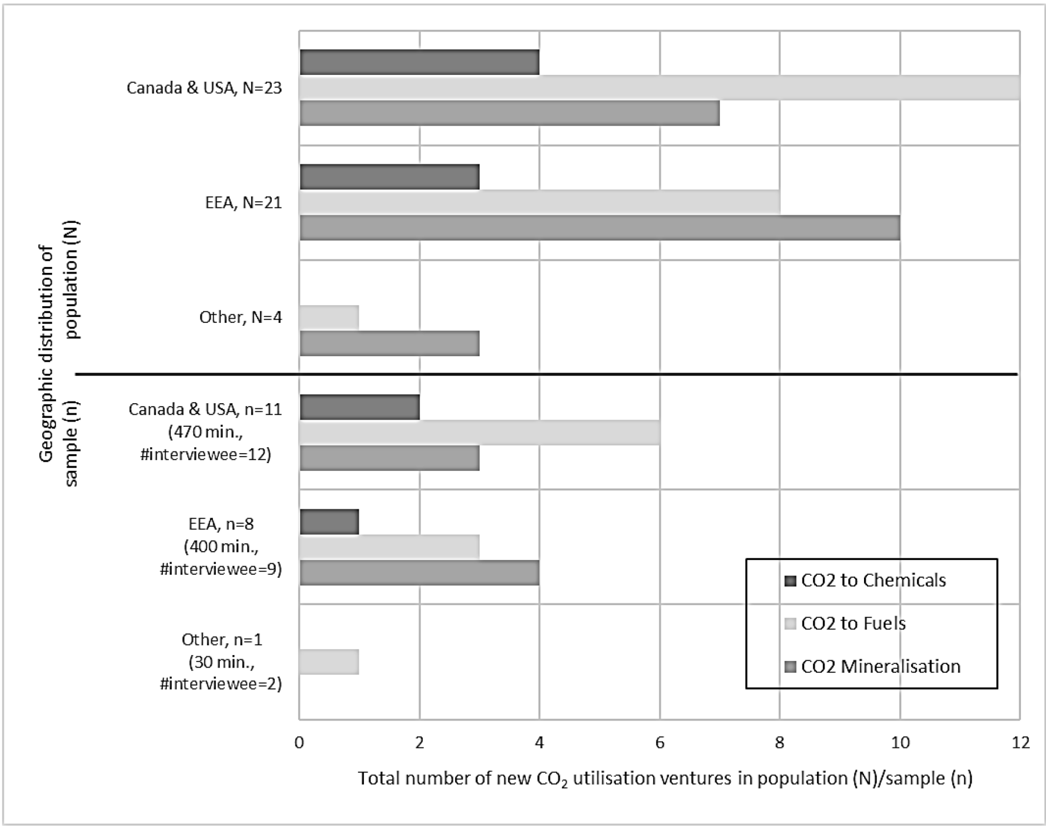

Figure 2-2: Overview of the identified population and sample

To enhance contextual understanding, additional data sources such as publicly available reports were used to triangulate the venture's positions (proposition testing). Furthermore, during the data collection process four interviews with a steel producer, utility, infrastructure provider, and chemical company were conducted in the EEA to give a broader perspective from additional stakeholders. These four interviews with five interviewees were surveyed over a total of 140 minutes.

2.5 Data Analysis

Data were analysed using the software Atlas.ti 7 (ATLAS.ti 2018). An open and axial coding process (Strauss and Corbin 2015) was performed to extract internal and external commercialisation barriers and increase the reliability of the analysis. Following the coding process, codes of each code family were manually extracted. The codes were further aggregated and duplicates were removed. This extraction revealed cross-family and cross-level occurrences of barriers and contextualised the data from the interview by comparing institutional settings and company types: the EEA vs Canada and the USA, and large incumbent vs new technology venture. Table 2-1 states an exemplary overview of the data analysis process.

Table 2-1: Exemplary overview of the data analysis process (adapted from Hahn and Ince 2016)

Data analysis process →		
Open Coding process: Transcripts are coded with different phenomena related to barriers and drivers	**Axial Coding process**: Codes are aggregated into structured theory-based code families; first relations within and across barrier family are revealed	**Extraction process**: Extraction and further condensation within the families, and identification of core barrier categories with drivers and cross-barrier relations
Iteration ⇄		
Results: Coded phenomena	Results: Barrier categories	Results: Barrier model with cross-barrier linkages
Example: – Unknown position within company – Multiple contacts in different business units – Feedback in development process – Lack of network access – …	Example: – Customer – Promoter – Network and knowledge – Strategy – …	Example: – Identification of gatekeepers – Immediate collaboration – …

2.6 Results

A qualitative multi-level model on the internal and external barriers to successful commercialisation has been developed based on the families from the coding process (cf. Figure 2-3). External barrier categories focus on the external stakeholders of the value-added chain of SOI and the internal categories reflect the sustainability-oriented venture itself. External stakeholder are public and private investors, future employees, partners in R&D and manufacturing, competitors, customers, governments, and society. The internal organisation is divided into strategy, size and structure, and resources of the organisation. Resources can be further broken down into infrastructural, technological and financial resources, knowledge and networks, and management and team in terms of social and human capital. Furthermore, a third main category was derived from the analysis, because of the reoccurring nature of three barrier categories at the immediate interface of internal and external barriers: promoter, location, and risk. They are referred to as cross-linkage barriers.

The following part provides an overview of the barriers of each category and their main drivers. Moreover, it indicates cross-barrier relationships across the three main categories: external, internal and cross-linkage barriers and compares the predominant institutional settings and company types.

All barriers and drivers in this section are extracted from the underlying data of the qualitative research, unless stated otherwise. They represent the individual perception of the new CO_2 utilisation ventures and industry player.

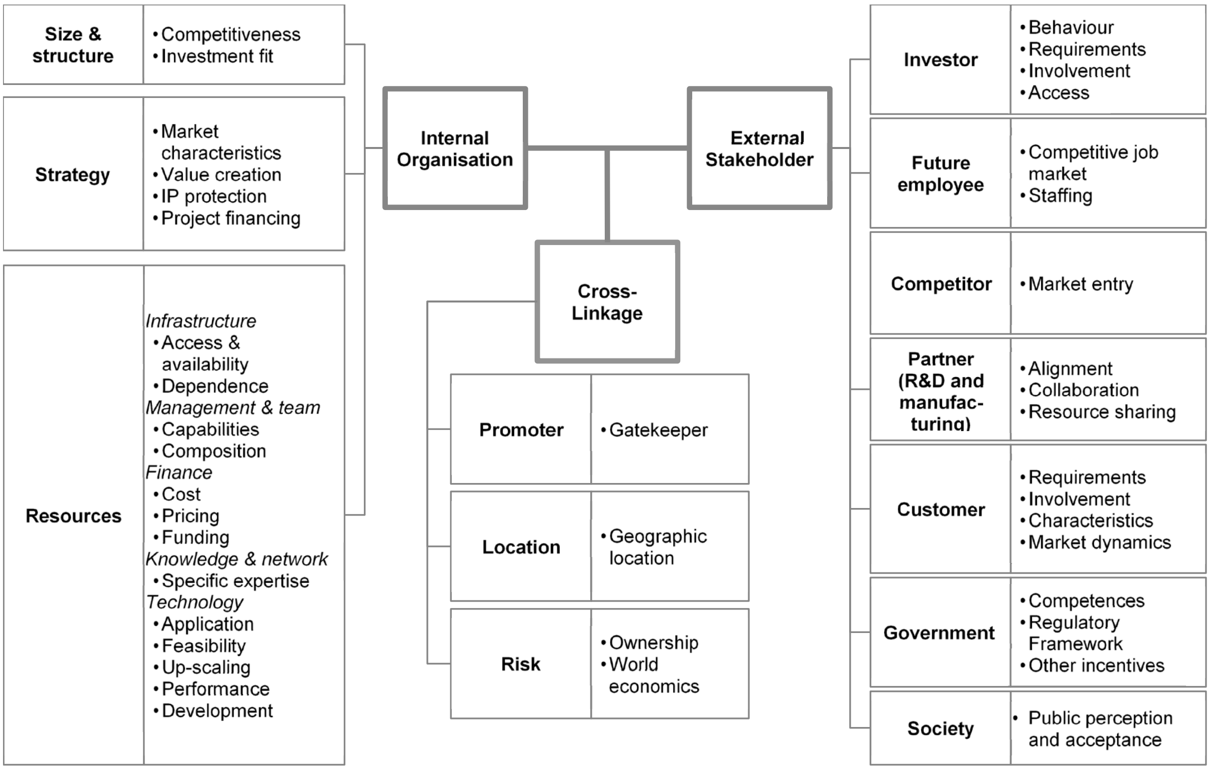

Figure 2-3: Multi-level barrier model

2.6.1 External Stakeholder

New CO_2 utilisation ventures encounter various commercialisation barriers in their external environment (cf. Table 2-2). This environment is mainly determined by investors, future employees, partners in R&D and manufacturing, competitors, customers, governments, and society.

Barriers when dealing with investors in the field of CO_2 utilisation fall within investment behaviour, requirements dilemma, operational and strategic involvement, and in access to investments. The risk taking of investors is not much different to other hardware-based technology investments. However, uncertainties in regulations, the preference for asset-backed investments, and the fact that there is often yet no market with a minimum assurance were reported to discourage the risk affinity for CO_2 utilisation further. In addition, study participants stated that the clean tech sector still suffers from a loss of reputation due to investment decisions during the mid-2000s: institutional investors without suitable sector-specific experience invested heavily into clean energy technologies (e.g., Rai et al. 2015) contributing to poor financial returns between 2000 and 2010 (e.g., Bygrave et al. 2014).

These experiences led to a set of requirements that put new technology ventures to the test. A proof-of-concept on an industrial scale (actual system prototype or proven technology in its final form) is often mandatory and existing agreements with off-takers/customers are required as described by the interviewees.

Moreover, the degree of an investor’s involvement can result in a trade-off-decision: the investor may bring crucial market and management expertise but might also curtail the new venture’s freedom and fail to acknowledge its expertise as reported differently by the study participants. Either way, the interviewees highlighted that institutional investors are necessary to scale-up and grow. Hence, access to these investments were noted to be of upmost importance and new CO_2 utilisation ventures stated to often lack the network to gain that investment access.

Barriers in the context of future employees are competitive job markets and the staffing process. Job markets like any other market are influenced by world economics. Especially the oil market developments pre and post the 2000s were pointed out to have shaped the availability of technical personal in the USA but also in Europe. In general, the risk affinity of future employees and thereby the willingness to work in a firm with a high probability to fail is claimed to be low. New CO_2 utilisation ventures also began to strategize and move to certain locations to get access to greater talent pools. Close ties to university can facilitate the staffing process. However, there is also a trade-of between proximity for partnerships and recruitment. Overall, fluctuation in the management, and the internal development of necessary skillsets and the organisational fit of future employees were described to remain challenging.
Additional barriers related to external stakeholders concern partners in R&D and manufacturing. The partner's alignment with new CO_2 utilisation ventures emerges as a barrier, when it comes to the strategy for a technology development that takes at least 3-5 years and the motivation that depends on the position within the value chain. Furthermore, there are proclaimed challenges in collaboration and resource sharing (knowledge transfer and infrastructure). New CO_2 utilisation ventures need to assess and identify potential partnerships to engage in a collaboration. The roles of partner, however, is not necessarily easy to define, the coordination of partnerships is resource intensive and the matchmaking process requires the presence of extensive networks as described by the interviewee. Nevertheless, outsourcing strategies and approaches to build entire synergetic ecosystems with crucial value chain stakeholders involved were identified as attempts to overcome shortcomings in resources. Knowledge transfer – by means of market and industry intelligence, and management expertise – and the provision of infrastructure, offer opportunities for building up IP portfolios and testing capabilities under real life conditions, but were recognised as very challenging to establish.
The competitor category reveals market entry barriers in form of lock out, subsidisation and scale effects. New CO_2 utilisation ventures claim to face threats of being locked out of the market by competitors temporarily lowering prices for commoditised products. Such entry deterrence strategies of large incumbents in high volume markets with little product margins are reported to require significant price advantages of new technology ventures over current prices to be competitive. Furthermore, inconsistencies within the subsidisation of renewable energy or fossil fuels directly influence competing technologies when certain technologies are favoured (e.g., Victor 2009; Hope et al. 2015) or exemptions for certain companies are made (e.g., the special equalisation scheme under the renewable energy sources act in Germany [§§ 63 ff. Erneuerbare-Energien-Gesetz - EEG 2017]). Aside from these subsidies, scale effects cater for low costs of mature technologies such as fossil-based productions as described by the interviewees.
During the interaction with customers new CO_2 utilisation ventures encounter barriers regarding a proof-of-concept, the participation of potential customers, specific customer characteristics, and global market dynamics. A proof-of-concept in form of a pilot production facility with a high quality of product samples is mandatory for most potential customers to sign any kind of offtake agreement; this in turn is often necessary for investors as recurrently pointed out by the study participants. However, risk profiles of customers are reported to vary depending on the position within the value chain (e.g., 1/10 of scale for several months vs full scale for several years). Moreover, new CO_2 utilisation ventures can share customers' risks by issue commissioning warranties. A financial challenge yet remains: either as a proof-of-concept or as the backing of warranties. Furthermore, customer's problems need to be acknowledged and the solutions need to be understood from both, the customer and the new CO_2 utilisation venture as pointed out by the participants. To do so, an early participation and specific customer characteristics are identified drivers that must be addressed. New CO_2

utilisation ventures have experienced challenges in complying with industry requirements such as ownership models, investment abilities, and customers' intrinsic motivations to lower the environmental impact. Policy intervention and market dynamics were described to further influence these specific characteristics and to be potential barriers in themselves. Overall there is little perceived willingness to pay a premium for environmentally and socially superior products in the field of CO_2 utilisation: Only one out of 14 interviewees sees a general willingness to pay a premium for carbon-based products; one interviewee does not know and 12 interviewee see no or very limited willingness of a small fraction of customers to pay premium prices.

Further barriers that are related to governments are in the categories competences, regulation and other incentives. In terms of competences, the study participants claim that there is a lack of foresight and most regulation is based on current rather than novel technologies. Moreover, responsibilities are often not clearly defined and passed on between different authorities (e.g., between the different Directorate-Generals of the European Union). With respect to regulatory frameworks translation, harmonisation, and sovereignty is often an issue for rolling-out CO_2 utilisation technologies globally. Regulation frameworks are perceived as too complex, volatile, and can even create market perversion e.g., by encouraging the generation of more and more energy rather than focusing on a more efficient use (e.g., via storage). The barriers for funding applications are noted to be considerable for small companies and thereby limit the funding access. Other incentives like a general sponsorship for the implementation of CO_2 utilisation technologies are underrepresented and long term strategies and global agendas for CO_2 utilisation were identified as still missing by the interviewees.

When it comes to society, the main barrier is public perception and acceptance. There is a perceived negative misconception of CO_2, especially when new CO_2 utilisation ventures are connected to the emitting industries. Dedicated marketing strategies and education programmes are identified as widely missing.

Table 2-2: Overview of external stakeholder barriers and drivers

Category	Barrier	Driver
Investor	Investment behaviour	Past investments
		Risk taking
	Set of requirements	Proof-of-concept
		Existing agreements
	Involvement*	Decision making*
		Management
	Access	Network
		Staged project financing
Future employee	Competitive job market	Market development
		Risk taking
		Geographical location
	Staffing	Skillset and organisational fit
		Fluctuation in management
		Close tie to university
Partner	Alignment*	Strategy alignment
		Motivational alignment*
	Collaboration*	Consortium coordination
		Identification and division of potential roles
		Partnership assessment
		Matchmaking*
		Outsourcing
		Ecosystem and joint projects
	Resource sharing (knowledge transfer and infrastructure)	Market and industry intelligence transfer
		Infrastructure provision (availability and access)
		IP portfolio
		Management experience
		Testing capabilities
Competitor	Market entry	Lock out
		Scale effect
		Subsidisation

Category	Barrier	Driver
Customer	Proof of concept	Quantity and quality of the sample
		Offtake agreements
		Multiple risk profiles
		Risk/burden sharing
	Problem acknowledgement and solution understanding	Early customer involvement in the development process
	Specific characteristics*	Compliance to industry requirements:
		-Ownership model
		-Investment inability
		-Intrinsic motivation to lower carbon footprint*
	Global market dynamics* and policy intervention	Decentralised energy production
		Carbon market
Government	Competences	Lack of foresight
		Responsibility
	Regulatory framework	Translation
		Harmonisation
		Sovereignty
		Complexity
		Volatility
		Market perversion
	Other incentives*	General sponsorship*
		Long-term strategies
Society	Public perception and acceptance*	Marketing strategies*
		Educational programmes

* perceived main barrier reported

2.6.2 Internal Organisation

New CO_2 utilisation ventures experience also barriers within their organisation (cf. Table 2-3). These barrier categories range from size and structure over strategy to resources. Like other new technology ventures, CO_2 utilisation ventures encounter challenges because of their size. The competitiveness is affected by capabilities to compete on market prices and even below-market (dumping) prices as reported by the study participants. Moreover, scale effects such as the fossil industry built up over decades, complex regulatory framework, and limitations to take on multiple roles simultaneously such as investor, owner, manufacturer and operator influence the perceived competitiveness even further. The internal structure of new CO_2 utilisation ventures greatly influences the decision making of investors. An understanding of the investment rationale is noted to enhance the chances of survival and future growth.

Strategy-related barriers relate to market characteristics, value creation, IP protection and project financing. The market entry strategy must meet the specific market requirements and characteristics. Hence, a focus on the technological application is observed to be necessary. Opportunities may arise when focussing on bridging applications to decarbonise the transportation sector or to store energy. New CO_2 utilisation ventures need to target customers that are at a particular stage in the value chain, even though their technology can have different outlets for different value chain positions. Moreover, they need to balance relevance in R&D and marketability of their technology and need to decide on how much value they want to capture and how to acknowledge and build on the existing competencies of their potential customers as reported by the interviewees. When approaching a customer, study participants noted that challenges regarding the intellectual property (IP) arise. A rigid patenting strategy might help to facilitate immediate interaction, but is also very capital intensive as pointed out by the interviewees. Having a sound strategy to finance and to implement collaborative projects holds further perceived hurdles that may be driven by staged project approaches.

Internal barriers in the resource domain are grouped into knowledge and networks, management and team, infrastructure, finance, and technology. New CO_2 utilisation ventures encounter challenges to obtain certain expertise such as management and market expertise, and application know-how. They often report to lack access to networks to build-up knowledge and approach key persons for innovation processes in external organisations, so-called gatekeepers (Allen 1970). Within the management and team category, capabilities such as adaptation abilities for dynamic team settings and changing environments and the management composition were reported by the study participants to hinder successful commercialisation.

Furthermore, infrastructure availability and dependence on existing infrastructure cause perceived internal challenges. In this regard, modifying existing equipment or using external facilities to rapidly deploy new technologies was described as greatly beneficial. However, compliance requirements from customers to build-up R&D facilities internally and the access to external infrastructure hinders the development of new CO_2 utilisation ventures. Moreover, centralised production systems with established infrastructure and the upkeep of an influx of required inputs such as CO_2 and energy apply further pressure on these ventures.

Financial barriers are reflected by costs, pricing, and funding. The capital costs for proofs-of-concepts and other testing actions are noticed as very high in the field of CO_2 utilisation. In addition, new CO_2 utilisation ventures report to be often incapable of either scaling down at capital expenditure rates that would enable technological applications (see economies of scale) or building the facilities large enough to make the capital expenditure feasible, because raw materials are not available in sufficient quantities. Furthermore, their pricing capabilities are limited and they are unable to compete on under-market (dumping) prices. Funding opportunities and cost or availability of inputs such as CO_2 and energy were stated to vary from one geographic location to another (see also Hendriks et al. 2013). Moreover, it is the experience of CO_2 utilisation ventures that the availability of funding sources is limited and that the exploitation of these sources is also challenging in terms of administration.

The last categories of internal barriers are of technological nature. They are related to application, feasibility, up-scaling, performance and technology development. Some new CO_2 utilisation ventures in the sample use platform technologies and therefore have a broad range of possible technological applications. This application range was identified by interviewees to bring challenges; research expertise and experience often determine the focus on an initial product rather than marketability or other market drivers. The study participants observed that new CO_2 utilisation ventures need to focus on market driven applications whilst ensuring a maximised flexibility to adapt to different CO_2 sources such as diluted or concentrated and large or small CO_2 sources. Furthermore, when showing the feasibility of their CO_2-based products and processes they must comply with time and resource-intensive testing and sampling requirements (e.g., life-cycle assessments, large simulations or present under real life conditions) of potential customers. Moreover, to get to a so-called proof-of-concept new CO_2 utilisation ventures have to up-scale their lab-scale processes over demonstrators to pilot plants. In the light of experiences from the participants, this up-scaling requires extensive engineering expertise and necessary capital.

A poor performance of CO_2-based products can hinder a successful commercialisation as well. Industry requirements such as the reported high level of reliability of power plant operations must be acknowledged. The willingness to pay a premium for CO_2-based products was highlighted as very limited, hence, the interviewees conveyed product performance needs to be superior to be competitive. Developing CO_2-based products takes time, especially when involving other stakeholders in the development process, coordination and feedback loops (e.g., external evaluation rounds). These stages were reported to be time consuming and very challenging.

Table 2-3: Overview of internal organisation barriers and drivers

Category		Barrier	Driver
Size and structure		Competitiveness	Pricing capabilities
			Scale effects
			Regulatory complexity
			Multiple roles
		Investment fit	Understanding investment rationale
Strategy		Market characteristics	Application focus
			Market entry strategy
		Added value	Targeting strategy for value chain
			Balancing R&D relevance and marketability
			Value capture
			Build on and acknowledge existing competencies
		IP protection	Rigid patenting strategy
		Project financing	Staged project approach
Resources	Knowledge and networks	Specific expertise	Management and market expertise
			Access to extensive network
	Management and team	Capabilities	Adaptation abilities
		Management composition	Set-up and fluctuation
	Infrastructure	Access and availability	Modification capabilities
			Outsourcing capabilities
			In-house R&D infrastructure
			External infrastructure
		Dependence	Centralised production systems
			Influx of required inputs
	Finance	Cost	Capital expenditure for proof-of-concept and testing
			Scaling capabilities
			Location dependency of input costs
		Pricing	Capabilities to compete on price
		Funding*	Location dependency of funding availability*
			Fundraising capabilities
	Technology	Application*	Technology platform
			Application determinants*
			Adaptability to input sources
		Feasibility	Testing and sampling compliance
		Up-scaling	Proof-of-concept expertise
		Performance	Compliance to industry requirement
			Product superiority
		Technology development	Customer involvement
			Duration

* perceived main barrier reported

2.6.3 Cross-Linkage

The third main category of the identified barriers are referred to as cross-linkage barriers (cf. Table 2-4). Barriers in this category can relate to both, internal and external barriers. They are re-occurring connecting elements within the commercialisation process and are grouped into three sub-categories: location, risk, and promoter.

New CO_2 utilisation ventures face various challenges in terms of the geographic location. The location does not only determine incentives and des-incentives such as regional or national regulation and funding opportunities, but it also feeds into the requirements for partnerships: the proximity to portfolio venture, the possibilities for joint ventures, and the existence of markets for a potential exit depend on the location of a collaboration as study participants have reported.

When it comes to risk, the barriers are: ownership and world economics. Owning capital-intensive assets is described to be too risky for most new CO_2 utilisation ventures, whereas the interviewees stated large industry players often own too many assets to take risks. Furthermore, the perceived risk averseness of their potential customers (and investors) can corner them into additional risk taking via warranty agreements. Global market developments and dynamics such as the economic crisis and the shift of the energy sector towards decentralised energy production were found to create further uncertainties and hinder long time commitments of several stakeholders.

Promoters are individuals that actively and intensively support the innovation process (c.f. Witte 1973) and thus are playing an important role in the commercialisation process of CO_2 utilisation. However, they are most of the times noted to be absent and identifying and convincing gatekeepers at any stakeholder organisation was recognised as considerably challenging. New CO_2 utilisation ventures reported that they face multiple organisational levels approaching large companies and find it difficult to identify key contacts. Hence, not only the identification but also the advocacy for a collaboration represent main barriers for these ventures. However, promoters for CO_2 utilisation do already exist internally within the founding and management teams of new technology ventures and externally among investors, partners and governments. Examples of this highlighted by the study participants include:

- Founders of new CO_2 utilisation ventures can have proven entrepreneurial skillsets and vast industry knowledge and networks from previous work experiences to enable the access to investors and potential customers and partner. Moreover, they cannot only bring specific know-how, but also have intrinsic sustainability-oriented motivation from previous experiences and see CO_2 as (market) opportunity.
- Effective technology and market knowledge transfer can also be performed by investors and partners. Moreover, investors and universities can provide R&D infrastructure or universities can grant access to extensive IP portfolios and talent pools.
- Manufacturing partners can manufacture to the specific requirements of new CO_2 utilisation ventures. Existing expertise and equipment allows for a quicker project implementation, bigger scale-up, and more value capture by being able to offer turnkey solutions.
- Government can administer sponsorship for new CO_2 utilisation ventures. This sponsorship may cover different forms, from R&D funding schemes, to dedicated knowledge transfer and infrastructure programmes.

Table 2-4: Overview of cross-linkage barriers and drivers

Category	Barrier	Driver
Location	Geographical location*	Incentives and des-incentives*
		Proximity to portfolio venture
		Possibilities for joint ventures
		Market existence for exit
Risk	Ownership	Asset ownership
		Risk/burden sharing
	World economics	Decentralised energy production
		Economic crisis
Promoter	Gatekeeper*	Identification and conviction*

* perceived main barrier reported

2.6.4 Cross-Barrier Relations and Comparisons

The study results do not only identify the internal, external and cross-linkage barriers of new CO_2 utilisation ventures, but also indicate the (perceived) relevance of the barrier categories. Cross-barrier relations were discovered first, by triangulating the reported barriers of new CO_2 utilisation ventures with the reported barriers of the four industry players (steel producer, utility, infrastructure provider, and chemical company). Second, by comparing two geographic location, representing two different institutional settings: Canada, the USA, and the EEA. Third, by considering ties between internal, external and cross-linkage barriers. Fourth, by having four categories of success factor (Song et al. 2008) ranked by the new CO_2 utilisation ventures. Lastly, by comparing the sample on an application class level.

Barriers in the categories customer, partner, technology, government, finance, infrastructure and strategy were reported the most by both new technology ventures and large incumbents. Whereas there was less reporting in the categories society, risk and knowledge and network. Differences were mainly in the categories investor and competitor, and promoter and team and management. The industry players reported more barriers in the first two categories, while the new ventures reported more in the latter two. Figure 2-4 gives a graphical overview of this data triangulation by plotting the relative reported barrier categories of the industry players against the relative reported barrier categories of new ventures.

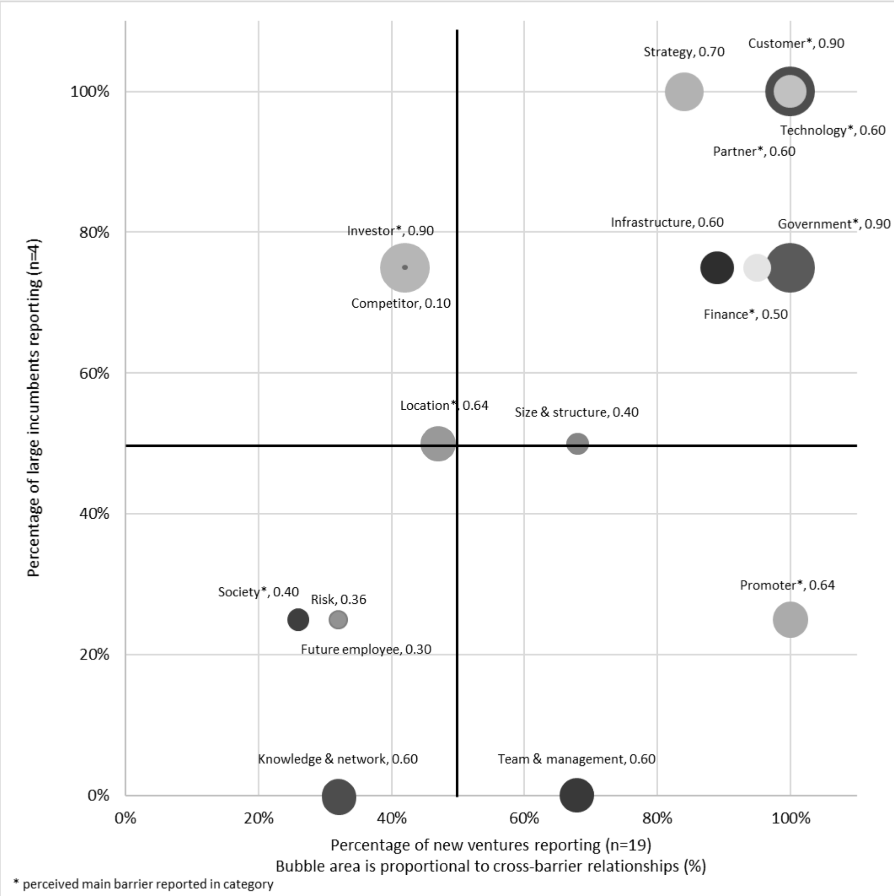

Figure 2-4: Reported barrier category matrix: new ventures vs incumbents

Comparing the two regions, the reported barrier categories are primarily similar. However, the categories risk and society were more often reported in the EAA and the categories team and management, investor, competitor, knowledge and network and future employee more often in Canada and the USA (cf. Figure 2-5). Figure 2-5 shows the relative reported barrier categories with regard to the two observed regions. Categories that are closer to the ordinate (EEA) than to the abscissa (Canada and the USA) indicate a higher importance/relevance in the EEA and vice versa. The closer a category is to the bisector, the less distinct its importance/relevance for one region is.

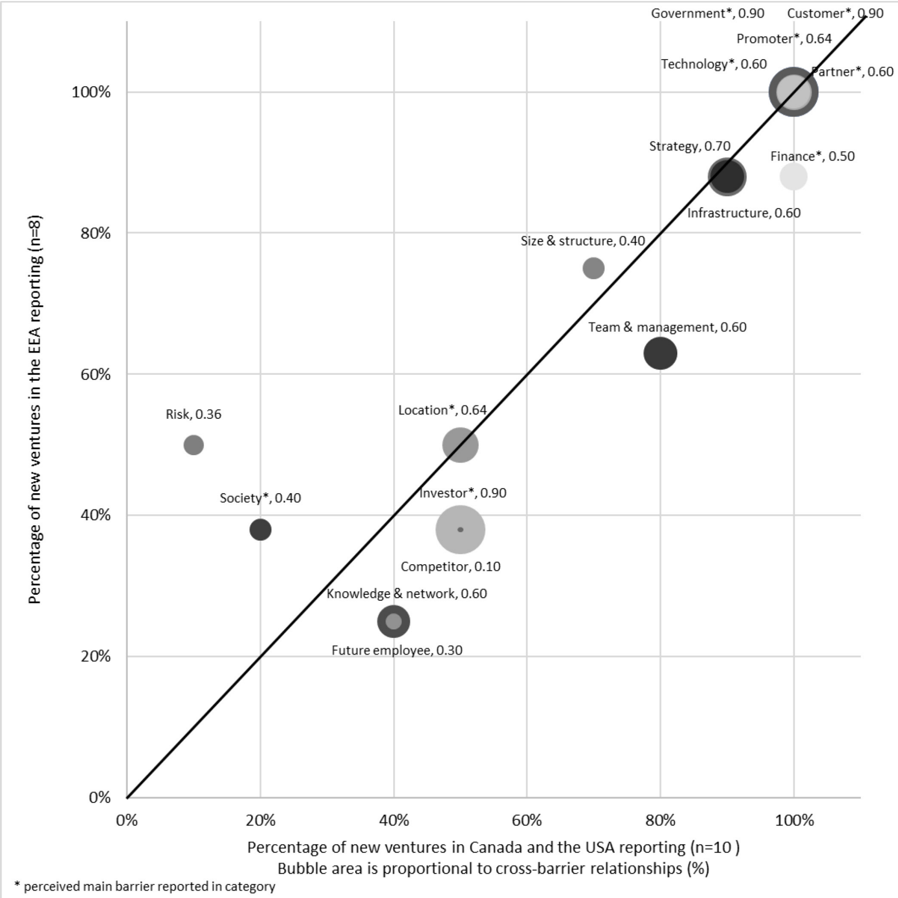

Figure 2-5: Reported barrier category matrix: Canada and the USA vs the EEA

The amount of cross-barrier relationships between the three main categories are also depicted in Figure 2-4 and Figure 2-5. The external categories customer, investor, government, partner; the internal categories strategy and all resource sub-categories; and the cross-linkage categories promoter and location have the most links with ties to more than 50% of the other main categories.

The emphasis on main barriers has been captured by coding terms such as “challenge”, “hurdle”, “issue”, “barrier” or “problematic” in combination with “main”, “biggest” or “most”. These perceived main barriers are in the categories partner, customer, investor, government, society, promoter, location, finance and technology (cf. Table 2-2, Table 2-3 and Table 2-4). Moreover, the perceived main barrier categories cover those barrier categories that have been reported by all new CO_2 utilisation ventures in the sample and include those barrier categories that have the most cross-barrier relationships (cf. Figure 2-4 and Figure 2-5). However, the perceived main barrier category society is only reported by the minority of new CO_2 utilisation ventures in the sample and have little relationships to other barrier categories.

Figure 2-6 reveals the ranking of success factor categories. Thus, market and opportunity are the highest ranked categories followed by team, resources, and strategic and organisational fit. The ranking slightly changes when breaking it down to the two geographic locations. For Canada and the USA the entrepreneurial opportunity is on the same rank as entrepreneurial team.

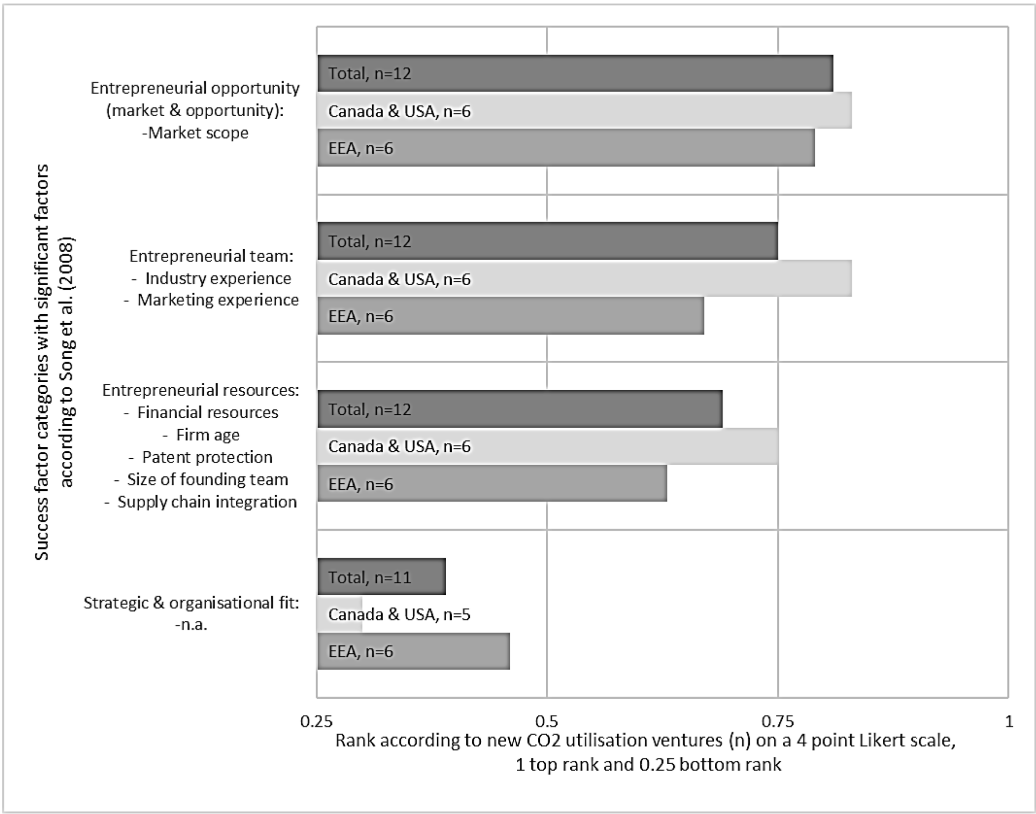

Figure 2-6: Success factor ranking according to Song et al. (2008)

Other comparisons can be made between the different application classes. For this matter the application class CO_2 to fuels was further broken down, when a new CO_2 utilisation venture aimed at technological outlets in CO_2 to fuels and CO_2 to chemicals. These ventures often pursue platform technologies that allow for the conversion of CO_2 to synthetic fuels and other more complex chemicals such as pharmaceuticals. Table 2-5 shows differences and relations of technology readiness level (TRL) and application classes. CO_2 mineralisation has the highest technological maturity, on average, followed by CO_2 to fuels, and CO_2 to chemicals.

Pursuing multiple application classes (CO_2 to fuels and CO_2 to chemicals) seem to impact the TRL. In most of these cases the venture has not decided on a business model or initial product yet. This is also depicted in the lowest averaged venture age of 4.8 years in this application class.

On average, the CO_2 mineralisation class has the highest TRL but less capital has been attracted and fewer employees are working in this field than in the CO_2 to fuels class.

Table 2-5: Overview of sample comparison

Application class	TRL of lead process (interview)	Capital attracted (in mUSD)	# employees	Venture age in 2015 (in years)	Years in company (average, if more than one interviewee; as of 2015)
CO_2 to chemicals	2-3	n.a.	4	3	3
CO_2 to chemicals	4-5*	n.a.	n.a.	4	0.5
CO_2 to chemicals	7-8*	50	30	11	2.5
Average CO_2 to chemicals	4-5	50	17	6	2
CO_2 mineralisation	3-4	n.a.	n.a.	5	5
CO_2 mineralisation	3-4	0.16	2	6	6
CO_2 mineralisation	6-8	5	10	3	3
CO_2 mineralisation	7	30	9	15	10
CO_2 mineralisation	7-8*	n.a.	n.a.	6	6
CO_2 mineralisation	8-9	130	75	10	5
CO_2 mineralisation	8-9*	n.a.	n.a.	7	7
Average CO_2 mineralisation	6-7	40	24	7.4	6
CO_2 to fuels	4-5	200	130	8	3
CO_2 to fuels	4-5	1.6	5	6	4
CO_2 to fuels	5	n.a.	12	4	4
CO_2 to fuels	5-6	20	14	13	13
CO_2 to fuels	9	12	20	6	6
Average CO_2 to fuels	5-6	58	36	7.4	6
CO_2 to fuels, CO_2 to chemicals	3-4	14	13	5	5
CO_2 to fuels, CO_2 to chemicals	4	5	7	1	1
CO_2 to fuels, CO_2 to chemicals	5	1	5	6	6
CO_2 to fuels, CO_2 to chemicals	5-6	200	140	10	10
CO_2 to fuels, CO_2 to chemicals	5-6	n.a.	10	2	2
Average CO_2 to fuels, CO_2 to chemicals	4-5	55	35	4.8	3.6
Average CO_2 to fuels+	5-6	57	36	6.1	4.8
Average total	**4-5**	**53**	**30.4**	**6.55**	**4.8**
Standard deviation (of the sample)	**n.a.**	**74.3**	**44.4**	**3.7**	**2.9**

*retained from third party information

Overall, the evaluation via various comparisons of the observed barrier phenomena remains challenging because of the qualitative nature of this study. However, the results at least indicate different levels of relevance. Figure 2-4,5,6 and Table 2-5 thereby provide an effective way to highlight these indications.

2.7 **Discussion**

For all the identified barrier categories, the interviewees provided several barriers and drivers. However, some categories have been reported more frequently than others and may be contextualised with Song et al.'s (2008) ranking:

Song et al.'s (ibid.) market and opportunity factors are mainly determined by the external environment of new CO_2 utilisation ventures. Hence, the proportion of reported barriers in the external categories as well as the emphasis on them are consistent and indicate the relevance of these categories. Song et al.'s interpretation of entrepreneurial team is best reflected in the internal barrier categories of team and management and knowledge and networks. Both seem especially relevant in Canada and the USA (cf. Figure 2-4). This fact is also being backed by the higher ranking of entrepreneurial team in this region (cf. Figure 2-6). Although, the resource-related categories cannot be clearly distinct from Song et al.'s entrepreneurial resources: Whereas factors such as financial resources are clearly related to the financial barrier category, patent protection and supply chain integration are more related to the strategy category. However, both internal categories (finance and strategy) seem to be of high relevance as well as technology and infrastructure. The less prominently ranked strategic and organisational fit would be best connected to the internal size and structure category. Even though cross-linkage barriers cannot be clearly related to Song et al.'s success factors, location and promoter seem to play a mediating role.

A support system in the context of entrepreneurship is defined as a system that "[…] comprises all actors, institutional settings and resources that help entrepreneurs in innovating successfully" (Fichter et al. 2016, p. 5).

The barriers of new CO_2 utilisation ventures relate to their stakeholders or actors (perceived main categories: partner, customer, and investor), their internal organisation including resources (perceived main categories: finance, strategies, and technology), categories) specific contextual settings such as institutional settings (perceived main categories: government and society) and relational settings (perceived main categories: promoter and location). Hence, the concept of a coordinated, dedicated support systems could be applied to provide effective leverage for a sustainability transformation of industries (Fichter et al. 2013).

2.7.1 Capital-Intensity: Collaboration, Compliance and Alignment (Actors)

The capital intensity is paramount in CO_2 utilisation technologies. New CO_2 utilisation ventures need to proof their technology in costly demonstrators and pilot plants. Shared infrastructure and cost-efficient business models have been recognised to be of help in overcoming capital challenges for these kind of technologies (Cleantech Incubation Europe – CIE 2014). New CO_2 utilisation ventures that invest primarily in people and not in bricks may be better able to adapt an organisational structure that comply with conventional requirements of institutional investor such as investment volumes.

Furthermore, there is a need for an immediate collaboration to enhance knowledge transfer and facilitate learning for new CO_2 utilisation ventures. Regional collaborative alliances with multiple stakeholder alongside the CO_2 value chain from CO_2 emission, capture, and utilisation to the consumption of CO_2-based products are wanted. Entire partnership systems could bring together (local) stakeholder to create specific business opportunities for CO_2 utilisation.

However, new CO_2 utilisation ventures also seem to lack the effective coordination of these approaches. Intermediating third parties (cf. van Lente et al. 2003; Altenburg and Pegels 2012; Kivimaa 2014) could ensure motivational and strategic alignment of different partners and coordinate the collaboration. Furthermore, these parties could help to overcome the (causality) dilemma where both, potential off-taker and investor, require a proof-of-concept and existing contracts by mediating between the different actors.

2.7.2 Disruptive Nature of Radical CO_2 Utilisation Innovation: Product Performance and Staged Project Approaches (Resources)

New CO_2 utilisation ventures face challenges when approaching conservative industries with radical solutions. The potentially disruptive nature of these solutions (Christensen 1997) may be the reason for a restraining behaviour of customers, investors, and other partners (cf. Gauthier and Gilomen 2016).

Large incumbents do not only hesitate when developing sustainability-oriented solutions themselves (cf. Ihlen and Roper 2014), but also are often reluctant to establish new facilities for a CO_2-based production. Building-up a new production can be disruptive for established companies, whereas retrofitting an existing production line is rather sustaining for them.

These different innovation natures may also be represented in the sample: An application class with a higher TRL and, at the same time, fewer capital attracted than another class could indicate that, e.g., capital efficient retrofitting approaches are more prominent in the first class (cf. Table 2-5: CO_2 mineralisation vs CO_2 to fuels). However, differences in TRL, attracted capital and number of employees could also be explained by different technology requirements (e.g., exothermic vs endothermic) or market conditions (e.g., resource availability).

Beside the disruptive or sustaining nature, the degree of the sustainability-orientation of an innovation seem to influence the commercial success of new CO_2 utilisation ventures. Hockerts and Wüstenhagen (2010) identified two dimensions of entrepreneurial activity that can lead to a sustainability transition of an industry: environmental and social performance, and market share. Hörisch (2015) builds on these dimensions and argues that sustainability-oriented new technology ventures need to master a coordinated interplay between sustainability effect and market impact to meaningfully contribute to sustainability transitions.

However, the findings of this study show that these dimensions tend to have a negative effect upon each other. An optimum CO_2 reduction is often not economically viable and market impact is achieved at the expense of the sustainability effect.

Consequently, new CO_2 utilisation ventures need to initially focus on the product's performance (economic value creation) rather than on its sole sustainability aspect (ecological and social value creation) to successfully commercialise their products in competitive mass markets. This focus may diminish the strong sustainability-orientation by emphasising innovation which does not have sustainability as a primary target, but even products or materials with very high sustainability effect could be positioned as more durable, robust or cheaper (cf. Driessen et al. 2013) to attain greater market impact.

Nevertheless, staged approaches such as a staged market entry strategy (cf. Clay 2013) could help to target niche markets with a high sustainability effect and move towards mass markets with increased economies of scale and knowledge about industry requirements. Trade-offs between sustainability dimensions may thereby be avoided.

However, some technologies cannot be economically viable on a niche-market scale. That is why an early application focus in consideration of the market circumstances is crucial. Platform technologies with various application options might help to diversify and dynamically adapt to new market developments, but the choice often overburdens new CO_2 utilisation ventures. Staged project strategies can help to generate initial revenue and get a better understanding of customers by starting with advisory projects on a potential CO_2 utilisation implementation.

2.7.3 Dependencies, Policy Interventions, and Public Perception: Dedicated Long-Term Support and Marketing Strategies (Institutional Settings)

The acknowledgement of regulatory systems and institutional settings are essential for CO_2 utilisation and shape support systems for entrepreneurship (Fichter et al. 2013). In this work two geographic regions with different institutional settings have been looked at: Canada and the USA and the EEA. However, there were more similarities than differences. Whereas risk averseness and societal acceptance seemed to play a bigger role in the EEA, institutional investors, human capital and knowledge transfer seemed to be more prominent in Canada and the USA.

The public perception of CO_2 utilisation influences new technology ventures. Even though only the minority of the new CO_2 utilisation ventures reported barriers in the society category, social acceptance has been recognised as a necessity for a successful commercialisation of SOI such as CO_2 utilisation (Jones et al. 2017). Dedicated marketing strategies enable these ventures to counteract the misperception of CO_2 utilisation, especially in the EEA (cf. van Heek et al. 2017).

Policy interventions and regulatory pressure might be another way to overcome barriers (Kneller and Manderson 2012; Brunnermeier and Cohen 2003; Jaffe and Palmer 1997; Parker et al. 2009), but represent dependency on rather short-term mechanism. Interventions such as feed-in tariffs for renewable energy technologies affect institutional investors in clean technologies (Bürer and Wüstenhagen 2009; Ghosh and Nanda 2010). Due to the larger number of private investments in the clean technology sector in Canada and the USA than in the EEA, a different importance of institutional investors might be attributed to the two institutional settings.

CO_2-based products can substitute fossil-based products, however, the technologies for the substitution are often not yet economically viable without evolving production systems or new regulations (Bocken et al. 2014). Some of these CO_2 utilisation technologies currently need excess energy from renewable energy production. This dependency of current inefficiencies in the distribution systems of renewable energies can lead to a shorten vision as interim solutions. However, clear responsibilities within existing regulatory frameworks and less complexity could already reduce barriers regardless of the institutional setting and the time horizon.

2.7.4 Cross-Linkage Barriers: Tailor-Made Solutions and Local Facilitation (Coordination)

The cross-linkage barrier categories of promoter and location especially stress the relevance of context and mediation for new CO_2 utilisation ventures.

Not only proximity aspects when dealing with external stakeholders (for partnerships: cf. Hansen 2014; for investments: cf. Knight 2012) and location-dependent (des-)incentives, but also the technological diversity within CO_2 utilisation call for a dynamic adoption to the specific needs of a new CO_2 utilisation venture. Hence, tailored support solutions for individual technological and geographic context are needed (see also Fichter et al. 2016).

The promoter model is a recognised concept to overcome innovation barriers (Gemünden et al. 2007). In this work, gatekeepers are key people in any commercialisation process of an external organisation whereas promoters are key to drive a specific innovation on different levels (Hauschildt and Schewe 2000).

With regard to the four person promotor model (Gemünden et al. 2007), the identified promotors in CO_2 utilisation are mainly power and expert promoters. Process and relationship promoters remain mainly unidentified or are missing. This is especially reflected in the challenge to identify and engage with gatekeepers outside the new CO_2 utilisation venture's organisation.

An intermediating third party could step in to facilitate the matching process and act as relationship promoter (ibid.).

2.7.5 Limitations and Future Research

The population size was determined by the fact that CO_2 utilisation is a relatively new and emerging field. The population of new CO_2 utilisation ventures was identified with little under 50 worldwide and the companies within the sample are on average 6.5 years old (cf. Table 2-5). The sample size made a full comparison of the application classes challenging and led to a lack of contrasting juxtaposition within the classes.

Additionally, comparisons between different conversion processes such as catalysis, artificial photosynthesis, photo-catalysis, and electrochemical reduction (cf. Styring and Jansen 2011) for the same product and different sustainable business models such as create value from waste or substitute with renewables and natural processes (cf. Bocken et al. 2014) are missing.

Comparisons of top management and operating staff within a single new CO_2 utilisation venture to view the phenomena from different perspectives (Eisenhardt and Graebner 2007) were rarely performed, because of the limited amount of knowledgeable people (cf. Palinkas et al. 2015) for this study. From the 23 interviewees, nine had not been with the company since its start, accounting for an average of being 4.8 years with the venture (cf.Table 2-5). Therefore, internal barriers have been aggregated to the organisational level only.

Although theoretical saturation was reached in the course of this analysis, future research should look at sustainability-oriented organisations in their growth phase in-depth to identify differences in the individual, group and organisational level (cf. Hueske and Guenther 2015). Such an in-depth analysis could also enrich data on the social dimension of sustainability, that is currently underrepresented due to the predominant focus on the technology development of most of the investigated new technology ventures.

In addition, quantitative comparisons could shed light on the differences in location and output- and process-based categorisations of new CO_2 utilisation ventures and longitudinal studies on sustainability-oriented ventures could contribute to a better understanding of success and failure factors of strong sustainability-oriented new technology ventures.

Furthermore, case studies on system intermediaries for the sustainability transition and their role in supporting these new ventures could help to further shape effective support mechanism.

2.8 **Conclusion**

2.8.1 Theoretical Implications

This work brings together SE, sustainability transition and barriers to successful commercialise radical SOI. These radical SOI show increased complexity when compared to conventional innovation. Multi-dimensional (economic, environment, and social) focal points such as the coordinated interplay of sustainability effect and market impact (cf. Hörisch 2015) or the problem of 'double externalities' (cf. Beise and Rennings 2005) and an extended external orientation towards more diverse stakeholders (including society or partnership ecosystems), e.g., to overcome resource constraints, to bring novel technology to the market or to share risks (cf. Jay and Gerard 2015) differentiate the commercialisation process of strong sustainability-oriented new technology ventures from conventional new technology ventures. Hence, this study supports the notion of describing radical SOI processes by adding sustainability-specific characteristics to conventional innovation processes (Driessen et al. 2013; Jay and Gerard 2015; cf. Walker et al. 2008).

An internal and external barrier framework (Hueske and Guenther 2015) has been applied and further developed for strong sustainability-oriented new technology ventures based on a qualitative interview study with 24 new ventures and large incumbents in CO_2 utilisation. A new cross-linkage barrier category has been added to the main barrier categories to highlight the relevance of connections between internal and external barriers. This category contributes to a better understanding of the importance of context for strong SOI such as CO_2 utilisation.

Stakeholder synergies and the creation of shared values (cf. Tantalo and Priem 2016) are experienced throughout the barrier analysis but especially in the partner category where entire stakeholder ecosystems drive the successful commercialisation of CO_2 utilisation. Hence, stakeholder synergies (Tantalo and Priem 2016) rather than stakeholder theory (Freeman et al. 2007; Freeman et al. 2010) could be supported by strong sustainability-oriented new technology ventures for external barriers.

Value-creating strategies through collaboration also occur internally with external interactions (Eisenhardt and Martin 2000). Organisational learning (cf. Teece et al. 1997) is represented foremost as driver in expertise gain in the knowledge and network category. Thus, dynamic capabilities seem appropriate for internal barriers of strong sustainability-oriented new technology ventures.

Both, synergies and learnings can be facilitated by cross-linking promoters that can reveal gatekeepers and mediate between stakeholder groups (cf. Hauschildt and Schewe 2000). In combination with the proximity dimension (Hansen 2014; Knight 2012) these intermediaries can lay the groundwork for local new venture support systems paving the way for multi-level perspectives on the entire system of strong SOI such as CO_2 utilisation (c.f. Geels 2011).

2.8.2 Strategies and Recommendation

Recommendations for a dedicated support system are derived from a commercial barrier analysis of new CO_2 utilisation ventures in the institutional settings of Canada and the USA, and the EEA. There are four levels of recommendations for strong sustainability-oriented new technology ventures, policy makers, and support providers: on a) actors, b) the resources, c) the institutional settings, and d) the coordination of a support system.

a. Strong sustainability-oriented new technology ventures and other actors from the entire value adding path of CO_2 utilisation (e.g., from CO_2 and energy supplier, R&D and upscaling partners to off-taker/customers) should take part in partnership ecosystems that are aligned and facilitated by intermediating third parties to exploit synergies such as increased value capture and knowledge transfer. Policy makers can encourage these ecosystems by providing necessary resources and means to pursue fruitful collaborations.
b. Strong sustainability-oriented new technology ventures should foster their focus on the CO_2-based product's performance, for example, by managing platform technologies and facilitate staged project approaches such as staged market entry strategies.
c. Policy makers should pursue in sponsorship for CO_2 utilisation such as regulatory frameworks with clear responsibilities and little complexity, for example, to ease access to funding opportunities and encourage internationalisation for strong sustainability-oriented new technology ventures.
d. Intermediaries should coordinate support systems, for example, to identify gatekeepers, spark collaboration by aligning strategies and motivations and enable support providers to tailor support solutions to the specific needs of a new CO_2 utilisation venture in a given environment.

2.9 **Author Contribution**

MK: main/single author, main contribution to the conception and execution of the work.

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2.12 **Conflict of Interest Statement**

The author declares that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.

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2.14 **Appendix (unpublished)**

2.14.1 Excerpt from Semi-Structured Interview Guide for New Ventures

1. Participant (organisation):
    a. Revenue/Capital attracted: _______ Mio EUR/USD
    b. Describe the kind of investors invested in your organisation. Why did they invest?
    c. Number of employees
2. Participant (person):
    a. Education
    b. Number of years working in CO_2 utilisation or a field related to CO_2 utilisation
    c. Have you been involved in the progress of focussing on CO_2 utilisation?
3. What have you (organisation) done in terms of CO_2 utilisation?
    a. Nature of the CO_2 utilisation technology (process, product, etc.)
    b. Level of success (Published? Patented? Implemented? Profitable?)
    c. Point of innovation (Basic research, R&D, manufacturing, etc.)
    d. Which TRL would describe your organisation best?
    e. Which projects/approaches have been most successful (or problematic)- if multiple experiences
4. Why did you do it?
    a. Internal/external demand
    b. Existence of champions
5. Who did it?
    a. Champions/Promoters, internal and external networks
    b. Most essential person(s)
    c. How did you (and/or) they become aware of CO_2 utilisation?
6. Were there any partnerships involved?
    a. Industrial groups
    b. Government
    c. NGO's, Public Sector
    d. External and internal networks (formal, informal)
7. Are there government policies (national and/or local) that have encouraged the development of this project?
8. What challenges did you encounter and how did you overcome these challenges?
    a. Economic problems
    b. Funding/financial problems
    c. Regulatory challenges
    d. Technical difficulties
    e. Organisation/Firm specific
    f. Differences in culture
    g. Market/Sector/Industry specific
        i. How did you assess and select your market for your product?
    h. Implementation/infrastructure
        i. Do you need highly specialised plants/facilities (high pressure, etc.)?
        ii. Can you fall back on existing infrastructures/standard components?
    i. Customer
        i. At what point in your development did you ask for the customers' feedback?
        ii. How did you approach the customer? What product/intermediate did you show case? What quantity/quality was required by the potential customer?
        iii. How was the feedback of the customer incorporated in the further development?
        iv. How did/do you access the ecological value? Are they willing to pay a premium?
    j. Did you have experience any challenges from your position in the value chain? Explain your business model.
    k. Other?
9. What were the surprises?
    a. What do you wish you'd known at the beginning?
    b. Characteristics of success (please rank)
        i. Market and opportunity: New product/service introduced and sold at greater price than production cost (opportunity dimension, market and environmental characteristics

   ii. Entrepreneurial Team: Management Team: Industry and marketing experience
   iii. Resources: Financial, IP, partnership & network, institutional characteristics
   iv. Strategic and organizational fit: competitive strategy, structure, processes, systems

10. What changes would improve it (make it easier to research/ innovate/implement CO_2 utilisation)?
11. What do you see as the future of CO_2 utilisation in Europe/America?
12. Questions, feedback of the interviewee?

Article 2

Strategies to Bridge the Valley of Death!? How to Improve the Risk-Return Ratio of Hardware-, Material- or Chemical-Based, Early-Stage Cleantech Venture Investments

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3 ARTICLE 2
Strategies to Bridge the Valley of Death!? How to Improve the Risk-Return Ratio of Hardware-, Material- or Chemical-Based, Early-Stage Cleantech Venture Investments

3.1 Abstract

This article identifies, compares and evaluates strategies that help early-stage, radical cleantech ventures bridge the "valley of death" between basic research and commercialization. A problem is that these types of venture often have a poor risk-return ratio. Thus, private venture capital investments in cleantech ventures have almost completely dried up, have moved to later, less risky investment stages or have moved to less capital-demanding software ventures. This problem is important because cleantech ventures (including hardware-, material- and chemical-based) are suggested to play a critical role in reducing negative externalities, i.e., environmental and social costs that have detrimental consequences to our society and our planet. These ventures thereby contribute to meeting the goals of global agendas such as the Sustainable Development Goals. The authors show why and how strategies improving the risk-return ratio can help to enable more investments in these types of venture. The risk-return theorem from finance theory serves as a theoretical framework. With a mixed-methods approach, the authors analyse investment decisions from 45 of the most prominent, early-stage cleantech investors and venture-investing experts in the EU and the USA with the aim of extracting strategies and of identifying their relative potential to de-risk and increase the return of radical, clean-technology venture investments. The authors [I] first develop a framework of 27 strategies in four archetypes that allow lowering risk and increasing return. [II] Second, we identify the stakeholders involved for a successful use of these strategies. [III] Third, we provide a first indication of their potential effect on future investment decisions. [IV] Fourth, we cluster the strategies to derive five areas of recommendation for the implementation of these strategies. The article's contribution to theory is the conceptual development of strategies, labelled "risk-return framework for radical cleantech" by the authors, that can serve as a basis for future research, and a consolidation of strategies across different research streams. The main contribution to practice is a "hands on overview" of how, with whom, and with what relative potential these strategies can be implemented.

3.2 Introduction

The topic of this research is the transition towards a sustainable society (Markard et al. 2012), with a focus on the role of radical clean technology (cleantech) ventures and how they are financed by risk capital or public money (Samila and Sorenson 2010; Bergset 2015; Bocken 2015; Nanda and Rhodes-Kropf 2017; Bidmon and Knab 2018).

The purpose of this article is to identify means of driving additional private investment into radical clean technology ventures to facilitate their formation and growth. This identification will be done by identifying, comparing and evaluating strategies that help to improve the risk-return ratio of cleantech venture investments (Knight 1921; Cochrane 2005; Guo and Whitelaw 2006). These strategies can help to increase investment volume and thus increase the likelihood of clean technologies bridging the "valley of death" between basic research and commercialization (Murphy and Edwards 2003; Markham et al. 2010; Jenkins and Mansur 2011). The focus of this research article will be explicitly on strategies enabling investments in early-stage hardware-, material- or chemical-based innovations. These types of ventures often share a particularly high risk and high capital demand, but they provide the highest potential

for the radical solutions that are needed for the transition towards sustainable production and consumption systems (Hockerts and Wüstenhagen 2010; Bidmon and Knab 2018).
Given the potential important role of cleantech ventures and the increased public attention on these investments, that cleantech investments started to decline in 2011 is counterintuitive (see Figure 3-1), and investments in early-stage ventures, particularly hardware-, material- or chemical-based, have almost completely dried up since 2008 in the USA (Gaddy et al. 2017). Even after slight increases in 2011, 2013 and 2015, early-stage venture capital (VC) investments levelled on average at approximately 40% below the investment level of 2008 (see Figure 3-1). One key argument is that cleantech ventures in general have shown a poor risk-return ratio. In addition, within the cleantech investment classes, the risk-return ratio is particularly poor for hardware-, material- and chemical-based innovations compared with other investment opportunities in the cleantech space, such as software-based cleantech (Gaddy et al. 2017; Marra et al. 2015).

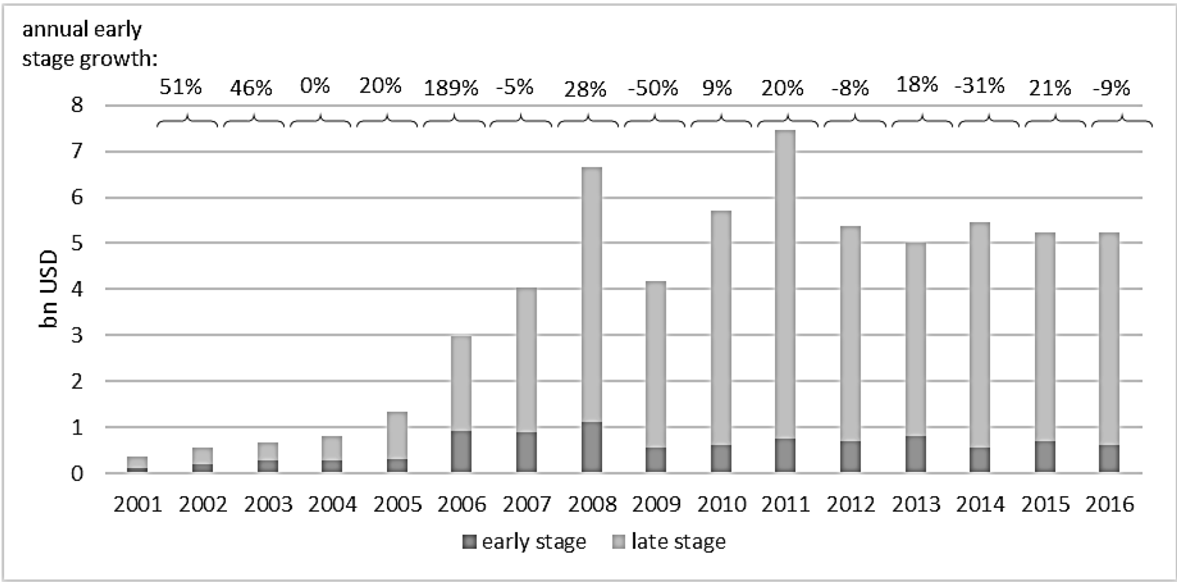

Figure 3-1: Total cleantech VC investment in the USA (adapted from Saha and Muro 2017; based on Brookings analysis of Cleantech Group's i3 Connect database)

The poor risk-return ratio and the low investment volume in cleantech ventures constitute an important problem because VC investors have been proven to play an important role in the commercialization of innovations via risk capital (cf. Wüstenhagen and Teppo 2006) – but do not appear to fulfil this role in the cleantech investment class. Not surprisingly, previous research has studied this problem from several angles.
A helpful research stream is VC investors' decision criteria in general (Hall and Hofer 1993; Macmillan et al. 1985). In the field of cleantech investments, strategies aiming at attracting investments to cleantech ventures can be clustered in three categories: [a] the effects of national and international policies, which often focus on clean energy (Bürer and Wüstenhagen 2008, 2009; Criscuolo and Menon 2015; Dinica 2006). They further include [b] national and regional-level structural enablers and barriers (geography, innovation clusters, innovation intermediaries, industry and location) in promoting cleantech financing (Chapple et al. 2010; Knight 2010; Chen et al. 2010; Polzin et al. 2016). Finally, [c] studies have analysed investors' individual differences, such as motivations and attitudes (Wüstenhagen and Teppo 2006; Parris and Demirel 2010; Marcus et al. 2013; Hoenig and Henkel 2015; Wang et al. 2015; Bocken 2015).
The above-mentioned research streams have greatly contributed to our understanding of how VC investors make investment decisions and of which strategies could help to attract more

investment to cleantech ventures. Important questions however remain: [i] How do all of these different strategies relate to each other, and how can they be conceptualized in a clear theoretical conceptual model? [ii] Where and when must different actors identified within and across these research streams act together to enable these strategies? [iii] What is the relative potential of strategies influencing the risk-return perceptions of investors who might consider investment in early, radical cleantech ventures? [iv] Are there strategies that are particularly useful in the area of radical cleantech investments, compared with traditional VC investments? In the theoretical foundation, we will show why we cannot currently answer these questions. In summary, we currently lack [1] a more systematic view of these interrelated strategies, [2] an explicit focus on the subcategory of early-stage, hardware-, material- and chemical-based ventures, and [3] a framework that allows for an assessment of the relative effectiveness of these strategies. Consequently, this research focusses on the underlying research question:

Q: What strategies can improve or have successfully improved the risk-return ratio of early-stage hardware-, material- or chemical-based clean technology venture investments? What is their potential effect and who are the players involved in their implementation?

3.3 **Theoretical Foundation**

3.3.1 Research Object – Cleantech Venture Investments

With the term "cleantech venture investments", we refer to investments in new organizations that attempt to bring cleantech from the idea stage to commercialization. To arrive at the stage of commercialization, these new ventures typically rely on public and private funding that is usually provided by a mix of government support programs, angel investors, VC firms and private equity firms. Cleantech venture investments tend to be very capital intensive and face greater technology risks (Cumming et al. 2016).

3.3.1.1 Cleantech, Resource Efficiency and Relative vs Absolute Improvements

Different definitions of the term cleantech exist, and no dominant definition has emerged (Caprotti 2012). Definitions of cleantech often include the common criterion of whether technologies contribute to resource efficiency and resource conservation (Kuehr 2007; Tierney 2011). A differentiation is occasionally made between "cleaner" and "clean" technologies (Kuehr 2007; Markusson 2011). Whereas "clean" describes a technology contributing to services or products that do not have any negative externality (i.e., no negative consequences for individuals, our environment or our planet more generally), "cleaner" technology refers to relative improvement compared with the status quo.

From a practitioner perspective, the "cleantech group" uses equally the previously mentioned relative resource efficiency criterion in its definition. The group includes in its analyses and industry reports "companies whose innovations realize economic value from doing *more with less*, in which one aspect of the *less* is a reduction in environmental impact and/or resource usage[9]".

Considering the fact that relative resource efficiency improvements can be offset by rebound effects (Freire-González 2017 Greening et al. 2000), this research aims to contribute to finding absolute rather than relative improvements (see also Sterman 2018). In practice, this hard target of absolute resource conservation and absolute reductions in emissions (even considering increased production and consumption resulting from the new product/service) is rarely met. It can only be met if overall production and consumption decreases or rises less than does the rebound effect. One key variable is whether the improvement is radical rather than incremental. Facilitating the commercialization of radical cleantech innovations is one of the main purposes

[9] www.cleantechgroup.com/coverage/overview, accessed June 20, 2018

of this research. Consequently, we define our research object as "investments in *new ventures, developing products and services that strive to have no negative environmental externalities, total use of inputs and full efficiency*" (Kuehr 2007 adapted from International Centre of Environmental Technology Transfer).

3.3.1.2 Focus on Hardware-, Material- or Chemical-Based Cleantech Venture Investments

Within the investment category of cleantech, this research focusses on the subcategory of hardware-, material- or chemical-based cleantech venture investments because these ventures are suggested to play an important role in our transition to a more sustainable society (see Section 3.3.2). Despite their high potential, hardware-, material- or chemical-based cleantech ventures are the ones receiving the least amount of investment (see Figure 1) due to their particularly high risk and capital intensity. In practice, the combination of radical, early-stage and cleantech are often supported by government programs, such as in the USA by the Department of Energy (DoE) Advanced Research Projects Agency – Energy (ARPA-E) or by the National Science Foundation Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR). Radical, early-stage cleantech ventures might also have backing from large corporations or well-known accelerators and incubators such as, e.g., the Greentown Labs, which has space for over 100 cleantech ventures and specializes in hardware-based cleantech ventures[10]. VC investments should however play an important role in this process, a role that is not currently filled (see Figure 3-1).

3.3.2 Importance of Radical Cleantech Venture Investments in the Transition towards a Sustainable Society

3.3.2.1 Unsustainable Civilization and Planetary Boundaries

The (almost complete) drying up of early-stage investments in hardware-, material- and chemical-based clean technology ventures creates an important problem because these types of ventures (if their technologies are successfully commercialized) are a powerful driver to fight detrimental externalities (societal or environmental costs) such as CO_2 emissions, (Coase 2013; Pigou 1960). Such externalities are often part of our existing production and consumption systems and contribute to an unsustainable civilization (Sterman 2012). Research on our planetary boundaries is concerned with the excessive use of our planetary resources and suggests that three of nine central boundaries have already been crossed (Rockström et al. 2009).

3.3.2.2 Transition Theory towards a Sustainable Society – A Call for Radical Solutions

Consequently, sustainability is receiving increasing attention (Sterman 2012). The field of transition research has as an underlying research question, how can we achieve the transition to a sustainable society (Geels 2011; Markard et al. 2012). Technology is one of many important levers for a transition to a more sustainable society (Sterman 2012). Research further suggests that a strong sustainability impact requires more radical changes (Roome 2012).

However, socio-technical systems undergo incremental rather than radical changes, which are not sufficient to address societal challenges (Markard et al. 2012). Thus, there is a shift in research from the role of generic technologies towards specific technologies (Hekkert et al. 2007), with greater attention to radical innovation (Markard et al. 2012). These radical innovation tend to have a greater effect on the environment than do their incremental counterparts because they commercialize entirely new products or processes with a (relatively) better environmental performance (cf. Hellström 2007; Slocum 2008). Incremental innovation, on the other hand, merely enhance eco-efficiencies of existing products and processes (cf.

[10] https://www.greentownlabs.com/, accessed June 28, 2018

Hellström 2007). The so called multi-level perspective (MLP) even defines a niche (which in our setting could be referred to new technology developments in hardware-, material- and chemical-based innovations) as "locus for radical innovation" (Geels 2011, p. 26). Hardware-, material- and chemical-based innovation meet the definition of radical innovation as they largely embody substantial changes at the product or process level. In contrast, we assign incremental efficiency improvements to primarily software-based innovation. Thus, in the context of sustainability-oriented innovation, radical cleantech and hardware-, material- and chemical-based cleantech are used interchangeably in this article.

3.3.2.3 Paris Agreement – Helping to "Drive" Capital to Cleantech

The importance of reducing externalities such as CO_2 emissions is also reflected in the 2015 Paris Agreement, in which 195 countries decided to reduce their carbon output 'as soon as possible', allocating 100 bn USD to financing climate change adaptation and mitigation measures every year by 2020 (UNFCCC 2015). Additionally, the Group of 7 called for the de-carbonization of the global economy until 2100 (G7 Germany 2015). It is thus of vital importance to ensure that capital allocation is effective and going to the "right places". In other words, it is particularly important to close the current gap in funding for more radical cleantech innovations.
Combining [i] the urgency of the problem with [ii] the potential that hardware-, material- and chemical innovations in particular provide for a quicker (because more radical) transition to a sustainable society and [iii] the expected higher capital supply indicates that we must channel a sufficient amount of capital towards the more radical technology innovations, particularly from VC investors, because they usually provide financing in the stages that are most relevant for determining a venture's future success.

3.3.3 Investment Decision Making – Barriers and Drivers for VC Investments

The underlying reasoning of this article is that if cleantech investors' decision-making criteria are known, it is possible to design strategies that positively influence their decision making. This causal logic has been shared in previous research studies (see e.g., Adam and Shauki 2014; Hall and Hofer 1993; Shepherd et al. 2000).

3.3.3.1 Decision Making is a Multi-Staged Process

The decision making of VC investors received significant and continuous attention from research in the past 40 years (Audretsch et al. 2012; Hall and Hofer 1993; Macmillan et al. 1985; Masini and Menichetti 2012; Tyebjee and Bruno 1984, Woike et al. 2015; Zacharakis and Meyer 2000). Concerning the decision process, Hall and Hofer (1993) showed in a comparative literature analysis and empirical study that investment decisions are being made via a multi-staged process (including deal identification, deal screening and venture valuation), and that decision criteria differ according to the stage of the evaluation process. Woike et al. (2015) categorize existing studies on VC investor decision making into two stages: a) the venture selection process and b) the deal evaluation process.

3.3.3.2 Venture Investment Criteria as Foundation for Investment Decision Making

Hall and Hofer (1993) clustered investment decision criteria in the categories [i] VC firm requirements, [ii] characteristics of the entrepreneur/team, [iii] nature of the proposed business, [iv] strategy of the proposed business and [v] economic environment of the proposed industry (see Table 3-1). This categorization is particularly useful for our setting because it shows that VC investment decisions depend not only on the investment object (ventures), but also upon the interplay between the ventures, the VC firm and the economic environment. Therefore, strategy recommendations intending to "influence" venture investments should consider all three of these categories.

Table 3-1: Previously suggested decision criteria for venture investment decisions (adapted from Hall and Hofer 1993)

Level	Categories	Investment decision criteria (barriers and drivers)
VC	[i] VC Firm requirements	a.) cash-out potential; b.) equity share; c.) familiarity with technology, product, market; d.) financial provisions for investors, e.) geographic location f.) investor control, g.) investor group, h.) rate of return, i.) risk, j.) size of investment, k.) stage of development
Venture	[ii] Characteristics of the entrepreneur/team	l.) ability to evaluate risk; m.) articulate re: venture; n.) background/experience; o.) capable of sustained effort; p.) managerial capabilities; q.) management commitment; r.) references; s.) stake in firm;
Venture	[iii] Nature of proposed business	t.) product/market considerations
Venture	[iv] Strategy of proposed business	y.) product differentiation; z.) proprietary product
Economic environment	[v] Economic environment of proposed industry	u.) market attractiveness; v.) potential size; w.) technology; x.) threat resistance

Subsequent research has brought a better understanding into many of these investment decision criteria. For example, patents (see criterion z. in Table 3-1) have been suggested as influencing investor decision making only when coupled with a prototype to indicate feasibility (Audretsch et al. 2012). Trademarks (see criterion z. in Table 3-1) have been shown to have an inverted u-shaped relationship with new-venture valuations, initially rising in importance but loosing relevancy in later funding rounds (Block et al. 2014).

Since the categorization of Hall and Hofer (1993) represented in Table 3-1, scholars have suggested new categories of investment decision criteria and added new investment decision criteria (see, e.g., Kollmann and Kuckertz 2010; Mason and Stark 2004; Zacharakis and Meyer 1998). There is, however, a very high degree of overlap between these categories and investment decision criteria. Differences arise largely from the exact stage of the VC investment decision-making process that the research is examining (initial business plan screening vs valuation of a venture), the categorization used (e.g., 5 vs 6 categories), or occasionally even the wording.

3.3.3.3 Investment Decision Criteria are "Cues" that are used to Determine a Perceived Risk-Return Ratio

The fact that these criteria are never 100% the same might be explained by not only contextual factors (stage of decision process, geographic differences, or industry differences) but also the fact that investors do not use exactly the same investment decision criteria, even for the same investment opportunity (Shepherd 1999; Woike et al. 2015). Additionally, VC investors use different forecasting and decision-making tools and strategies (Shepherd and Zacharakis 1999; Woike et al. 2015). The underlying commonality is, however, that there is a set of frequently shared investment criteria, and these criteria are ultimately used to develop the investors' perceived risk-return evaluation of an investment opportunity (Cochrane 2005).

There is an indication that cleantech VC investors might use other investment decision criteria. Previous research suggested, e.g., that reputational risks might incentivize VC investors to consider social, ethical, and environmental aspects, which could lead even "traditional VC investors" to start building cleantech or more generally sustainability oriented funds and portfolios (Scholtens 2006). Determining whether cleantech VC investors use additional investment decision criteria is thus one aspect to examine. However, the ultimate decision of for-profit investors will eventually be the risk-return ratio. For this reason, a more promising approach might be to examine strategies that have influenced or could influence the risk-return ratio of hardware-, material- or chemical-based cleantech opportunities. This approach is particularly promising for our purpose because cleantech ventures typically suffer from a particularly poor risk-return ratio.

3.3.4 Risk-Return Ratio and the Valley of Death of Cleantech Venture Investments

3.3.4.1 Investor Perceived Risk-Return Ratio

The risk-return relationship is a core concept in financial theory (Guo and Whitelaw 2006), is widely used in the evaluation of VC investments (Cochrane 2005), and is described as a key activity of VC investors prior to investing in a venture (Tyebjee and Bruno 1984). The methods and tools used to estimate the risk-return ratio depend upon the stage of the target venture. Some investments are made based on formal methods, such as discounted cash flow (DCF), or a multiples method. Previous research has suggested however, that the actual risk-return ratio is often identified indirectly through the investment decision criteria described in the section above (Hall and Hofer 1993), without the use of formal methods. We suggest that three collectively exhaustive levers exist to conceptualize potential options that exist for improving the risk-return ratio and allowing bridging the valley of death: [i] decreasing risk or improving return by either [ii] reducing the costs or [iii] increasing the revenues of the venture investment.

3.3.4.2 Reducing Risk and Improving Return

Previous research has suggested that risk-reduction strategies are key to new venture survival (Shepherd et al. 2000). Shepherd et al. (2000) examined the new venture management level and introduced the concept of mortality risk, which in large part depends upon “newness”, which in turn is composed of novelty to the market, novelty in production, and novelty to management. Risk-reduction strategies should be primarily evaluated according to their potential to reduce uncertainty (Shepherd et al. 2000). Given the high importance of risk reduction, scholars have suggested and analysed a wide range of risk categories. Wüstenhagen and Teppo identified the following categories for the field of cleantech: market risk, technology risk, people risk, regulatory risk, and exit risk (Wüstenhagen and Teppo 2006).

Wüstenhagen and Teppo (2006) further show that risk and return can be evaluated not only at the level of the investment object (venture) but also for the actual investment made, from the viewpoint of the investor. According to Wüstenhagen and Teppo (2006), VC return is a product of three variables: (1) the *purchasing price* that the VC investor paid for the venture investment, (2) the *sales price* that the VC investor gains from exiting the venture investment, and (3) the *time between the investment and the exit* (ibid.). Furthermore, they argue that the best return results from purchasing low and selling high quickly (ibid.).

If we examine the valuation of ventures for potential exit, two methods exist for how to increase this valuation over time (see, e.g., Stewart et al. 2001): reducing cost and increasing revenue. Strategies that increase the likelihood of an investment being made can also affect the valuation of the venture prior to the investment and hence increase the purchase price and weaken the increase of the return. However, the effects of these strategies are ongoing and should be outweighed by higher sale prices and investor skills in the due diligence and negotiation process. “Real options analysis could be an appropriate way to value [the investment] opportunities and companies, because the process of discovery, approval, and commercialization involves a series of real options” (Linnenluecke et al. 2016, p. 128). This approach is, however, rather complex in practice and requires simulation (ibid.). The time factor (cf. Wüstenhagen and Teppo 2006) is difficult to handle because long holding periods are unavoidable in cleantech due to a lack of exit channels (cf. Migendt et al. 2017). Furthermore, VC adjusts very slowly to changes in the capital supply or demand, because of the requirements for raising funds (Gompers and Lerner 2004). Time is therefore best considered a risk.

3.3.4.3 Valley of Death – Conceptualizing the Risk-Return Relationship

The valley of death can be described graphically by mapping cumulated cash flow of a new venture over time, which creates a "deep valley of death" when private investors do not provide sufficient funds to bring a technology from its creation and development to the market, and no other financial resources are available (Murphy and Edwards 2003; Stern 2007). The exact conceptualization varies between authors, but the overall concept is well established in research (Barr et al. 2009), policy (European Commission - Directorate General Environment 2009) and, e.g., specifically in the clean energy sector (Jenkins and Mansur 2011).

Figure 3-2 shows schematically how a technology is developed by a new venture from the idea stage (basic research/invention) to development and demonstration, followed by commercialization (see x-axis in Figure 3-2). The bold blue line in the graph shows the cumulated cash flow over time. Before revenues start to flow, technology developments take time and demand high amounts of capital. On the second y-axis, Figure 3-2 schematically shows the level of risk for the investment, which decreases over time because technologies and corresponding business models are further advanced in their development, and the risk of failure of a venture decreases. Furthermore, the valley of death shows schematically how either risk must be reduced or return increased to improve the risk-return ratio.

Figure 3-2 additionally shows typical players for capital supply in this phase and indicates roughly when in the process they tend to invest. It also shows the particularly high negative cumulative cash flow that occurs at the time when independent for-profit VC investors would usually invest.

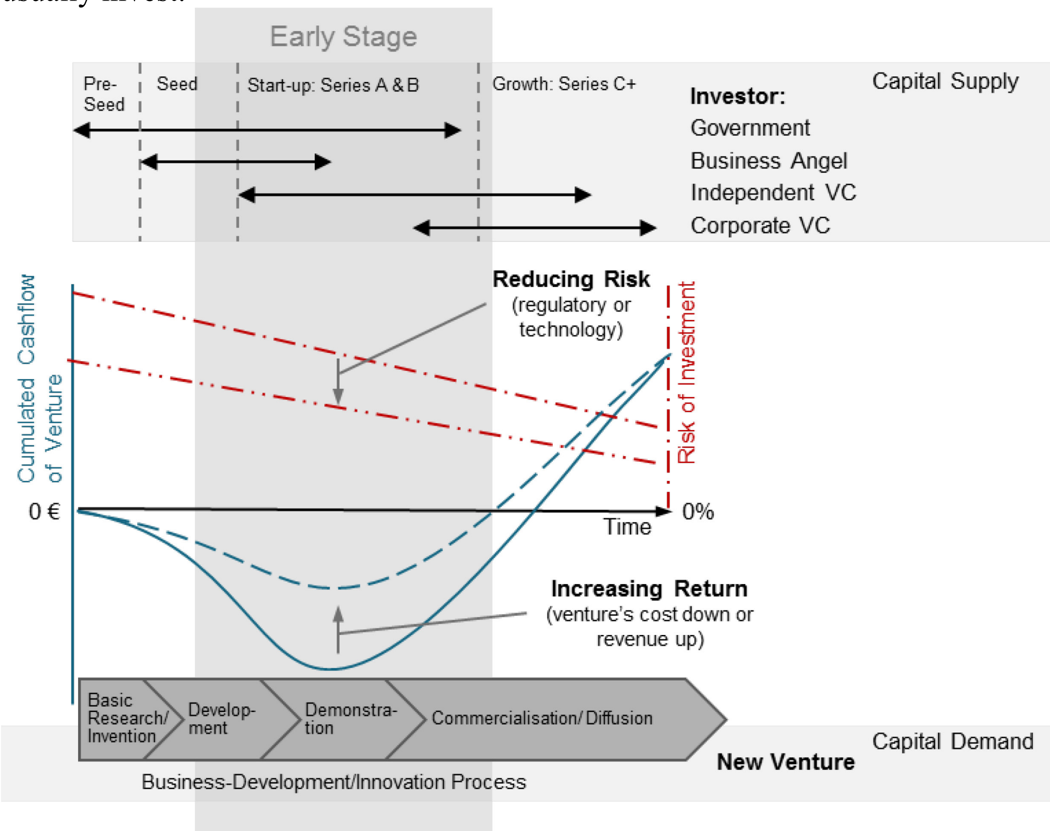

Figure 3-2: Risk-return (schematic) across the valley of death (adapted from Murphy and Edwards 2003)

3.3.5 Strategies Suggested to Bridge the Valley of Death for Specifically Cleantech Ventures

Given the importance of helping cleantech ventures bridge the valley of death, a wide range of strategies have emerged from different research fields (occasionally not currently in the form of a strategy recommendation but rather in the form of causal relationships that can serve as a basis for strategy development). Most of this research is on green technologies or cleantech in general; however, a specific focus on our identified research need, "investment decisions of for-profit investors investing in early-stage, radical cleantech" is very rare. A valuable exception is a recent study by Gonzalez (2016).

Research that has suggested means of helping cleantech ventures bridge the valley of death can be clustered into three categories: [a] national and international cleantech policies, [b] national and regional-level structural enablers and barriers and [c] investors' individual differences, such as motivations, attitudes and venture-level strategies. Strategies at the level of national and international policies have most likely drawn the highest attention from researchers thus far, particularly in the field of renewable energies.

3.3.5.1 National and International Cleantech Policies [a]

Governments are frequently mentioned as important actors helping cleantech ventures bridge the valley of death by, e.g., providing large loans and demonstration projects (Hargadon and Kenney 2012). Bürer and Wüstenhagen (2009) analysed investors' preferred policies that might help bridge the valley of death for clean energy innovations. They provide a comprehensive list of 23 policies and rank these according to investor preferences. Feed-in tariffs for renewable energy is the highest ranked policy (mean score of 4.16 on a five-point Likert scale), and government VC funds ranks as the least attractive policy (2.29 on a five-point Likert scale) (Bürer and Wüstenhagen 2009). The large difference of 1.87 points (on the five-point Likert scale) between the top and lowest-ranked strategy indicates that investors appear to have clear preferences and supports the fact that it makes sense to identify these preferences to inform policymakers accordingly. Criscuolo and Menon (2015) suggest that these policies additionally must have a long-term perspective and create credibility and trust to positively influence investment decisions.

3.3.5.2 National- and Regional Level-Structural Enablers and Barriers (geography, innovation clusters, innovation intermediaries, industry and location) [b]

Research has suggested that cleantech often needs a strategic approach when matching the technologies developed in a specific geographic region (e.g., good preconditions for wind and solar) with preconditions such as local demand for these products and additionally good access to capital (Knight 2010), because financing outside regional cluster demands an additional risk-premium (Chen et al. 2010). A further valuable strategy, particularly addressing the need for technology development and the need for creating returns and reducing costs was combining incubator and prototyping space (Fullmer 2014). This concept is currently being followed by Greentown Labs[11], who provide space for over 100 cleantech ventures and closely link these ventures with investors when providing technology development infrastructure and relevant networks. However, innovation intermediaries must go beyond traditional models to focus "[…] on bottlenecks in the innovation process to bridge the 'valley of death' and other structural holes, thereby going beyond funding basic or applied R&D and demonstration" (Polzin et al. 2016, p. 41). Intermediaries must therefore coordinate different sources of capital and broker between actors (e.g., public and private) during the innovation cycle (cf. Howells 2006).

[11] www.greentownlabs.com, accessed July 14th, 2018.

3.3.5.3 Investor' Individual Differences, such as Motivations and Attitudes and Venture-Level Strategies [c]

A study that comes close to our purpose was done by Wüstenhagen and Teppo (2006), who examined investor-perceived risk and return in the clean energy market. Similar to our argumentation in this article, they identified long lead times (risk) and capital intensity as key aspects that hinder investor investment, and suggested that these aspects should be addressed at the level of the venture by adapting the business model. Another perceived barrier to investment in their study (ibid) was the tension between societal and private benefits. Although for-profit investors by definition usually consider only the private benefits in their risk-return evaluations, strategies targeting the additional public benefits might be successful in drawing more investors into the cleantech space; Bocken (2015) found that cleantech investors have a belief that business can be used to create public good. One step further would be the more recent suggestion to increase the effect of the role of investors and non-profit foundations in financing cleantech, possibly including social and environmental considerations even in the risk-return evaluation (Kearney et al. 2014). Addressing this suggestion is however out of scope for this article because the focus is primarily on for-profit cleantech investors.

The interplay between investor motivations and perceptions reflects that these motivations can be influenced by for example venture-level strategy communications, showing the level of complexity to consider, including, e.g., studies examining policies or country-level differences. Following the overview about these relevant research studies and strategies to bridge the valley of death, we identify three key questions that in our opinion cannot currently be answered satisfactorily from existing research.

3.3.6 Need for [1] Consolidation, [2] Focus on Early-Stage Radical Cleantech and [3] Evaluation of Relative Effectiveness

Based on our literature review, we have identified several problems and questions that require further research.

[1] *Consolidation*. The strategies to bridge the valley of death are often discussed within "research silos". To date, no overall overview exists concerning how these strategies relate, concerning which stakeholders are involved across these research fields, or concerning who is responsible for initiating these strategies. Therefore, there is a clear need to consolidate the different strategies into a single framework to provide clear and informed advice to all relevant stakeholders.

[2] *Focus on early-stage, radical cleantech investments*. Research focussing explicitly on strategies addressing for-profit investors investing in urgently needed radical cleantech innovations in the early-stage is scarce. These types of investment share specificities such as high risk and long holding periods and are likely to need dedicated strategies in addition to existing, more generic strategies or decision criteria presented in this theoretical foundation.

[3] *Effectiveness – what strategies addressing investor-perceived risk-return should be pursued?* We know little about the relative effectiveness of the different strategies that have been developed (comparisons exist at best in the field of policies). The risk-return theorem appears to be the framework that will allow the evaluation and categorization of these strategies.

3.4 **Research Design**

3.4.1 Research Setting and Choice of Methods

The empirical setting is the cleantech venture investment landscape in the EU and the USA, with a focus on investors that have or are considering investments in early-stage, radical cleantech. The choice of method deemed appropriate to answer the research question was a mixed-method approach (Creswell and Plano Clark 2018) with sequential data collection and analysis. In-depth exploratory interviews (n=45) and survey data (n=14, 12 complete and 2 incomplete) were obtained to draw accurate and meaningful conclusions from the data (ibid.). This approach allowed the elaboration of existing theories (Eisenhardt 1989) via an analysis of investor decision-making and strategizing. A second important rationale for this methodological approach is that previous research has suggested that for decisions involving *high risk*, experimental research designs do not simulate reality well (Harrison et al. 2007). We follow previous research procedures (Sandberg et al. 1988; Tyebjee and Bruno 1984) and ask VC investors to describe their reasoning for actual investment decisions, rather than asking directly for investment decision criteria.

Theory-driven purposeful sampling was used to identify and cover knowledgeable individuals (Palinkas et al. 2015) from *all types* of relevant investor categories (n=34). These categories are angel investors, corporate investors, governmental investors, impact investors, high-net-worth individuals, private equity investors, and VC investors. Furthermore, venture investing experts (n=11) have been included in the sample to triangulate investor decision-making and strategizing. A detailed overview of the interview sample is shown in Table 3-2.

3.4.2 Data Collection

Identifying and in particular accessing a sample of cleantech investors and experts in the field of early-stage, radical cleantech is extremely challenging. Informants for this study have been identified via internet research, the authors' attendance at dedicated conferences for cleantech investing (e.g., Ecosummit Berlin 2015–2016), the authors' personal and university networks (e.g., MIT Alumni Association or EIT Climate-KIC) and recommendations of interviewed experts and investors.

The selection of the informants was based on their track record, knowledge and expertise to invest in early-stage radical cleantech (Creswell and Plano Clark 2018), and their availability and willingness to participate in the study (Bernard 2002) to make effective use of the authors' limited resources (Patton 2015). The authors selected the interviewees across a range of geographies, namely the EU (n=15) and the USA (n=30) (Eisenhardt and Graebner 2007), resulting in a valuable sample of 34 investors (20 independent VC investors, 6 corporate VC investors, 3 governmental VC investors, and 5 angel investors), and 11 experts (researchers, agencies such as incubators, and expert networks). For the quantitative survey, only investors (34 investors) and one expert from research with extensive venture investing experiences were considered, with a response rate of 40%, and an even distribution of respondents from the USA (n=7, 5 complete and 2 incomplete) and the EU (n=7).

3.4.2.1 Qualitative Data (ex-post reflection on actual investment cases)

In a first step, *interviews* were conducted in person if possible or otherwise via telecommunication between October 2015 and July 2016. This design allowed for a unique perspective on not only the decision-making of each stakeholder individually but also the interactions and dependencies amongst all of the different stakeholders. A semi-open questionnaire was used to not only ensure rigor in the data collection process but also allow for stakeholder-specific adjustments during the process of data collection. This design allowed the authors to refine the questionnaire over time to adapt to an increased understanding of the observed phenomena. The depth of the analysis could thereby be broadened. Furthermore, the data collection process was accompanied by a workshop of all researchers that collected data in the different geographical areas (the EU and the USA) to enable a spillover effect and share learnings about both the phenomena/observations and the applied methods.

Table 3-2: Overview of the sample

Date of Interview	Type of Interview	Notes & Memos	Recorded & Transcribed	Operational Area	Type of Organisation	Participation in Survey
16.10.2015	Personal	x		USA	Independent VC	Yes
19.10.2015	Telecommunication		x	USA	Independent VC	No
20.10.2015	Telecommunication	x		USA	Expert - Platform	Not included^Δ
21.10.2015	Telecommunication	x		USA	Independent VC	No
23.10.2015	Telecommunication	x		USA	Independent VC/Impact Investor	No
26.10.2015	Telecommunication		x	USA	Corporate VC	Yes (incomplete)
27.10.2015	Telecommunication		x	USA	Corporate VC	Yes (incomplete)
27.10.2015	Telecommunication	x		USA	Independent VC	No
29.10.2015	Telecommunication	x		USA	Independent VC/Impact Investor	No
04.11.2015	Telecommunication	x		USA	Expert - Incubator	No
09.11.2015	Personal	x		USA	Expert – Agency	Not included^Δ
17.11.2015	Telecommunication	x		USA	High-Net-Worth Investor Network/Angel Investor	Not included^Δ
25.11.2015	Personal		x	EU	Governmental VC	Yes
02.12.2015	Telecommunication	x		USA	Independent VC	No
03.12.2015	Telecommunication	x		USA	Expert – Agency	Not included^Δ
07.12.2015	Telecommunication		x	EU	Independent VC	Yes
07.12.2015	Personal	x		USA	Expert - Incubator	Not included^Δ
08.12.2015	Telecommunication	x		USA	Angel Group	Not included^Δ
08.12.2015	Telecommunication	x		EU	Independent VC	No
09.12.2015	Telecommunication	x		USA	Expert - Incubator	Not included^Δ
10.12.2015	Telecommunication		x	EU	Corporate VC	No
10.12.2015	Telecommunication	x		USA	Angel Group	Yes – excluded*
10.12.2015	Personal	x		USA	Independent VC	No
11.12.2015	Personal		x	EU	Governmental VC	No
11.12.2015	Personal		x	EU	Independent VC	No
15.12.2015	Personal	x		USA	Micro VC/Angel Group	Yes
16.12.2015	Telecommunication	x		USA	Independent VC	No
21.12.2015	Telecommunication	x		USA	Independent PE/VC	Yes
21.12.2015	Telecommunication		x	EU	Independent VC	Yes - excluded*
29.12.2015	Telecommunication	x		USA	Expert – Venture	No
08.01.2016	Telecommunication		x	EU	Independent VC	Yes
11.01.2016	Telecommunication		x	EU	Governmental VC	No
15.01.2016	Telecommunication		x	EU	Independent VC	Yes
16.01.2016	Personal		x	EU	Angel Investor	Yes
16.01.2016	Telecommunication		x	EU	Independent VC	Yes
25.01.2016	Telecommunication		x	EU	Independent PE	No
27.01.2016	Telecommunication	x		EU	Corporate VC	No
11.02.2016	Telecommunication	x		USA	Corporate VC	No
17.02.2016	Personal	x		USA	Expert - Incubator	Not included^Δ
26.02.2016	Telecommunication	x		USA	Expert – Venture	Not included^Δ
26.02.2016	Telecommunication	x		USA	Independent VC (Dept Finance)	No
11.03.2016	Telecommunication	x		USA	Independent PE (+ Dept)	No
16.03.2016	Telecommunication	x		USA	Expert – Venture	Not included^Δ
27.05.2016	Personal		x	EU	Corporate VC	Yes
07.07.2016	Telecommunication		x	USA	Expert - Research	Yes
10 months	Total: 45	Total: 28	Total: 17	USA: 30 / EU: 15		Yes: 14 / No: 21 (40% resonse rate)

* = excluded, as indicated investor would not consider investing in early stage radical cleantech
Δ = not included in quantitative investment scenario evalution, as not usually taking cleantech investment decisions

The semi-structured interview guide was three-staged (see Appendix 3.9.1 for an excerpt):

- Background information about investors
- Description of an investment case in cleantech with a positive investment decision
- Description of an investment case in cleantech with a negative investment decision

All interviews were either recorded and transcribed (over 600 audio minutes were transcribed) or captured in research memos (cf. Strauss and Corbin 2015).

3.4.2.2 Quantitative Data (ex-ante decision making on standardized investment scenario)

In a second step, an *online survey* (SurveyMonkey 2018) from January until April 2018 was performed with the purpose of triangulating the strategies extracted from the qualitative interviews ex-post (i.e., reflecting actual investment decisions made) with an ex-ante perspective (i.e., how would these extracted strategies influence a future investment decision). An iterative pre-test of this quantitative survey was performed with three researchers in the field of sustainable entrepreneurship and one cleantech investor outside the sample between May and October 2017. As described in Table 3-2, the initial sample was reduced to those who would consider investing in early-stage radical cleantech (32 investors and 1 expert in total; 14 responded; 40% response rate).

All 14 respondents were introduced to a simplified notional early-stage, radical investment opportunity (see Appendix 3.9.2) that was designed to be on the verge of being of interest for investors. Before participating in the survey, investors were asked whether they would generally consider investing in radical, early-stage investments. Two further participants had to be excluded, leaving a sample of 12 respondents (34% final response rate). The fact that only 2 had to be excluded provides a fairly good validation of the initial qualitative interview sample, which aimed at extracting strategies from investors investing in early-stage, radical cleantech ventures.

The survey included all 27 strategies with a short description of each strategy (see Table 3-3). The strategies were clustered based on the risk-return categories into six survey pages. These pages and the strategies on each page were randomized to reduce bias in the survey responses (e.g., Lavrakas 2008). All participants were asked whether the strategy would significantly increase the likelihood that they would make a positive investment decision in the given investment scenario. Data were obtained on a five-point Likert scale from strongly 'disagree' (1) through 'neither agree nor disagree' (3) to 'strongly agree' (5). Information such as investment preferences (software-based vs hardware-, material-, or chemical-based), and investment stages and volumes were also captured by the survey.

3.4.3 Data Analysis

The data analysis was performed in a 7-staged process to [I] develop the 27-strategy framework with four strategy archetypes, [II] identify the strategy stakeholders, [III] identify the potential strategy effects, and [IV] derive five areas of recommendation on implementation of the 27 strategies (see Figure 3-3).

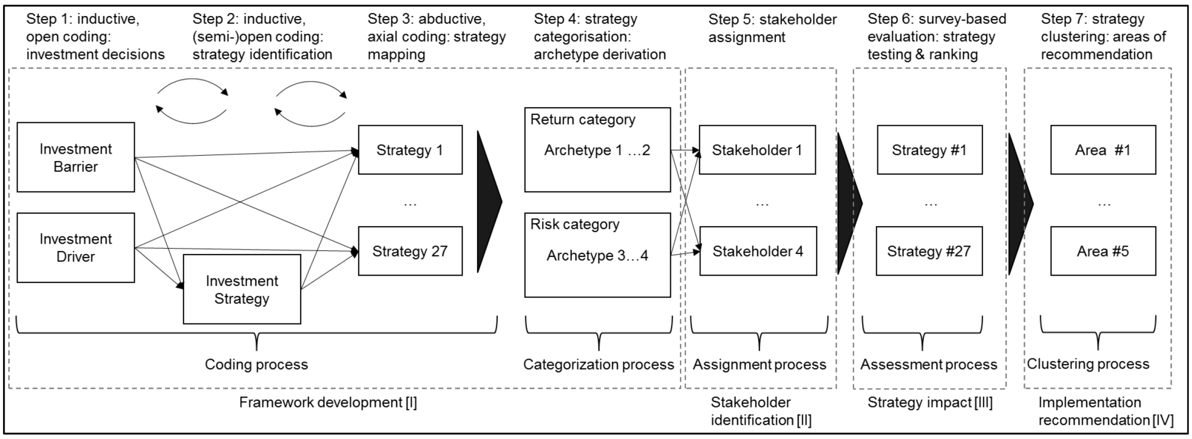

Figure 3-3: Data analysis process

Interview data analysis was performed using the Atlas.ti 8 (ATLAS.ti 2018) software. Axial coding (Strauss and Corbin 2015) was used to extract patterns of interlinked investment drivers, barriers and strategies. The coding process was performed in the first three distinctive steps of the data analysis:

1. Open inductive coding of investment criteria to reveal drivers for (in favour of) and barriers to (against) investments in new cleantech ventures
2. Coding for applied and suggested strategies for investments in new cleantech ventures

3. Iterative mapping of driver and barrier codes to coded strategies, and thereby linking Hall and Hofer's (1993) investment criteria to the developed strategies (see Table 3-6 in Appendix 3.9.3)

The authors derived 27 strategies from this process. All strategies were challenged and discussed with 3 dedicated cleantech investors outside the sample in April 2016. In a follow-up process (step 4 in the data analysis), each strategy was categorized according to its effect on the risk-return ratio of the investment or on the investor and the venture. Strategies are grouped into four archetypes: cost decreasing, revenue increasing, regulatory risk, and technology risk. Moreover, the stakeholders that are necessary to perform a strategy have been identified and assigned to the corresponding strategy (step 5 in the data analysis). In step 6 of the data analysis, the derived strategies were tested and assessed via the *online survey* (see Section 3.4.2). In the last step of the data analysis, the number of reported codes per strategy and the number of main actors involved in the strategy implementation have been mapped against the survey results to cluster the strategies and derive archetypes (step 7 in the data analysis) (see Figure 3-3).
From this mapping, the authors were able to glean strategic responses for each stakeholder that could affect the cleantech system in a desired and positive way.
Informed consent was obtained from all research participants. Answers from both the interviews and the survey were anonymized, and it is not possible to link the statements back to individual subjects.

3.5 **Results**

The results of this mixed-methods research will be presented in parallel with the data analysis process (see Figure 3-3): First, the strategy framework and the stakeholder assignment from the qualitative data analysis will be described. Second, we outline the strategy ranking according to semi-quantitative data from both the interviews and the survey. In addition, we will develop propositions to pave the way for future research.

3.5.1 Emerging Strategies, Risk-Return Classification, and Stakeholder Assignment (qualitative interview results)

Twenty-seven strategies emerged from our analysis. They have been grouped into four archetypical categories that combine the strategy effects on the risk or return of the investment. We label these categories as a 'risk-return framework for radical cleantech'. The first two archetypes describe the effect on the return of the investment in terms of either [i] costs or [ii] revenue of the venture. The last two archetypes combine strategies affecting the regulatory or technology risk of the investor. A full categorization into the four archetypes and short descriptions of all strategies are shown in Table 3-3. Furthermore, exemplary quotes from the interviewees are given in Table 3-6 (in Appendix 3.9.3) to validate the rationale of developing and deriving the strategies from the qualitative data. In the following section, we present the framework with 27 strategies [I] and the assignment of stakeholders [II] based on the four categories.

Table 3-3: Twenty-seven strategies for radical cleantech venture investment risk-return optimization by key stakeholders

Strategy Archetype	Strategy Name	Description of Strategy	Stakeholder involved in Strategy Implementation
a. Cost Reducing	Project financing and pre-financing	New venture establishes trusted relationship with partner or customer to build pilot or full-scale facility on demand to pre-finance production	Venture, customer
	Licensing	New venture pursues a licensing model, allowing others to exploit technology and reducing its capital expenditures (CAPEX) for own production facilities	Venture, customer
	Outsourcing	New ventures outsources part of the internal value chain or a business unit to external partner, e.g., new venture contracts external manufacturer to produce product and provides raw materials (toll/contract manufacturing)	Venture, service provider

Strategy Archetype	Strategy Name	Description of Strategy	Stakeholder involved in Strategy Implementation
	Outsourcing for shares	New venture gives shares to strategic investor (e.g., corporate VC investor) in return for the use of its production facilities	Venture, service provider
	Use of proven parts	New venture uses existing technology parts and infrastructure to minimise costs for procurement	Venture, service provider
	Intermediation	Third party creates public and/or private support centres to facilitate the cleantech ecosystem by, for example, providing networks and enables for a shared use of resources or infrastructure to reduce costs for acquisition or R&D and production	Service provider
	Grant money	Government supports new ventures by providing grant money to cover costs for early research and development	Public authority
b. Revenue Increasing	Adjust for the sustaining of customer's operations	New venture structures and adjusts technological applications and business model in a way to minimise customer's costs and risks to implement new technology, e.g., allow for retrofitting (improve or add on to existing infrastructure rather than to replace it)	Venture, customer
	Performance and application focus	New venture pursues a framing or communication strategy that is not solely focused on sustainability and puts the performance of the product rather than the technology as highest priority in development process	Venture, customer
	Staged market entry	New venture employs staged market entry to capture the low-hanging fruits in the interim markets, e.g., niche (value) than commodity (volume) market or consumer markets that require less CAPEX than business markets that require more CAPEX	Venture, customer
	Public procurement	Government procures cleantech-based products to directly support its deployment	Public authority
	Recurring revenues	New venture ensures stable and predictable future revenue model, e.g., by maintenance, subscription, and service fees (e.g., for predictive maintenance)	Venture, customer
c. Regulatory Risk	Regulatory independence	New venture designs business model or financial model to be independent from regulation, e.g., subsidies or taxes	Venture
d. Technology Risk	Bigger investment volume	Limitted partner (LP) and general partner (GP) agree on a bigger fund size	LP, GP
	Higher-risk but higher-impact strategy	Investor focuses on high risk, high impact portfolios to attract impact investors and/or philanthropic investors (e.g., family offices)	LP, GP
	Longer holding period	LP and GP agree on a longer or unlimited holding period, i.e. evergreen fund	LP, GP
	Cleantech sector specialization	Investor gains market and technology knowledge by sufficiently observing a sector prior investment decision to focus and specialise on a cleantech sector and/or technology	GP
	Strategic syndication	Different investors syndicate to share risks, and to gain knowledge and competitive advantage in fields of strategic interest to reduce technology risk	GP, GP
	Venture debt financing	GP provides debt financing to venture to incentivise it by maintaining greater ownership and reducing investment risk for VC, e.g., by continues interest payment/repayment	GP
	Risk diversification in portfolio	Investor counterbalances higher risk venture investments with lower risk venture investment profiles within portfolio	GP
	Investment insurance	Third party insures investment or gurantees performance of certain technologies (in case of underperformance or failure), e.g., to meet runtime requirements of conservative customer or investor	Service provider
	Regulatory interventions	Government penalises technologies with detrimental side effects to internalises external cost, e.g., by carbon pricing	Public authority
	Tax benefits	Government incentivises investors by tax reductions on investment sumv	Public authority
	Subsidization	Government supports new technology diffusion by providing incentives for technology implementation or deployment, e.g., feed-in tariff (EEG – Germany)	Public authority
	Public funds	Government creates fund to invest in stages with capital demand, e.g., series A and B in cleantech, sovereign wealth fund (SWF)	Public authority
	Public investment mirroring	Governments mirrors sum of private investment, e.g., KfW in Germany	Public authority, GP
	Public-private funds	Government and private/corporate investors create fund, e.g., High-Tech Gründerfonds (HTGF - Germany) fund, Mission innovation (Bill Gates)	Public authority, GP

3.5.1.1 A. Cost-Reducing Strategies

The first category consists of the strategies *project financing and pre-financing*, *outsourcing*, *outsourcing for shares, use of proven parts, intermediation, and grant money* contributing to a potential cost reduction for the venture. This reduction is primarily achieved via improved demand-side management of the venture and effective interaction with customers, the venture's involvement with third parties in their business operations (e.g., manufacturing or tailor-made support) or reduction of expenses.

3.5.1.2 B. Revenue-Increasing Strategies

The strategies *adjust for the sustaining of customer's operations*, *performance and application focus*, *staged market entry*, *public procurement,* and *recurring revenues* in category two increase the revenue of a venture by improving interaction with the venture`s customers or adjusting the value capture aspect of the venture's business model.

3.5.1.3 C. Regulatory Risk-Reduction Strategies

The third category with strategy *regulatory independence* allows decreased regulatory risk for the investor via alignments in the business model of the ventures. The strategies *regulatory intervention*, *subsidization*, and *tax benefit* also affect this category because they might increase a venture's or investor's dependence upon public authorities. However, these strategies primarily affect the technology risk and will be described in the next category.

3.5.1.4 D. Technology Risk-Reduction Strategies

The fourth and last category hosts the most strategies. Strategies in this category affect the technology risk for the investor in the form of both the general partner (GP) managing the VC fund and limited partner (LP) investing in the VC fund. *Greater investment volume*, *higher-risk but higher-impact strategy*, *longer holding period, cleantech sector specialization, strategic syndication, venture debt financing*, and *risk diversification in portfolio* take effect via changes in the business model of the investor (value proposition, value creation and delivery, and value capture). However, *investment insurance*, *regulatory interventions, tax benefits, subsidization, public funds*, *public investment mirroring*, and *public-private funds* affect the technology risk via either indirect interference from public authorities and other third parties (e.g., creation of favourable conditions to commercialize technology) or direct supply of capital from public authorities. Based on the classification of these 27 strategies in parallel with our developed risk-return framework, we suggest the following propositions:

> *Proposition 1: Strategies aiming at improving the investor-perceived risk-return ratio of cleantech investments can be clustered and evaluated by their potential to decrease technology and regulatory risk and improve return via cost reduction and revenue increase.*

> *Proposition 2: A holistic approach aiming at improving the investor-perceived risk-return ratio of cleantech investments should consider strategies targeting the venture, investors, public authorities (policies), service providers (e.g., incubators) and customers.*

3.5.2 A First Indication of the 27 Strategies' Impact Potential (semi-quantitative survey results)

Of the participants in the survey (n=14), 86%[12] did not meet the initial criterion for exclusion and would invest in early-stage hardware-, material- or chemical-based new cleantech ventures. Nineteen of the 27 strategies were ranked[13] as being (rather) likely to significantly increase the likelihood of a positive investment decision (≥3 arithmetic mean), whereas four of the 27 were assessed to neither increase nor decrease this likelihood (=3 arithmetic mean). Another four strategies were evaluated as not increasing the likelihood of a positive investment decision (<3 arithmetic mean). In ten cases (4 increase, 4 neutral, and 2 not increase), the standard deviation of the sample was greater than one. On average (arithmetic mean), the standard deviation of the sample was slightly less than one (0.978). Figure 3-4 presents a ranking via a box plot of all strategies, in which positive ratings are marked in green, neutral in yellow, and negative in red.

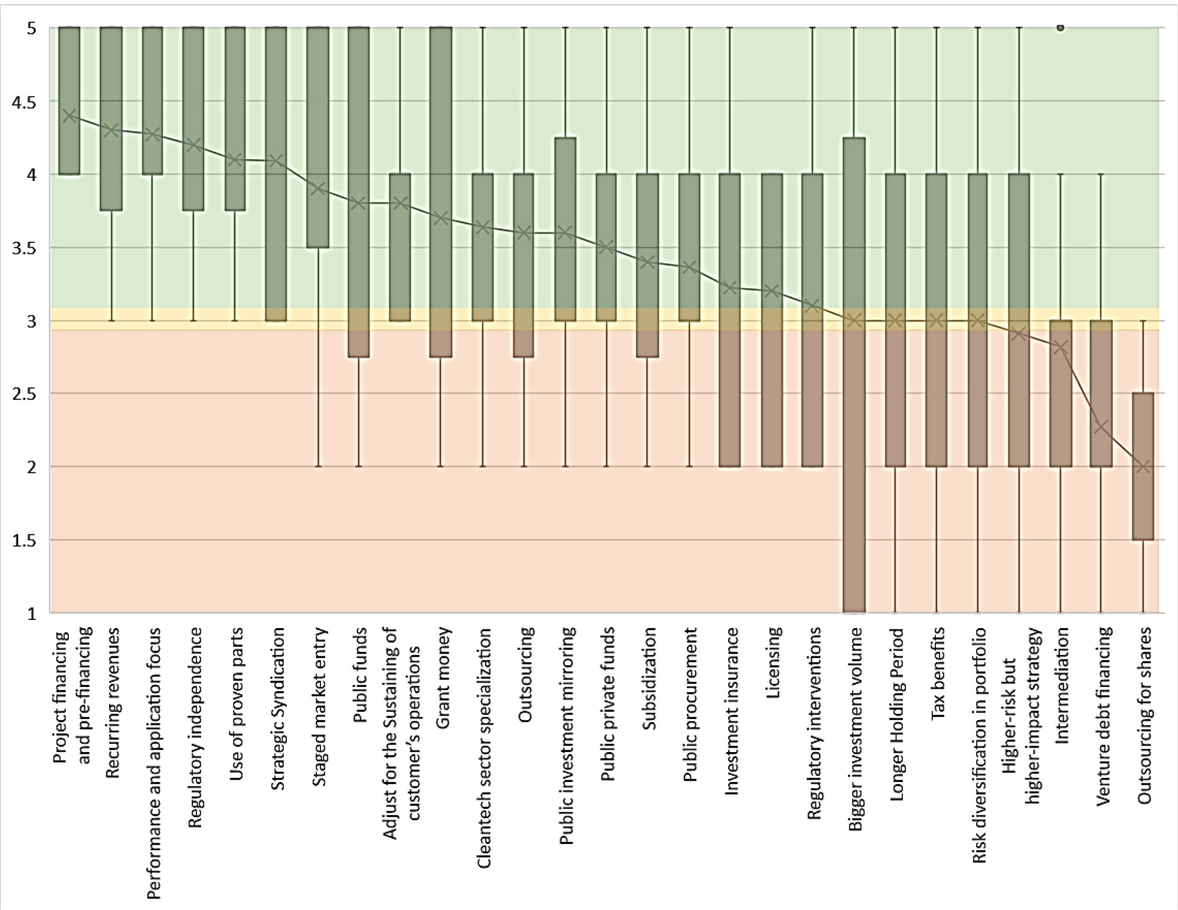

Figure 3-4: Strategy ranking to significantly increase the likelihood of a positive investment decision (on a five-point Likert scale: 1-strongly disagree, 2-disagree, 3-neither agree nor disagree, 4-agree, 5-strongly agree); n=11.

3.5.3 Relevance and Potential of the Identified Strategies (mixed-methods results)

To cluster the ranked and reported strategies and to derive suitable recommendations, we plotted the perceived potential (strategy ranking from survey) against the perceived relevance for an investor's decision making (strategy report from interviews) for each strategy. Furthermore, we included the reciprocal of the minimum number of stakeholders that are necessary to implement each of the strategies. Figure 3-5 maps these three dimensions to group

[12] Of which are 14% unlikely, 29% somewhat likely/maybe, 22% likely, and 21% very likely/absolutely to invest.

[13] On a five-point Likert scale: 1-strongly disagree, 2-disagree, 3-neither agree nor disagree, 4-agree, 5-strongly agree.

the strategies into five clusters and to develop our strategy recommendation on five different implementation levels. In the following section, these five clusters will be presented.

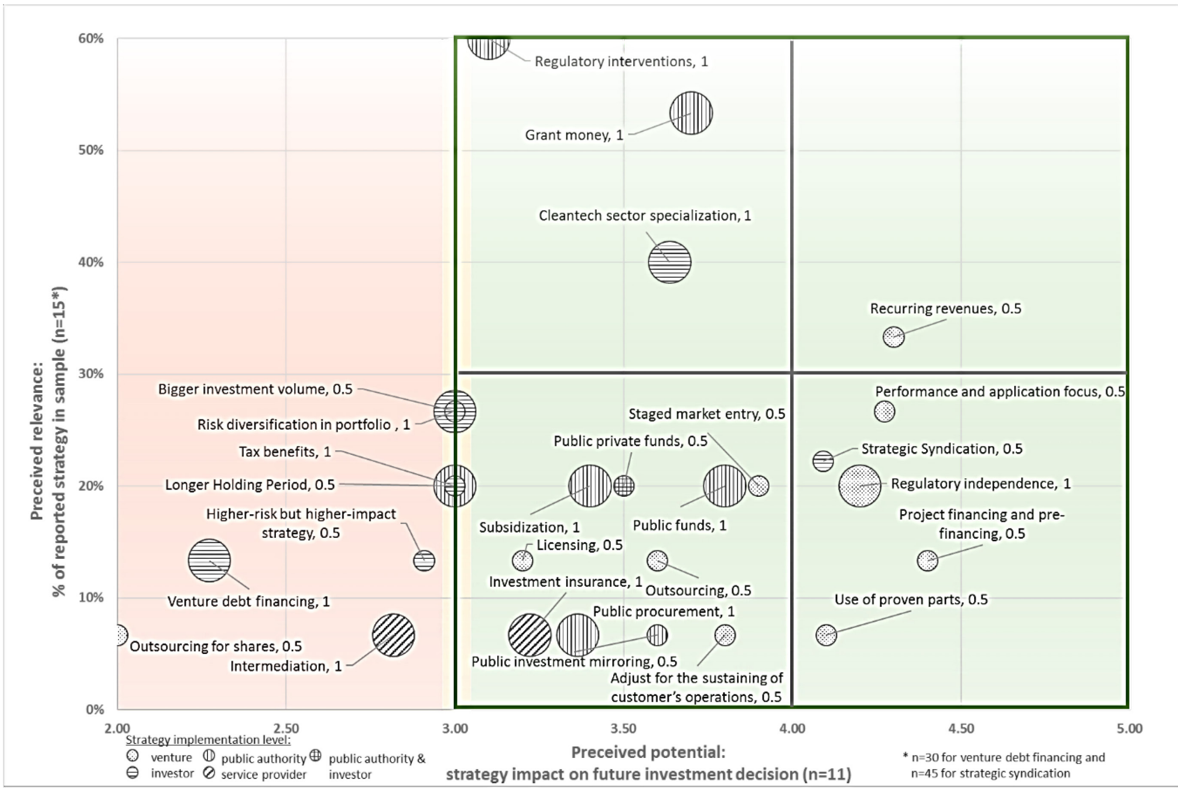

Figure 3-5: Strategy awareness/potential matrix

3.5.3.1 Neglect Cluster

The first cluster consists of strategies with little perceived potential or no positive effect on investment decisions (≤3 arithmetic mean). These strategies should be *neglected* by investors, ventures and policymakers. Moreover, few investors reported on these strategies (>30% of subsample). Hence, the perceived relevance of these strategies is modest. Cost reducing and technology risk archetypes are represented in this cluster, and the implementation level of these strategies is primarily at the investor level.

3.5.3.2 Downstream Strategies Cluster

The second cluster comprises strategies that are perceived as rather positive but less relevant by the investors in our sample. Strategies in this cluster cover most archetypes from cost reducing and revenue increasing to technology risk and are implemented primarily at the public authority or venture level. The strategies in this cluster can be considered *downstream* strategies and should be applied subordinately to strategies in clusters three to five.

3.5.3.3 Reconsider Cluster

Cluster three consists of strategies with similar perceived potential to that of cluster two strategies but with a higher perceived relevance. Hence, strategies in this cluster should be *reconsidered* for application, at least as a first choice. Only three strategies are in this cluster, with two archetypes (cost reducing and technology risk) and implementation levels (investor and public authority).

3.5.3.4 Prioritize Cluster

The strategies in cluster four cover all archetypes and focus on the business model of either the investor or the venture (strategy implementation level). These strategies are perceived as potent to positively affect the investment decision but at the same time as less relevant. Thus, investors and ventures should *prioritize* the implementation of these strategies.

3.5.3.5 The Pursue and Encourage Cluster

The last and fifth cluster comprises only of one strategy in the revenue up archetype. Ventures should *pursue,* and investor *encourage* the implementation of this strategy as it has a high potential and high relevance.

3.5.3.6 Synthesis of Results – Helping Stakeholders Select the Right Strategy

To synthesize our results, we compiled Table 3-4, in which all strategies are sorted based on (i) the implementation level, (ii) recommendation type, and (iii) archetype. Furthermore, this table provides an overview of the ranking of the (a) potential, (b) relevance, and (c) implementation complexity (number of stakeholders involved).

Table 3-4: Managerial recommendation on implementation level

Implemen-tation Level	Strategy	Recommen-dation Area	Archetype	Potential***	Relevance**	Implementation Complexity*
Investor	Strategic syndication	Prioritize	d. Technology Risk	■■■	■■□□	■□
	Cleantech sector specialization	Reconsider		■■□	■■■□	■■
	Risk diversification in portfolio	Neglect		■□□	■■□□	■■
	Bigger investment volume			■□□	■■□□	■□
	Longer holding period			■□□	■■□□	■□
	Higher-risk but higher-impact strategy			□□□	■□□□	■□
	Venture debt financing			□□□	■□□□	■■
Public Authority / Investor	Public-private funds	Downstream	d. Technology Risk	■■□	■■□□	■□
Public Authority	Grant money	Reconsider	a. Cost Reducing	■■□	■■■■	■■
	Regulatory interventions		b. Revenue Increasing	■■□	■■■■	■■
	Subsidization	Downstream	b. Revenue Increasing	■■□	■■□□	■■
	Public procurement			■■□	■□□□	■■
	Public funds		d. Technology Risk	■■□	■■□□	■■
	Public investment mirroring			■■□	■□□□	■□
	Tax benefits	Neglect	d. Technology Risk	■□□	■■□□	■■
Service Provider	Investment insurance	Downstream	d. Technology Risk	■■□	■□□□	■■
	Intermediation	Neglect	a. Cost Reducing	□□□	■□□□	■■
Venture	Recurring revenues	Pursue/ Encourage	b. Revenue Increasing	■■■	■■■□	■□
	Regulatory independence	Prioritize	c. Regulatory Risk	■■■	■■□□	■■
	Performance and application focus		b. Revenue Increasing	■■■	■■□□	■□
	Project financing and pre-financing		a. Cost Reducing	■■■	■□□□	■□
	Use of proven parts			■■■	■□□□	■□
	Staged market entry	Downstream	b. Revenue Increasing	■■□	■■□□	■□
	Adjust for the sustaining of customer's operations			■■□	■□□□	■□
	Licensing			■■□	■□□□	■□
	Outsourcing		a. Cost Reducing	■■□	■□□□	■□
	Outsourcing for shares	Neglect	a. Cost Reducing	□□□	■□□□	■□

*	minimum number of stakeholder to implement strategy: ■□ : >1 (i.e. higher complexity); ■■ : =1 (less complexity)
**	% of reported strategy in sample: ■□□□ : <15%; ■■□□ : >15%, <30%; ■■■□ : >30%, <45%; ■■■■ : >45%
***	impact on future investment decision: □□□ : rather disagree; ■□□ : neutral; ■■□ : rather agree; ■■■ : agree

Our analysis shows that not all strategies are likely to positively influence investor decision making. Conversely, some strategies have influenced decision making (based on the ex-post analysis of investment decisions and based on the ex-ante quantitative survey). However, many strategies also cannot be influenced by a single stakeholder, which makes this field complex. We have not encountered a case in which a strategy radically changed the risk-return perception of the investor. Consequently, we suggest the following three propositions:

Proposition 3a: Strategies targeted at the risk-return perception of cleantech investors evaluating cleantech investments have been successful in the past and can lead to increased investments in the future, provided they are applied more often and by the right stakeholders.

Proposition 3b: Strategies targeted at the risk-return perception of cleantech investors can incrementally improve the risk-return perception, but "extreme cases" require new financing models that go beyond the strategies developed in this article.

Proposition 3c. Even for cases with extremely poor risk-return perception, applying the strategies as identified in this research will lead to an improvement in the risk-return ratio.

3.6 **Discussion**

The research question guiding our analysis was *What strategies can improve and have successfully improved the risk-return ratio of early-stage hardware-, material- or chemical-based clean technology venture investments? What is their potential effect and who are the players involved in their implementation?* In the following, we discuss our findings considering existing studies about not only cleantech investing but also about conventional investing to derive universal recommendations for early-stage, radical cleantech venture investments bridging the valley of death.

3.6.1 Strategies to Bridge the Valley of Death?

Radical cleantech such as new energy technologies – unlike other (conventional) industries – requires substantial capital beyond R&D to become commercialized, and investments will be difficult to realize. However, the capital invested in fossil-based technologies is a sunk cost and accounts for low energy prices (cf. Hartley and Medlock 2017). To bridge the valley of death for these technologies, dedicated financial support beyond market pull and technology push policies alone is needed (cf. Bürer and Wüstenhagen 2009; LaBelle and Goldthau 2014). Thus, our findings suggest the implementation of investment strategies to traverse the valley of death by various stakeholders from the public and private sectors (see Figure 3-2).

3.6.2 Strategy Rankings for Policy – Investors Clearly Prefer some Policies over Others

We found that not all identified strategies are perceived as favourable to draw more private capital into early-stage hardware-, material- or chemical-based clean tech and thereby to bridge the valley of death (see neglected strategy cluster). Bürer and Wüstenhagen (2009) and Polzin et al. (2018) made a similar discovery when measuring the perceived effectiveness of policy measures to mobilize investments in cleantech ventures; some measures are perceived as negative or neutral (ibid.). Moreover, there is little deviation between Polzin et al.' s (2018) rankings from the investor's perspective, Bürer's and Wüstenhagen's (2009) assessment and our investor rankings (see Table 3-5). Only government VC funds and government investment in private VC funds are perceived as ineffective[14] in Bürer's and Wüstenhagen's (2009) study, whereas we found a positive perception of these strategies in our research.

Table 3-5: Investors perception on policy measures (adapted from Polzin et al. 2018; Bürer and Wüstenhagen 2009)

Policy approach	Polzin et al.'s policy measure	Effectiveness	Bürer's and Wüstenhagen's policy	Effectiveness	Strategy	Potential
Innovation policy (technology push)	R&D subsidies	+	Demonstration grants/R&D/grants for SMEs/investment subsidies	+	Grant money	+
	R&D tax credits	+	Tax breaks for entrepreneurs	+		
	Research infrastructure and incubators	++	Incubators and soft support measures	-		
Innovation policy (market pull)	GHG emission trading system		CO_2 tax, CO_2 trading and certified emission reduction	+/-	Regulatory interventions	+
	Cash rebates and subsidies	-	Reduction of fossil fuel subsidies	+		
	Direct investments (into complementary assets)	+/-	Government VC funds	-	Public funds (direct investments into companies)	+
	Co-investing (into companies)	++	Government investment in private VC funds	-	Public private funds Public investment mirroring	+ +
	Loans and loan guarantees	++				
	Tax incentives	++	Residential and commercial tax credits/production tax	+		
	Feed-in tariffs	+/-	Feed-in tariffs	++	Subsidization	+
	Product standards and regulation	--	Technology and performance standard/renewable fuel or portfolio standards	+		
	Information, networking and conferences	+			Intermediation*	-
	Public procurement	+	Public procurement	+	Public procurement	+
			Renewable certificate trading	+		
Framework conditions for VC	Capital market development (exit possibilities)	+				
	Tax policy	+	Tax breaks for investors	-	Tax benefits	+/-
	Bankruptcy legislation					
	Labour-market regulation	+				
	Intellectual property					
	Institutional investors	+				
					Investment insurance*	+

Perceived effectiveness or potential by investor: --: negative or disagree (<2); - negative or rather disagree (>2, <3); +/- neutral (=3); +: rather positive or rather agree (>3, <4), ++ positive or agree (>4)
* implemented by service provider, e.g., public authority

3.6.3 Clear Need to Consider Different Stakeholders and Implementation Levels

However, most research on the valley of death suggests action from public authorities to bridge or traverse the valley of death (e.g., Frank et al. 1996; Bürer and Wüstenhagen 2009; Wüstenhagen and Menichetti 2012; Masini and Menichetti 2012; Polzin 2017; Polzin et al. 2018). Our findings cover multiple implementation levels: public authorities, investors, ventures and service providers. The risk dimension is dominated by potent strategies at either the investor or public authority implementation level, whereas the return dimension is largely covered by high-ranked strategies at the implementation level of ventures. Overall, the strategies at the venture level are ranked highest, followed by strategies at the public authority, investor and then service-provider levels (see Table 3-4). Nevertheless, scholars such as

[14] Governments should rather not pick winners to avoid interference with market dynamics (Bürer and Wüstenhagen 2009).

Wüstenhagen and Teppo (2006) addressed the risk-return ratio via action at multiple levels and argue, for example, that appropriate business models of new ventures that "allow for maximum impact with limited capital input" (ibid. p.70) can decrease the technology risk of VC investments.

3.6.4 Technology Risk and Regulatory Risk are Dominant, but Subcategories Exist

In addition to the technology risk, scholars have discussed other risks that investors must face in the clean energy sector (e.g., Wüstenhagen and Teppo 2006) or in more general settings (e.g., Fiet 1995) to navigate the valley of death. Being active in cleantech rather adds to the conventional risks by increasing uncertainty, e.g., via complex phenomena such as climate change (Heal and Kriström 2002). Nevertheless, our study reveals the main risks that are specifically affected by the sustainability-orientation of cleantech investors and ventures: technology and regulatory risk. The effect of our identified strategies on regulatory risk can be perceived as positive (see *regulatory independence*) or negative (see regulatory intervention, tax benefits or subsidization). Bürer and Wüstenhagen (2008) discuss how this regulatory risk can be managed and distinguish active from passive approaches to managing it; active approaches for investors include employing people with strong policy backgrounds to pursue regulatory affairs management or lobbying approaches, whereas passive approaches include diversification at the venture or fund level (ibid.). We found that risk diversification at the fund or venture level was identified by our sample (see *risk diversification in portfolio*). However, it was perceived as less relevant and neutral in its effect on an investment decision by cleantech investors. Dedicated personnel for lobbying or policy engagement were absent in our sample. In the following section, we will continue to discuss the strategies that were deemed specific for radical, early-stage cleantech investments.

3.6.5 Service Provider's Strategy Implementation to Reduce Cost and Technology Risk

Intermediaries that match between investors and ventures are suggested to mitigate risk for cleantech venture financing via expertise and networks (Bergset 2015). Polzin et al. (2018) describe 'information, networking and conferences' as being perceived positively by investors as policy measures to mobilize early-stage investments in cleantech. The mentioned information, networking and conferences share some characteristics of the intermediation strategy that we identified. However, our findings show that cleantech investors perceive *intermediation* in the sense of facilitation of cleantech ecosystems[15] to not increase the likelihood of a positive investment decision (see Table 3-5).
Furthermore, we found that investment insurance is perceived as moderately potent but largely irrelevant by the investors in our sample. Kasemir et al. (2000) state that government guarantee schemes such as state guarantees for losses on equity investments in new ventures exist in parts of Europe. However, these schemes must be harmonized to reduce complexity and inconsistency in the early-stage VC investment market in Europe (ibid.).

3.6.6 Venture's Strategy Implementation to Reduce Cost

Capital intensity is a key characteristic of hardware-, material- or chemical-based cleantech such as clean energy technologies (cf. Wüstenhagen and Teppo 2006). To overcome this capital intensity, ventures are advised to engage in measures to reduce their cost, such as licensing or engaging in manufacturing partnerships (e.g., outsourcing) (ibid.). Results of our analysis show different approaches to engage in partnerships with, e.g., manufacturers or licensees (*use of proven parts, licensing, outsourcing* and *outsourcing for shares*). Whereas all strategies are

[15] Full description of *intermediation* strategy: Third party creates public and/or private support centres to facilitate the cleantech ecosystem by, for example, providing networks, and enables a shared use of resources or infrastructure to reduce costs for acquisition or R&D and production.

perceived as less relevant, the perception of their potential varies; outsourcing and licensing are somewhat similar with moderate potential, whereas use of proven parts is top ranked. High potential and outsourcing for shares are ranked last, with no increasing effect on the likelihood of making a positive investment decision. However, these strategies can also come at a price; for example, whereas outsourcing production to a different geographical location (e.g., China) might have the economic benefit of decreased costs, the CO_2 footprint might be increased and have a negative effect on the overall sustainability performance of the new venture (cf. MoosaviRad et al. 2014). New ventures must be aware of such trade-offs to make strategic decisions beyond pure financial returns, particularly when approaching impact investors whose foci go beyond profits. Furthermore, they must closely focus attention on not only their sustainability performance but also the overall performance of their value chain (cf. Li et al. 2014).

3.6.7 Venture's Strategy Implementation to Increase Revenue and Reduce Regulatory Risk

Other means of addressing capital intensity from a new venture perspective are generally to pivot the business model or, more precisely, the value proposition (product/service offering, customer segments, and customer relationships), value creation and delivery (key activities, resources, partners, and distribution channels) or the value capture (cost structure and revenue model) element of the business model (cf. Bocken et al. 2014). Our findings suggest ranked strategies for all business model elements: value proposition (*performance and application focus, and adjust for the sustaining of customer's operations*), value creation and delivery (*regulatory independence*), and value capture (*recurring revenue, project financing and pre-financing, and staged market entry*). In terms of value capture, recurring revenues can be achieved by employing additional services and/or software in addition to technological applications as part of the business model. With respect to project and pre-financing, Agrawal (2012) suggests that project financing reduces total financing costs. He introduces risk mitigation strategies when using project financing for cleantech such as renewable energy technologies (ibid.). However, project financing applies to projects rather than companies, and technologies must be proven and mature to be eligible and accepted, e.g., via sophisticated IP protection (cf. Foxon et al. 2005). Its applicability in early stages might therefore be limited. Furthermore, Clay (2013) proposes a staged approach for cleantech products to achieve cost-competitiveness over time. Hence, niche markets can be served initially by focussing on the performance of a cleantech product (see also *performance and application focus*) rather than competing on prices. Mass markets will be addressed in a later stage once economies of scale are realized.

3.6.8 Public Authority's Strategy Implementation to Increase Revenue and Reduce Cost and Technology Risk

Our findings show that one-fourth of the identified strategies are implemented by public authorities and therefore can be described as policy measures, supporting the notion of attention towards these measures to bridge the valley of death (e.g., Frank et al. 1996; Bürer and Wüstenhagen 2009; Wüstenhagen and Menichetti 2012; Polzin 2017; Polzin et al. 2018). We found that non-diluting *grant money* and *regulatory interventions* in particular internalize externalities such as the introduction of a price on carbon dioxide. Such interventions are perceived as rather increasing the likelihood of a positive investment decision. In their research on early-stage investments in cleantech, Polzin et al. (2018) grouped policy measures into three different policy approaches: innovation policies that either create (a) a technology push or (b) a market pull and (c) framework conditions for VC. Adopting this categorization, most of our strategies are in the category market pull (see Table 3-5). Only *grant money* is part of the

technology pull group, and *tax benefits*[16] is allocated to the framework condition category. In addition to Polzin et al. (2018), other scholars also discussed the effectiveness of these policy measures (cf. Yang and Oppenheimer 2007). Yang and Oppenheimer (2007) argue that *subsidization* and *public procurement* can produce a market pull; however, these strategies also require significant funding from public authorities because of the great volumes that are necessary to achieve a sustainability impact; the effectiveness is highly uncertain (ibid.).
Veugelers (2012) advocates a combination of different strategies to increase the leverage of policy instruments; regulatory interventions and subsidies should be combined with public funds that directly invest in new ventures (ibid.). Polzin et al. (2018) follow a similar line of thought, identifying equity rather than debt financing as key to early-stage cleantech ventures. Hence, public authorities should leverage public funds to mobilize more private investment (see *public-private funds* or *public investment mirroring*).

3.6.9 Investor's Strategy Implementation to Reduce Technology Risk

We found that only two strategies at the investor implementation level are perceived to have a (rather) positive effect on the investment decision. S*trategic syndication* is thereby perceived as the most potent strategy. Syndication has been widely discussed for VC investments (e.g., Lockett and Wright 2001; Brander et al. 2002; Dimov and Milanov 2010). Particularly novel investments (early-stage, first-round investments) are more likely to be syndicated (cf. Dimov and Milanov 2010). Investors use syndication to share the risk of investments that have great information asymmetries with the new venture (cf. Lockett and Wright 2001). Syndication among (VC) investors can also increase the rate of return compared with standalone investments by adding value from, for example, complementary skillsets and the pooling of resources of investors and ventures (Brander et al. 2002). However, Dimov and Clercq (2006) note that syndication might not only build up expertise for investor and venture but also increase the risk of investment default when investors " […] count on the efforts of their co-inventors to turn around the performance of disappointing deals […]" (ibid., p.220). Conversely, the specialization of investors might also reduce the risk that an investment in a new venture fails because of crucial expertise and understanding that the investor gained when specializing in a particular field of technology (ibid.). *Cleantech sector specialization* is the second strategy that is perceived as potent at the investor implementation level in our study. Specialization is associated with lower required returns for early-stage venture investments because investors have greater access to information and greater control over risks (Manigart et al. 2002). In addition to specialization, portfolio diversification is another method to reduce the exposure to risk (cf. Ruhnka and Young 1991; Norton and Tenenbaum 1993). Particularly in cleantech such as clean energy, a diversification among different types of clean energy and/or a portfolio mix of clean and conventional power generation assets can reduce risks (cf. Wüstenhagen and Menichetti 2012). Nevertheless, our sample perceived *risk diversification in portfolio* to have a neutral effect on their early-stage investment decision. The same applies to the strategies *greater investment volume* and *longer holding period.* Migendt et al. (2017) state that the cleantech sector in the US lacks accessible exit channels. Hence, long holding periods might already be unavoidable (ibid.).

3.6.10 Investor's Strategy Implementation – Impact Investing and Non-Equity Financing

Furthermore, our findings suggest that when targeting traditional for-profit investors for early-stage radical cleantech investments (as is true in this research setting), *higher risk but higher-impact strategies should be neglected* and ventures financed with debt. The decision to use equity or debt financing to finance a business has important implications for a venture in terms

[16] *Innovation insurance* is also in this group if the service provider is a public authority.

of performance, business operations, business development and survival (cf. Cassar 2004). When deciding on debt financing, two factors increase the chance of obtaining debt financing: [i] IP such as patents and [ii] previous backing by VC investors (Rassenfosse and Fischer 2016; Hochberg et al. 2018). Hardware-, material- or chemical-based cleantech ventures are asset- and research-intensive; thus, IP and assets might be available to back a loan at a later stage in the venture's development. However, financing these ventures in an early stage and before larger scale demonstrations of the technology might be too risky for an investor to engage in *venture debt-financing*. Moreover, the reliance of new, pre-revenue ventures on debt is high (Robb and Robinson 2013).

Bocken (2015) and Höchstädter and Scheck (2015) note that impact investing is mostly being addressed in grey literature (e.g., Simon and Barmeier 2010); the scope of the academic literature is very limited. However, Höchstädter and Scheck (2015) provide a first review of the concept of impact investing and conclude that impact investments are made when venture investments are not currently commercially attractive; "Either the risk of the investment is perceived to be too great, or the investment will never be able to yield risk-adjusted competitive returns due to the investee's business model" (ibid., p. 456). Hence, some research advances into value considerations beyond financial return and towards a broader understanding of value (e.g., financial, social and environmental) (e.g., Emerson 2003).

3.7 **Conclusion**

In this research, we built on transition research to show why hardware-, material- and chemical-based cleantech innovations have the potential to play an important role in a transition to a sustainable society. We further showed that for-profit VC investments in early-stage radical cleantech ventures have almost dried up and suggested that the root cause for lack of investments that can be addressed strategically is the poor risk-return ratio of these ventures. Consequently, our research aimed at identifying, comparing and evaluating strategies that can improve or have successfully improved the risk-return ratio of these investments from the perspective of for-profit VC investors.

3.7.1 Summary of Results

In triangulating between the literature and empirical data, [i] we identified 27 strategies that are the most prominent for positively influencing the risk-return perception of cleantech investors considering investing in early-stage, radical cleantech ventures. We [ii] showed and suggest that all of these strategies can be clustered and evaluated based on risk and return as lowest common denominator, with the four underlying archetypes cost decreasing, revenue increasing, technology risk and regulatory risk. We [iii] showed that the five stakeholders – venture, investor (GP and LP), customer, service provider and public authority – can all influence the investor-perceived risk-return ratio [iv] and showed which strategies are perceived as having more potential than others. Finally, we [v] developed a strategy recommendation matrix consisting of the five areas: neglect, downstream, reconsider, prioritize and pursue. With these results, we contribute to theory and practice in several ways.

3.7.2 Theoretical Contributions and Implications

In our theoretical foundation, we 1) propose integration research studying investor decision criteria with respect to the valley of death, which leads to an extended version of the valley of death, with risk and return subdivided as revenue increasing and cost decreasing as lowest common denominator for the analyses of all decision criteria proposed by research thus far. We 2) further contribute to theory by consolidating several, separate research streams to date, in the broad areas of cleantech policies, geographic and regional-level contextual factors and individual-level investor decision making and behaviour, into the risk-return framework for radical cleantech. We 3) validate our risk-return perspective introduced in the theoretical foundation and propose the four archetypes, technology risk, regulatory risk, cost decreasing and revenue increasing.

3.7.3 Contributions for Practice and Implications

We contribute to practice by 4) providing a hands-on overview of strategies, involved stakeholders and investor-perceived potential that can be used by the multiple stakeholders involved in helping cleantech ventures bridge the valley of death. 5) We strongly suggest creating awareness about the different stakeholders that are needed to successfully implement these strategies. Finally, 6) we show that focussing *only* on policies neglects firm-level strategies that are equally (and some even more) important.

3.7.4 Limitations and Future Research

We identify three limitations, and build on these limitations to suggest future research. First, we do not expect that our list of strategies is exhaustive. Other strategies might exist and/or be developed in the future. The 27 strategies are however based on 45 in-depth interviews with key actors in the field of cleantech VC investment, advancing greatly our understanding of cleantech-specific strategies, with a solid theoretical foundation. We suggest building on these strategies and refining and complementing them in future research. Hence, longitudinal venture investment case studies covering the selection and due diligence process until the investment exit can contribute to measure the success of the identified strategies and to increase the understanding of the interplay and effects when implemented in combined sets of strategies.

Second, the identified strategy potential (i.e., the subjective evaluation by cleantech investors of whether the strategy would increase their likelihood to invest in such a venture) is likely to depend upon contingent factors. For example, outsourcing production for shares (instead of direct payments) was considered critical. However, in a situation in which a corporate investor participated in an investment round and could provide its own production capacities, this solution might make sense. Because we identified a "standard" investment scenario for the identification of strategy potential, we could not consider contingent factors. Other relevant contingent factors are likely to be, e.g., the exact technology that is being developed, regulatory environment/geographic differences and the combination of investors investing in a venture – an area that needs further research.

Finally, a limitation might come from the fact that due to the particularly high capital demand and long technology development cycles, the traditional VC investment model might simply not be the right model for the "real breakthrough" technologies (Gaddy et al. 2017). We thus suggest continuing in two directions: [i] Develop out-of-the-box solutions that challenge the traditional VC investment model to help to develop completely new solutions for the financing of these important technologies. [ii] Continue to refine our understanding of how the risk-return ratio of those cleantech ventures can be improved and of which ventures have the potential to be financed by the traditional VC investment model, with a slightly improved risk-return ratio. The recent opening of the Greentown Labs in Cambridge/USA, which is to our knowledge the world's largest cleantech only dedicated incubator, with space for over 100 ventures, shows that in the future, we can expect capital demand from new cleantech ventures and capital supply from cleantech investors.

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3.9 Appendix

3.9.1 Excerpt from the semi-open interview guide

- Describe a clean technology company where you have invested capital, and that seemed to have relatively lower risk than other similar stage investments
  - What is the story of this investment?
  - What was your rationale for investing?
  - What were the greatest risks in this investment?
  - Did certain regulations or public policies affect your investment decision at all?
  - Did sustainability considerations affect your investment decision at all?
  - Was the team's management sustainability-oriented?

- Describe a clean technology company that you considered, but after diligence chose not to invest capital because of relatively higher risk than other similar stage investments
  - What is the story of this investment?
  - What were the greatest risks in this investment?
  - What were your other rationales for not investing?
  - Did certain regulations or public policies affect your investment decision at all?
  - Did sustainability considerations affect your investment decision at all?
  - Was the team's management sustainability-oriented?

3.9.2 Investment scenario

Investment opportunity in company "CleanTEK":

Business Summary: Company "CleanTEK" is a promising technology company that helps solving an important problem in the cleantech sector.
Investment Stage: CleanTEK is in the earliest stage that you have considered for investment so far.
Need/opportunity: This clean-tech venture is working on a technology that if it works as planned has the opportunity to disrupt a subarea of the cleantech industry and has extremely good growth perspectives.
Solution: The solution is a hardware/software-based technology, that has IP protection opportunities and is very scalable.
Top Milestones: The technology development is in a promising phase, but in order to achieve high growth still needs considerable capital investments.
Management team: You have met the team in person and came to the conclusion that it outperforms most other teams you have seen, which raises your confidence in the success of this investment opportunity.
Use of proceeds: Your proceeds will be used for the technology development aiming to develop/increase (future) revenue streams from this technology.
Overall risk-return evaluation: After the due diligence, you are hesitating, the overall outlook is positive, but the technology intensiveness and the amount of capital is high (as very typical for cleantech investments). At the same time, the overall criteria are very promising.

3.9.3 Exemplary quotes

Table 3-6: Overview of exemplary quotes from interviews (partially based on data from Gonzalez 2016)

Strategy	Decision Criteria (Hall and Hofer 1993)	Quote(s)	Investor Type	Operational Area
Adjust for the sustaining of customer's operations	Product/market consideration	*"[...] the best thing you can do is to develop your technologies so that you can prove that you can make a better product. Then go through the assimilation processes trying to engage large companies that have the cash to build the full-scale facilities, develop the process so that it can be assimilated by that larger company without a large capital cost."*	Expert - Research	USA
Bigger investment volume	Size of investment/Investor control	*"We have needed to do early stage cleantech with some fund which were between 40-60 million euro size in order to be able to follow our investment in time, because when you work in cleantech, it takes time."*	Independent VC	EU
Bigger investment volume	Size of investment/Investor control	*"Clearly there are going to be some more evergreen-like situations that could fund longer term projects. The only problem with that is, again, if you actually do the math, right, if you have a payback way out in 20 years, it better be a heck of a big return for you to justify making the investment now."*	Independent VC	EU
Grant money	Technology	*"When we invest for instance in France when you invest, it's not so difficult to have in front of that, non-dilutive money for the start-ups. So in fact, it can build up and accelerate much faster and so I think the public, there are a lot of public support on financial support."*	Independent VC	EU
Grant money	Technology	*"If you're able to get Horizon 2020 money, you're able to get a strategic investor which often times is an energy utility or an oil company. [...] You might get those companies on board or into more capital intensive cleantech venture investments, but that's not true for pure private VC funds."*	Independent VC	EU
Higher-risk but higher-impact strategy	Investor control	*"We came up with the first idea and focus, and then went out and tried find LPs who were of the same mind and interest as us… certainly if you have a lot of LPs, [sustainable investing] is driven by the GP."*	Independent VC/Impact Investor	USA
Intermediation	Market attractiveness	*"We try to bring many start-ups onstage doing a pitch, plus we bring sponsors on stage and the sponsors are mainly people who want to do business and invest into the start-ups. Sometimes a Law Company or Consulting Firm is among the sponsors and then they still want to do business with everybody at the event."*	Angel Investor	EU
Intermediation	Market attractiveness	*"If you can create homes, bases, and communities for these companies, then more of them will emerge earlier in the pipeline."*	Expert - Incubator	USA
Investment insurance	Cash out potential	*"OK, you buy that device and if something happens that the performance goes down, or something, you are covered by this kind of insurance. Then, we have seen, then it's much easier to sell these kind of devices, if you give at least for a certain period of maybe three to five years a revenue guarantee or performance guarantee."*	Corporate VC	EU
Licensing	Proprietary product	*"For a licensing company if you can raise tens of millions of dollars you probably can be successful in being revenue positive within a 5-10 year period of time, but if you wanted to build a manufacturing entity your raise is going to have to be more like hundreds of millions of dollars instead."*	Expert - University	USA
Longer holding period	Investor control	*"Time horizons matter a lot. [A prominent cleantech VC] was saying that given her track record, her LPs are willing to be more patient and give some wiggle room that may require bigger longer bet. Results matters and she has a track record to point to, and concrete examples for why they took longer and how they were able to work with them."*	Expert - Agency	USA
Outsourcing	Product/market consideration	*"In the early-days of the technology valley of death, you need to figure out what you're going to do in-house versus what you're going to outsource. A start-up can't do it all in-house, you would have to raise hundreds of millions, so you have to find the right partners and leverage existing infrastructure where possible, and be selective about partners, suppliers, and what you do in-house."*	Expert - Venture	USA
Performance and application focus	Background/experience	*"I've walked away from a lot of investments with superstar CEOs who didn't know enough to bring in an experienced person who knew the customers or look after the nuts and bolts of growing a business while they worked on product roadmap."*	Angel Group	USA

Strategy	Decision Criteria (Hall and Hofer 1993)	Quote(s)	Investor Type	Operational Area
Performance and application focus	Background/experience	*"The clean tech companies that do make it in our portfolio are the ones that believe in the technology, that are clean tech and environmentally oriented, but in the end sell a product and lose all the other eco and bio and whatever stamps that there are."*	Governmental VC	EU
Performance and application focus	Background/experience	*"We've kind of spent the last two years gradually evolving how we communicate the opportunity to investors, and we actually don't talk too much about the circular economy per se now, it's more about the ability to improve asset productivity."* *"We don't talk about clean tech, we talk about SME's, we talk about investment opportunity and these types of businesses that are doing what they're doing, simply because we know that that's framing which can be problematic."*	Independent PE	EU
Performance and application focus	Background/experience	*"'green' was translated more into 'well I have a material that's more chemically durable, stronger, I can make it much faster, I can stockpile my raw material instead of having to order on demand'"*	Expert - University	USA
Public funds	Investor group	*"The last couple of years we have seen some sovereign world funds from Asia and the middle east investing in those kind of things, but the traditional European investors… difficult to get them involved in, in these kinds of ventures."*	Governmental VC	EU
Public investment mirroring	Investor group	*"The KfW [German government-owned development bank] is involved and their strategy is that they always co-invest with some other investor and they basically mirror their investment."*	Corporate VC	EU
Public-private funds	Investor group	*"10 years ago, there was no seed money. That was a big problem. Government identified this problem They established e.g., the High-Tech Gründerfonds in Germany. The problem was solved in Germany. There now is enough seed money."*	Corporate VC	EU
Public procurement	Market attractiveness	*"First of all, public actors are buyers and should be buyers of clean technologies and green products they can become a customer to too many of these start-ups."*	Angel Investor	EU
Recurring revenues	Product/market consideration	*"Right now we are more and more going into energy services. So, that has something to do with the transition of the utilities and all the energy companies. But our business models are dominating with recurring revenues and so the risk is much less in that sense."*	Independent VC	EU
Regulatory independence	Threat resistance	*"We built our business from the beginning to not rely on incentives or subsidies, which is a big difference from our competitors who almost all are heavily subsidized by the government.*	Expert - Venture	USA
Regulatory independence	Threat resistance	*"The strength of our investment thesis is that we're not too beholden to government incentives around, you know, green infrastructure or environmental regulations."*	Independent PE	EU
Regulatory interventions	Market attractiveness	*"Only the public sector [...] can create the incentive for these industries to bloom again. Be it by, you know, changing the regulatory environment, creating incentives, the carbon price, you know manipulate or influence the carbon market, so that carbon prices go in the direction where early stage hardware technology investment makes economic sense again."*	Independent VC	EU
Regulatory interventions	Market attractiveness	*"If the regulation is not supporting that business model of such a technology, then it goes very very slowly and it's really a pain. So, regulations are really a key driver of that and can help a lot here."*	Corporate VC	EU
Cleantech sector specialization	Familiarity with technology, product, market	*"Acceleration can happen if you give the entrepreneurs time to figure out what their technology is capable of first, and then you orient them to the appropriate market. That market could be one VC underwrites or maybe one they don't."*	Expert - Incubator	USA
Cleantech sector specialization	Familiarity with technology, product, market	*"We do our homework during the due diligence, we try to get smart in the particular business of one start-up in a particular sector, along the way when we look at that company in detail until we come to an investment decision, positive or negative, and then post investment we continue to get smarter and better connected in order to create more value post investment in this particular market."*	Angel Investor	EU
Staged market entry	Product differentiation	*"There are two things which really can speed up technology development in general: [...] first, find a market in the consumer industry; then comes back to the industry applications.!*	Corporate VC	EU
Staged market entry	Product differentiation	*"You have to have some DNA around commercializing something with a near term market they could reach quicker and scale to larger reach buyers that have quicker cycles, think*	Independent VC	USA

Strategy	Decision Criteria (Hall and Hofer 1993)	Quote(s)	Investor Type	Operational Area
		through the business cycle more so instead of one large long-term market a lot of interim markets." *"The mistake the cleantech sector made was it thought itself like biotech. You spend years developing something in storage or generation to reach a commodity market, but there is no reward like the next blockbuster pharmaceutical. Cleantech has to create real revenue markets along the way to keep going. That's hard to do because it requires a lot of thinking."* *"... If you're doing a battery company, maybe you create smaller batteries for [Internet of Things] and don't create car batteries, but start with toys because you're closer to the individual customer. [One] company started by selling hydrogen toys, reached the energy customer first with science kits, and they did very well. That was enough to keep them going and experimenting on bigger scale."*		
Strategic syndication	Investor group	*"Well syndication is indeed a good way of developing expertise, or making sure you have the expertise round the table. In order to make the good decision. So, you can think of syndicating a deal with a corporate investor."*	Governmental VC	EU
Strategic syndication	Investor group	*"Syndication is generally a good thing. It allows you to spread the risk. You can bring in other skillsets. It's usually too risky to go all alone in one venture."*	Corporate VC	USA
Subsidization	Market attractiveness	*"China of course has done exactly the same thing. They too have picked favourite places and they've put a lot of support and subsidies in real businesses there and they've created world champions that stand on their own."*	Independent VC	EU
Subsidization	Market attractiveness	*"What's critical often times is not so much the subsidies but their certainty. If you're trying to grow a company that takes 10 years and subsidies are only for 2 years it's detrimental. Certainty is all important and still is."*	Expert - Venture	USA
Use of proven parts	Technology	*"Production it's a big area where start-ups can decide to become more capital efficient because they will not they do not have to raise the money to build the factory"*	Angel Investor	EU
Use of proven parts	Technology	*"Something that is truly capital-intensive will have to raise an equal amount of equity, and if it's off-the-shelf technology then they could get standard equipment finance and project-based finance."*	Independent VC (Dept Finance)	USA
Venture debt financing	Investor control	*"When you look at the capital stack, equity is the most expensive dollars in. If you can bring in debt, it's a good situation."*	Expert - Venture	USA
Risk diversification in portfolio	Cash out potential	*"Building your portfolio and I'm not saying we're doing that right, we'll see at the end, but indeed you try to mix up different types of risk profiles in order to have an overall performance that could be relevant for a LP."*	Governmental VC	EU
Risk diversification in portfolio	Cash out potential	*"[...] that's a combination of a vision, a strategic decision to diversify the fund we work on, but also an opportunity which was offered to the team to raise this fund."* *"We try to mix. [...] We try to have some deals which are very early stage dedicated to cleantech, but we know that it will take time and we will have put a lot of capitals in [those...] On the other side to do some deals where we know that it could go much more faster and easier. We try to be balanced on this investment."*	Independent VC	EU

Article 3

Innovation Intermediaries: What Does it Take to Evolve and Survive Over Time?

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4 ARTICLE 3
Innovation Intermediaries: What Does it Take to Evolve and Survive Over Time?

4.1 Abstract

Innovation intermediaries are recognised as crucial actors that can facilitate the innovation process and contribute to sustainable entrepreneurship. More precisely, they are key in the effective coordination of sustainability effect and market impact in sustainable entrepreneurship where both large incumbents and new entrants affect the sustainability transition by sustainability performance and market share.

However, little is known about the temporal dimension of innovation intermediaries and how they change over time to survive.

An in-depth case study design with a comparative approach was chosen to examine four innovation intermediaries at different development stages in related fields of technology in Europe, the USA, and Australia.

This study sheds light on the evolution and survival of innovation intermediaries: First, by describing the dynamics in an intermediary's (a) characteristics, (b) scope, (c) objectives, and (d) roles and activities. Second, by identifying at least four factors influencing an intermediary's survival: (i) neutrality, (ii) technological context, (iii) shared consensus, and (iv) internal value creation.

4.2 Introduction

Addressing contemporary environmental problems such as climate change, biodiversity loss, and natural resource depletion requires changes to existing socio-technical systems (Geels 2011). Such changes are systemic and encompass deep structural changes in existing energy, chemistry, transport, and agri-food systems covering their related technologies, policies, markets, consumer and business practices, cultural meanings, and scientific knowledge (Grin et al. 2010) . And in particular tackling climate change requires urgent decarbonisation of energy supply and demand (Matschoss and Heiskanen 2017). Technological change is often argued as a necessary component of strategies to tackle such contemporary environmental problems even though not sufficient in itself due to the multifaceted nature of these environmental problems (Kanda 2017). Furthermore, relevant technological innovations take decades to reach mainstream markets due to barriers such as lock-ins to high carbon technologies, path dependencies, and resistance from incumbents. Thus, supporting the innovation and widespread diffusion of technologies for decarbonisation is of keen interest for policy makers and researchers alike (Matschoss and Heiskanen 2017).

In addressing resource depletion and climate change, a promising technological development relates to technologies that are developed with the intention to capture carbon dioxide (CO_2) and utilise it for CO_2-based products or permanently store it in geological formations. Such technologies particularly CO_2 utilisation continue to emerge characterised by high capital intensity and radicality compared to alternative technologies (Kant 2017). And even though these technologies have the potential to convert CO_2 into raw material, with some related products such as CO_2-based fuels about to reach mainstream markets, and thereby gaining increasing relevance for sustainability transitions, there is a continued need for their rapid and widespread diffusion if such technologies are to make a meaningful contribution to sustainability transitions (Kanda et al. 2016; cf. Boons and Lüdeke-Freund 2013). To support the development and diffusion of such innovations, support systems comprising of "all actors, institutional settings, and resources that help entrepreneurs in successfully generating and implementing innovation" (Fichter et al. 2013, p. 75) has emerged in many countries. This article focuses on a particular type of actor within such support systems referred as intermediaries.

Howells (2006, p. 720) defines an innovation intermediary as "an organization or body that acts [as] an agent or broker in any aspect of the innovation process between two or more parties". Innovation intermediaries are recognized as crucial actors that can facilitate the innovation process (Howells 2006; Boon et al. 2011) and contribute to sustainable entrepreneurship (Gliedt et al. 2018). Intermediaries facilitate the innovation processes by assuming different roles such as mobilising and distributing resources (e.g., Polzin et al. 2016), creating spaces for networking and collaboration between different actors (e.g., Hakkarainen and Hyysalo 2016), and advocating for policy change and renewal among several other roles (e.g., Kivimaa 2014). Sustainable entrepreneurship at the receiving end of intermediation activities is an essential driving force in the creation and transformation of ecologically and socially sustainable economic systems (Pacheco et al. 2010) and a vital ingredient for sustainability transition (Markard et al. 2012).

Even though the literature on intermediaries continues to grow (see Gliedt et al. 2018 for a recent review), certain research gaps remain to be addressed. For example, until recently (e.g., Kivimaa and Martiskainen 2018), there has been little research about the evolution of intermediation and the sustainment of innovation intermediaries' roles and activities over time (Hakkarainen and Hyysalo 2016). A better understanding of the temporal dimension of intermediaries and intermediation is relevant due to the fact that innovation intermediaries are key in the *effective coordination* of sustainability effect and market impact in sustainable entrepreneurship (Hörisch 2015). Both large incumbents and new entrants can engage in sustainable entrepreneurship and impact sustainability transition by improving the sustainability performance and/or increasing the market share (Hockerts and Wüstenhagen 2010). And in particular, sustainability-oriented innovations such as CO_2 utilisation technologies that use CO_2 to produce fuels or chemicals (Styring et al. 2015a), competing to substitute fossil resources on mass/commodity markets (Bocken et al. 2014), may not be economically viable from the start but require external change to bring viability in the future (ibid). Innovation intermediaries can *amplify the necessary change* for these technologies by advocating for them (e.g., Kilelu et al. 2011).

The purpose of this article is to contribute to the understanding of innovation intermediaries' evolution and survival by answering the following research question: *How do innovation intermediaries evolve over time, and what are the survival factors in that evolution?* This article explores this question by analysing innovation intermediaries at different development stages in similar fields of technology via case studies. The rest of the article is structured as follows: Section 4.3 reviews previous literature to highlights research gaps which warrant the guiding research question. The research methods used to collect and analyse the empirical data is presented in Section 4.4, followed by a presentation of the empirical results in Section 4.5 and their discussion in Section 4.6. Conclusions are drawn with implications for theory and policy in Section 4.7.

4.3 **Previous Literature**

4.3.1 Roles of Intermediaries in Innovation and Sustainability Transitions

The concept of innovation intermediaries has received extensive scholarly attention in the last decade (Gliedt et al., 2018). The concept can be traced back to open innovation in which intermediaries acted as brokers as firms progressed from linear and supply-side driven innovation to include users through co-creation and also to access complementary resources (Chesbrough 2006). In recent times, intermediaries have become strongly connected to the sustainability transitions literature (Kivimaa et al. 2017). In specific, there have been scholarly contributions on how intermediaries can facilitate transitions in different socio-technical systems such as in urban infrastructure (Hodson and Marvin 2010), energy systems (Kivimaa 2014), housing systems (Kivimaa et al. 2017) and in driving forward national agendas such as the circular economy (Barrie et al. 2017).

Traditionally, intermediaries have performed bilateral facilitating roles by assisting individual firms to reach their innovation objectives (Howells 2006). However, as the innovation process has become increasingly complex involving several actors, their networks, and institutions, this one-to-one intermediation activities are being complemented by “systemic intermediaries” (van Lente et al. 2003). Systemic intermediaries do not operate on the individual firm or project level but rather on the network level, in innovation systems or even transitions (van Lente et al. 2003; Kivimaa 2014; Klerkx and Leeuwis 2009).

One of the most studied aspect of intermediaries is their roles in facilitating innovation processes and sustainability transitions (Martiskainen and Kivimaa 2017). And by extension, there are different lists of roles attributed to intermediaries and even some redundancy and confusion regarding the different roles (Klerkx and Leeuwis 2009). The roles attributed to intermediaries include articulation of needs and requirements, identification of needs, creation of business cases, communication and development, project management, managing external resources and organizational development, foresight and diagnostics, scanning and information processing, knowledge processing and combination/recombination, gatekeeping and brokering, testing and validating, accreditation, validation and regulation, protecting the results, commercialisation and evaluation of outcomes (Howells 2006; Bessant and Rush 1995). However, Hakkarainen and Hyysalo (2016) in a recent article have criticised the approach of listing the various roles of intermediaries as a rather rudimentary way to theory building and advocate for more analytically oriented typology of intermediary roles with more insights into the specificity regarding the content of the different roles. Stewart and Hysalo (2008) argue that the different roles of intermediaries can be grouped into *facilitating* – providing opportunities and space for other people to act; *configuration* – adjusting the material and symbolic form of technology often in minor ways as well as how it is interpreted and used; and *brokering* – establishing, nurturing, adjusting and altering of connections between different actors.

A particular research gap in the literature regarding the roles of intermediaries in innovation is that apart from a few studies (e.g., Hakkarainen and Hyysalo 2016; Martiskainen and Kivimaa 2017), the roles of intermediaries have been studied as being static. In fact, as Martiskainen and Kivimaa, (2017) put it, much of the literature has focused on the roles of intermediaries with little knowledge available on how intermediaries and their intermediation activities change over time in innovation processes (Kivimaa and Martiskainen 2018) . Furthermore, there is compelling empirical evidence to support the fact that the content and form of intermediary work evolves over time as a response to the changing contextual conditions (Kivimaa and Martiskainen 2018). The issue of longevity and survival is particularly important because in order for intermediaries to facilitate the systemic changes needed for sustainability transitions, intermediaries need to have longevity as an organization and also they need to be capable of changing their roles, adapt their roles to evolving structures and also hold multiple roles at the same time (Hakkarainen and Hyysalo 2016). Thus much finer information on the content and form of intermediation activities is needed which goes beyond listing of intermediary roles (Hakkarainen and Hyysalo 2016).

4.3.2 Survivability of Intermediaries and Intermediation Activities

The literature identifies a number of factors which are important for the long-term survival of intermediaries and their intermediation activities. In her study of systemic intermediaries striving for energy system transitions, Kivimaa (2014) identified that one factor for the success of such intermediaries was their neutrality. Neutrality in this regard refers to the independence of intermediaries from public administration and politics, finance or technology. These different types of neutrality gave the intermediary trust among different parties which they usually intermediate in-between. For example, being independent from public administration is regarded as particularly crucial for encouraging informal intermediation activities and also personal relationships between actors necessary to drive forward sustainability transitions (Matschoss and Heiskanen 2017). Financial dependence of public administration can also be problematic for building trust since such authorities can limit the freedom of the intermediary to set their own agendas and also act freely indicating a level of lock-in to existing economic and institutional conditions. This can contribute to miss-trust from different actors, networks and institutions regarding the intermediation abilities of the particular intermediary. On the other hand, technological neutrality refers to intermediaries not explicitly supporting a particular technology, and though such a stance is likely to increase trust among their clients, the urgency of climate change and sustainability transitions requires that intermediaries sometimes have to be outspoken and biased towards certain technologies or parties (Klerkx and Leeuwis 2009).

In addition to seeking neutrality and impartiality in their activities, intermediaries also have to balance different kinds of demands and expectations placed on them that have direct influence on their present and future position (Klerkx and Leeuwis 2009). Another key issue regarding the survivability of intermediaries is with regards to source and stability of funding. Intermediaries can receive their funding from public and/or private sources and this can have significant impact on their intermediation activities. Publicly funded intermediaries have their funding mainly from governmental budgets e.g., government ministries, public taxes or municipal bodies (van Lente et al. 2003), while private sources of funding typically include client fees. However, the distinction between public and private source of funding is not a dichotomy but rather as a continuum since publicly funded intermediaries can receive a share of their funding from private source and vice versa. More importantly, intermediaries which are initially public funded can also seek to or be mandated to be self-financing in the course of time as they become more established, independent and also their clients appreciate the importance of their intermediation activities (cf. Kivimaa and Martiskainen 2018). Indeed, the source of funding also affects the neutrality and the trust that intermediaries have among their stakeholders. Source of funding influences whether intermediation activities are generic or tailored to meet the specific needs of different groups and also if intermediaries seek long term strategic intermediation activities necessary for sustainability transitions or are actively seeking to secure funding for their own survival (Hodson and Marvin 2010). Achieving a balance between different types of expectations is particularly complex in the case of mixed funding (public-private). This gives rise to a social dilemma as intermediaries have to remain credible to the different actors between whom they mediate, and balance between short-term with long-term considerations essential for their proper functioning.

4.4 Research Design

The research is designed to capture the temporal dimension of the intermediation process in related fields of technology. A detailed analysis of entities at different stages (e.g., technological maturity, age of entity) is used to map characteristics, scope, objectives, roles and activities, and assess the evolution of innovation intermediaries. A case study design with a comparative setting (Yin 2013; cf. Eisenhardt 1989; Eisenhardt and Graebner 2007) was chosen to examine four innovation intermediaries: two in the field of CO_2 utilisation and two in the field of Carbon Capture and Storage (CCS). This design emphasises comparison within and across contexts to draw from causalities and acknowledges a well-developed methodology for project-based and systemic intermediation. The empirical setting was selected to be Europe, the USA and Australia. This selection is based on the existence of institutional framework that support sustainability-oriented innovation and with the ambition to show a diverse set of cases among which any similarity on their evolution and survival could be compelling.

4.4.1 Sample and Data Collection

The cases that have been carefully chosen in the field of CO_2 utilisation, and CCS allow for an observation on various levels (e.g., technology maturity, age of entity). CO_2 utilisation converts CO_2 molecules to other molecules in innovative approaches (Kant 2017) whereas CCS captures CO_2 mainly from point sources and stores it in geological formations (e.g., Styring and Jansen 2011). Both, CO_2 utilisation and CCS qualify for the need to coordinate sustainability effect and market impact (Hörisch 2015). They have a high sustainability effect because they either increase resource efficiency (Naims 2016) or mitigate climate change (Styring and Jansen 2011). In addition, they are on niche markets (Aresta et al. 2013) or the most costly technology to abate CO_2 emissions (Nauclér and Enkvist 2009)[17]. Hence, the related fields of technology reflect the underlying relevance of a need of coordination.

Technologies in both fields are at different stages of maturity (e.g., Styring and Jansen 2011). However, on the four development levels (1) basic research, (2) R&D, (3) demonstration, and (4) commercial application, the majority of CCS technologies are at a later stage in the demonstration phase (e.g., Coninck et al. 2009; Bui et al. 2018) and CO_2 utilisation technologies are mainly int the R&D phase transitioning to demonstration (e.g., Zimmermann and Schomäcker 2017). Furthermore, intermediating actors in these two fields of technology have different ages. The average age of CCS intermediaries is 10.75 years and the average age of CO_2 utilisation intermediaries is 2.75 years.

The authors used a purposeful sampling approach to identify four critical cases (Palinkas et al. 2015) of intermediation for CO_2 utilisation and CCS to make effective use of limited research resources (Patton 2015). The paper's focus on these fields of technologies drastically reduced the population of intermediaries for sustainability-oriented innovation: the authors identified nine ongoing (as of October 2016) initiatives that qualify as intermediary according to Howell's (2006) definition and are not primarily networking associations or conference providers; three in the field of CO_2 utilisation and six initiatives in the field of CCS. The identification process was carried out by desk research (examples of keywords: "[field of technology] initiative*", "[field of technology] activit*", "[field of technology] program*", "[field of technology] association*". etc.) and the author's attendance at workshops and conferences in the field of CO_2 utilisation and CCS in 2015 and 2016. Some of the identified initiatives were present at those events, others were recommended to the authors by experts in the respective field of technology (snowball sampling). The final case selection was based on the criteria of few and in-depth observations, the (perceived[18]) degree of a case's activity, accessibility of interviewees in management or steering positions, and a diverse and broad operational focus in the sample (see Figure 4-1).

The authors used existing and new personal contacts to knowledgeable individuals to start the data collection in 2016. Both, interviews and documentation have been used as a data source to compare bottom-up, industry-initiated and top-down, government-initiated entities in Europe, the USA, and Australia.

Eight interviews have been conducted in person (in Germany and Australia) or via telecommunication between September and December 2017. A semi-structured open interview guide was used to explore characteristics, scope, objectives, roles and activities over time and

[17] CSS is even considered as a non-profit technology because of its costs without current financial returns (https://setis.ec.europa.eu/setis-reports/setis-magazine/carbon-capture-utilisation-and-storage)

[18] As most frequently reported by the experts or frequent participation at events

to identify challenges and drivers in the evolution. The following four items have been addressed (see Table 4-3 in Appendix 4.11.1 for an excerpt of the semi-structured interview guide):

- Introduction and background of entity and interviewee
- Characteristics and scope of entity (source of funding, governance, ownership, level of activity, innovation phase)
- Objectives and goals of entity (may include objectives of different partners or members)
- Roles and activities to achieve objectives

The interviews took between 22-62 minutes. All interviews have been recorded and transcribed to enable a rigor data analysis. All interviewees have been asked for consent prior to participation in the study. Furthermore, interviewees approved the transcription when required and the interview data has been anonymised for the analysis. A detailed description of the interviews per case can be found in Table 4-1.

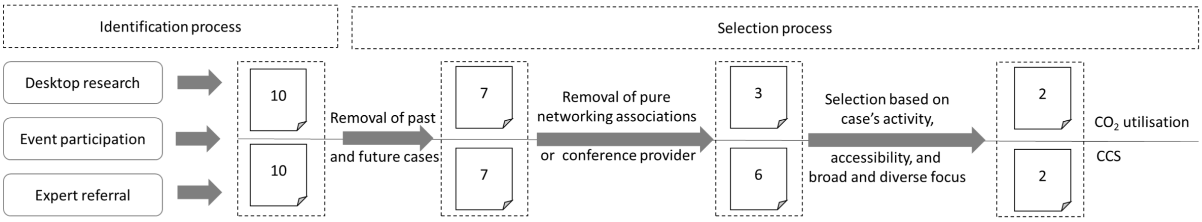

Figure 4-1: Overview of sampling process

Table 4-1: Case study overview (long)

	Founding date of intermediary	Age of intermediary [in years]	Field of technology	# of interviewee(s)	Date of interview(s)	Duration of interview(s) [in min]	Position in intermediary	Time in intermediary [in years]
Case 1 (government/ industry-initiated)	05/2014	3.5	CO_2 utilisation	1 (lead partner 1)	26/09/2017	62	Programme manager (spokesperson)	2 (2)
				2 (lead partner 1)	06/11/2017	55	Steering committee member	2
				3 (lead partner 2)	02/11/2017	37	Programme manager (spokesperson)	2 (1)
				4 (lead partner 2)	16/11/2017	28	Supervisory board member and initiator	2
Case 2 (industry-initiated)	01/2016	2	CO_2 utilisation	1	10/11/2017	22	Scientific advisory board member	1
				2	21/11/2017	23	CEO	2

	Founding date of intermediary	Age of intermediary [in years]	Field of technology	# of interviewee(s)	Date of interview(s)	Duration of interview(s) [in min]	Position in intermediary	Time in intermediary [in years]
Case 3 (government -initiated)	06/2009 transition in 03/2013 (2014 ongoing)	3.75+3.75=7.5	CCS	1	24/11/2017	62	CEO	6
Case 4 (government -initiated)	10/2003 transition in 12/2005 (renamed 12/2014)	2+(9+3)=14	CCS	1	04/12/2017	30	COO	3

Publicly available and partially confidential documentation published between 2010 and 2017 has been used to triangulate the interview data and saturate the data collection process. The documentation ranged from presentations and webinars to detailed reports about the cases from the entity in the sample or from external sources. However, the age of the research subject affects the availability of these documents (see Figure 4-2).

During the data collection process one case became particularly interesting due to its foreseeable termination by the end of 2017. Hence, the depth of that case was deepened by multiple interviews with both operating and strategizing personnel from the lead partners of the initiative in the sample (see Figure 4-2).

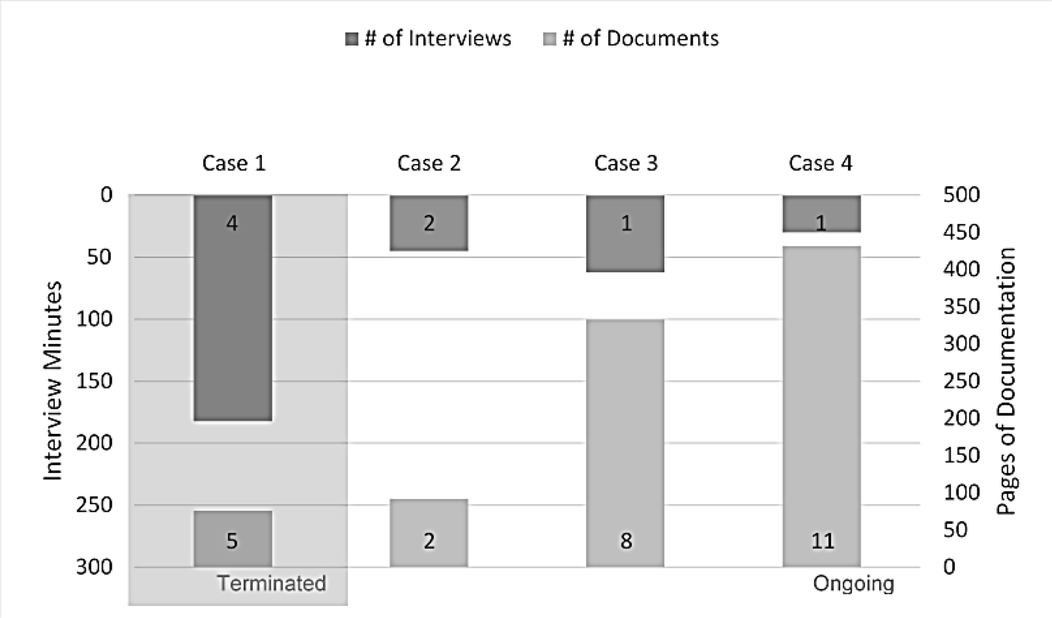

Figure 4-2: Case study depth

4.4.2 Data Analysis

A staged coding process (Strauss and Corbin 2015) was used to analyse the data via the software Atlas.ti 8 (ATLAS.ti 2018) and manual data extraction. Following Gioia et al. (2013) we structured our iterative analysis – where we went back and forth between the data and emerging theoretical themes and dimensions – in multiple distinct phases (see Figure 4-3).

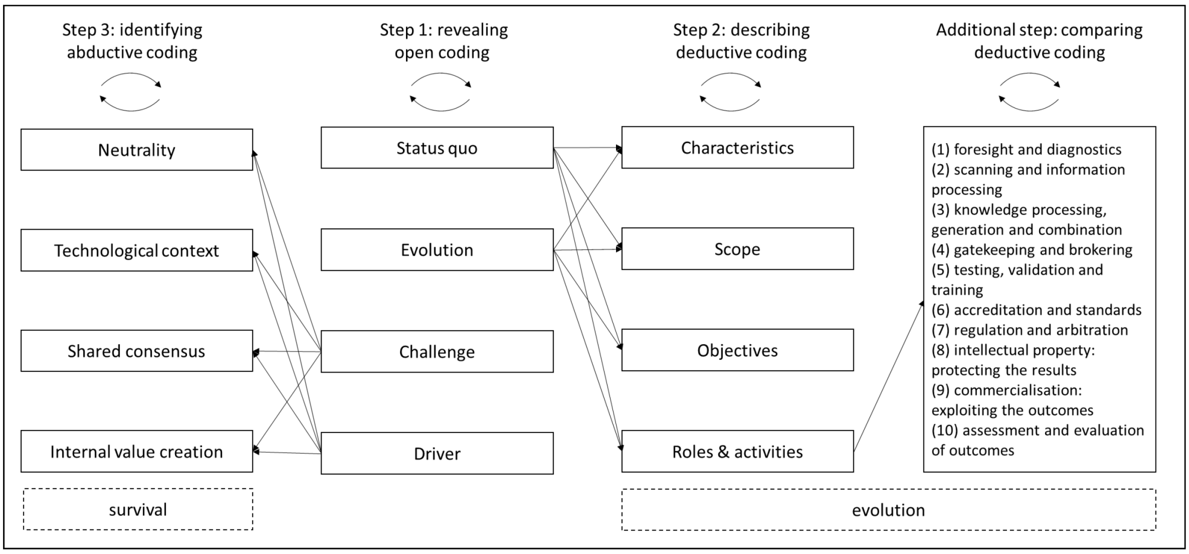

Figure 4-3: Coding process

First step (open coding): Revealing status quo, evolution, driver and challenges of innovation intermediaries

In an (semi-)open coding process the authors focused on keywords reflecting the status quo, evolution, driver and challenge of an innovation intermediary. Statements of the interviewees (quotes) have been iteratively categorised, and similar observed phenomena have been labelled so that codes and code categories emerged from the texts.

Second step (deductive coding): Describing the evolution

Code categories reflecting the evolution were then refined, condensed and further aggregated together with code categories reflecting the status quo into four theory-based code themes that were deductively queried in the interview: characteristics, scope, objectives, and roles and activities. The themes characteristics and scope were thereby broken down into sub-themes. All themes were derived from literature that describes and classifies innovation intermediaries based on typologies (e.g., Howells 2006; Kanda et al. 2015; Klerkx and Leeuwis 2009) .

Third step (abductive coding): Identifying dimensions of survival

Code categories reflecting the driver and challenge followed were inductively condensed and further aggregated by manual extraction into 23 code themes in an axial coding process. Ultimately these categories were assigned to four overarching code dimensions that abductively narrowed down the main driver and/or challenge of innovation intermediaries: neutrality (e.g., Kivimaa 2014), technological context (e.g., Kanda 2017), shared consensus (e.g., Klerkx and Leeuwis 2009; Laur et al. 2012) and internal value creation (e.g., Silva et al. 2018).

Additional step following the second step (deductive coding): Comparing roles and activities as proxy for the evolution

In a parallel process, codes in the code theme 'roles and activities' have been categorised based on an existing typology of intermediation roles from Howells (2006) to ensure that all relevant roles and activities have been covered. The authors choose this typology to maximise the information being capture in each type. Other typologies leave little room for comparison across the different types due to the limited amount of types (e.g., Stewart and Hyysalo 2008). Howells (2006) divides the roles of an innovation intermediary into ten categories: (1) Foresight and diagnostics, (2) scanning and information processing, (3) knowledge processing, generation and combination, (4) gatekeeping and brokering, (5) testing, validation and training, (6) accreditation and standards, (7) regulation and arbitration, (8) intellectual property: protecting the results, (9) commercialisation: exploiting the outcomes, and (10) assessment and evaluation of outcomes. All documents have been coded using this typology via Atlas.ti's "auto coding" function to complete and triangulate the interview data. Search strings for the auto coding have been derived from the interview codes and all matches have been manually checked by the coder.

Information about the number of reported codes per Howells' (ibid.) category and case have been mapped to enable for a comparison between cases and fields of technology (see Figure 4-5 in Section 4.5.1.4). The field of technology is thereby used as a proxy for the temporal dimension. Furthermore, the maximum amount of codes from CO_2 utilisation have been subtracted from the maximum amount of codes from CCS to enable a comparison along Howell's (ibid.) categories and shed light on the evolution (see Figure 4-6 in Section 4.5.1.4).

4.5 **Results**

This section presents the results as outcome of the coding process. Figure 4-4 provides therefore an overview of the data structure. The data structure is also used to organise the results section: First, status quo and evolution will be presented based on the characteristics, scope, objectives, and roles and activities of the innovation intermediaries in the case study. Second, drivers and challenges as determinants for survival will be presented based on four dimensions: neutrality, technological context, shared consensus, and internal value creation. Aggregated code themes for these dimensions will thereby further help to structure this section. Table 4-4 in Appendix 4.11.2 provides a detailed overview of the codes related to evolution themes and survival dimensions and references to the four cases.

4.5.1 Status Quo and Evolution

The characteristics, the scope, the objectives, and the roles and activities of an innovation intermediary evolve over time. This section describes this evolution and provides an overview of the status quo of these categories and sub-categories (see Table 4-2). Furthermore, a comparison of the roles and activities per case and field of technology serves as proxy to give further insights about the evolution of intermediaries.

4.5.1.1 Characteristics

Characteristics of the studied intermediaries are described using their sources of funding, governance structure, and type of ownership model which is a continuum from private to public (Perry and Rainey 1988). Case 3 and 4 were initiated with a similar funding structure by governments and received main funding from public actors such as national and regional governments. A minor source of funding from industry evolved over time to another substantial source. Both cases are currently funded by a mix of public and private sources ranging from membership fees over revenues to residual and new funds from governments. Case 2 was initiated by industry and is mainly funded by private high-net-worth individuals, foundations, and corporates, but potentially also by governments via grant money. Case 1 got its initial funding with the requirement to be financially self-sustaining in the future from the government. The governance structures of case 3 and 4 was set up and remained as membership organisation with an (independent) board of directors. Case 2 is governed privately with an advisory board. Case 1 inherited the ownership model from the co-initiating[19] public-private partnership (PPP), whereas case 3 and 4 evolved from government-initiated organisations to private, not-for-profit organisations that financially self-sustain its operations. All three cases are membership-based. Case 2 was set up as a private not-for-profit organisation.

4.5.1.2 Scope

The scope of each case is described by the level of activities, phase in the innovation process, operational area, and technology focus.

Case 1, 2, and 4 are predominantly active on a project level in the innovation phase of technology (and knowledge) development. However, some activities are also performed on a system level. Case 3 is mainly active on a system level with some activities on a project level. Furthermore, case 3 evolved from focussing on the development, demonstration, and deployment of technology to a focus on deployment and diffusion phase of innovation.

All cases, except case 3, which operates globally, concentrate their operations on a specific geographical region (USA, Europe or Australia)

Case 2, 3, and 4 have a broad technology focus and include all technologies from their field in their scope. Case 1 has a rather narrow focus on a technology pathway.

[19] The other initiator came from industry.

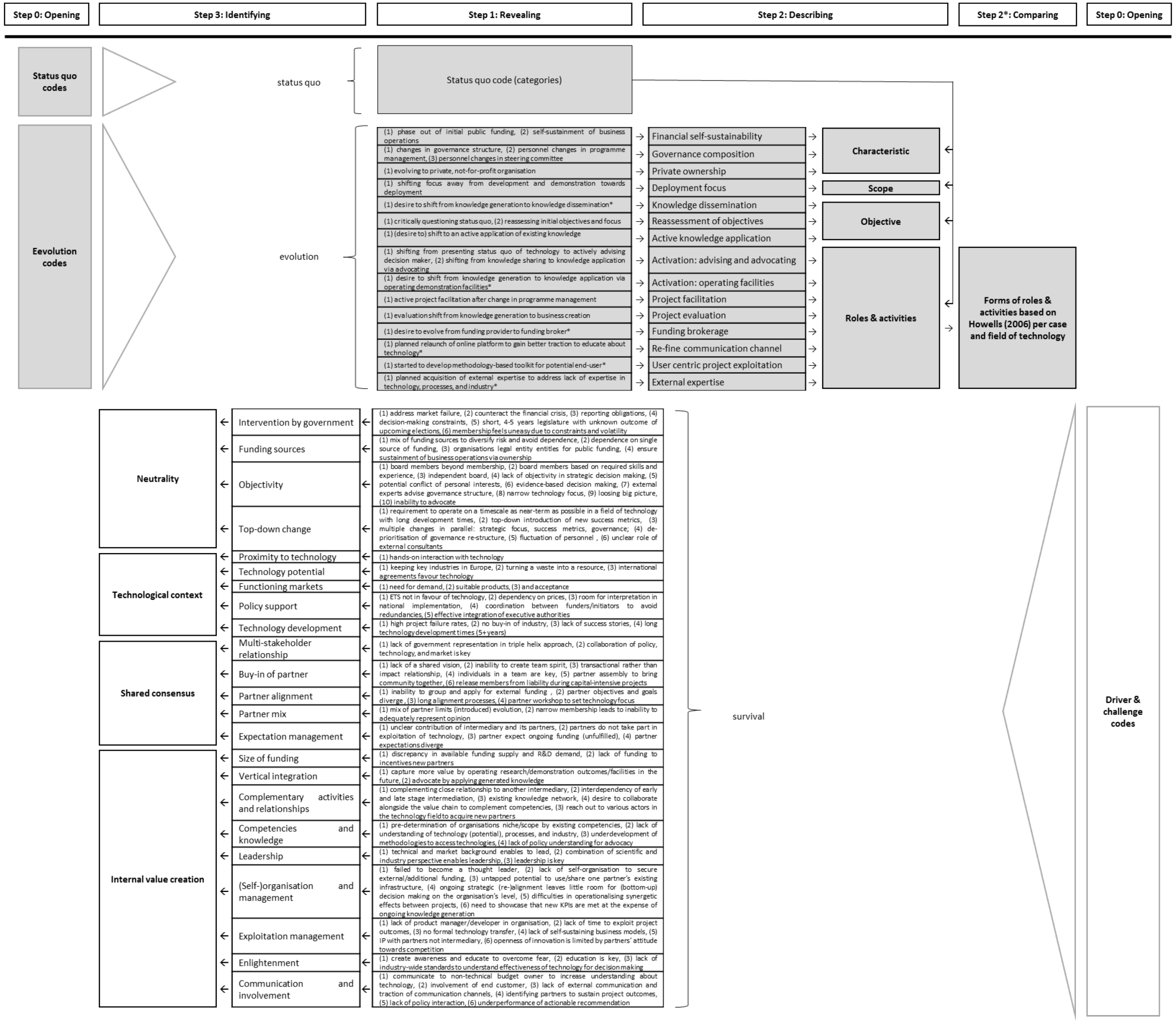

Figure 4-4: Data structure

Table 4-2: Overview of cases' characteristics, scope and objectives (status quo)

	Source of Funding	**Governance Structure**	**Ownership model (legal form)**	**Level of activities**	**Innovation phase**	**Operational area**	**Technology focus**	**Objectives**
Case 1 (government/industry-initiated)	Public funding as main source. Private funding (revenues, substantial membership fees) was intended to replace public source, but was aborted	Joint public-private collaboration with programme management and steering committee between lead partner 1 (PPP) and lead partner 2 (industry) at the ratio of partner 1 to partner 2: 50/50→100/0	Inherited PPP model: membership-based	- Project level: parallel running point innovation projects alongside - System level: projects on system level; actionable recommendation for stakeholder currently underperformed	Technology and knowledge development	Supranational	Narrow: fraction of CO_2 utilisation technologies	Support the creation of a CO_2 re-use value chain/market (connect solution provider and seeker), unite partners with common interest, and discover opportunities *Partner objectives:* Partner 1: climate impact (short-term) Funder: innovative solution (short-term) Partner 2: strategic alliances across 3 P's Research partner: research funding
Case 2 (industry-initiated)	Private funding from high-net-worth individuals, foundations, corporations as main source. Additional public funding from governments	Privately governed with advisory board and absent self-dealing	Private not-for-profit organisation (charity)	- Project level: expert advises, collaboration - System level connectivity	Technology development	National	Broad: all CO_2 utilisation	Promote and catalyse the deployment of carbon conversion technologies
Case 3 (government-initiated)	Mix of public and private funding sources via residual funds, membership fees and revenue	Governed as private and public member organisation with board of directors, board selection panel, annual general meeting, etc.	Government-initiated private membership organisation (Australian corporations law company limited by liability)	- System level: contextualisation of big picture - Project level: contract research	Deployment and diffusion	Global	Broad: all CCS	Accelerate the deployment of CCS, capacity building in non-OECD countries

	Source of Funding	Governance Structure	Ownership model (legal form)	Level of activities	Innovation phase	Operational area	Technology focus	Objectives
Case 4 (government-initiated)	Mix of public and private funding sources at the ratio of 1/3 national government, 1/3 industry, 1/3 regional/international government	Governed as private and public member organisation with board of directors, four committees, etc.	Government-initiated private membership organisation (Australian corporations law company limited by liability)	- Project level: demonstration and research projects	Technology development (TRL 1-7)	National	Broad: all CCS	Demonstrate improvements in CCS technologies

4.5.1.3 Objectives

Table 4-2 provides an overview about the current objectives of each case and – in case of case 1 – of the involved partners.
Overall, the objectives evolved:

- Case 3 shifted from accelerating the development, demonstration and deployment to accelerating the deployment of technology.
- After the decision to terminate the programme and the critical reassessment of the initial objectives, case 1 intended to shift from knowledge generation/development to the dissemination and diffusion of this knowledge after the evolution from a grant-funding programme to a financially self-sustaining programme failed.
- The vision of case 4 is not only to perform research project but also to operate the project outcomes such as demonstration facilities.

4.5.1.4 Roles and Activities

Roles and activities are the means which innovation intermediaries take on and carry out in order to achieve their objectives.
Case 3 evolved from a role of combining and sharing knowledge to a role of actively advising decision makers, an opinion former and advocating for technology. Whereas case 4 intend to move from knowledge generation via research and demonstration projects to the application of accumulated knowledge for the active operation of demonstration facilities. Changes in the governance structure affected case 1's activity to recombine knowledge between partners: the programme management initiated project facilitation, e.g., via annual assembly to create synergies between project partner. Moreover, the shift from a focus on research to commercialisation was accompanied by a change of key performance indicators (KPIs) and consequently an evolution of the project evaluation activity.
More evolvement in roles and activities was planned or intended by case 1:

- Evolving from the role of a funding provider to a role of a funding broker that exploits external funding sources.
- Further activities to make use of effective communication channels to educate about the technology.
- User centric project exploitation via methodology-based toolkits (e.g., life cycle assessments or techno-economic assessments) for potential customers.
- Sharpen technology screening and commercialisation activities via the acquisition of experts in the respective field.

Table 4-5 (in Appendix 4.11.3) gives an overview of the current roles and activities per case. Furthermore, it provides data about the reported codes in each of the 10 activity categories by Howells (2006).
Figure 4-5 presents a way to present the evolution of activities: it compares the patterns across the 10 activity categories of the two fields of technology that represent different evolutionary stages. The patterns are created by using the maximum of the reported codes per Howells' category and case in the respective field of technology.

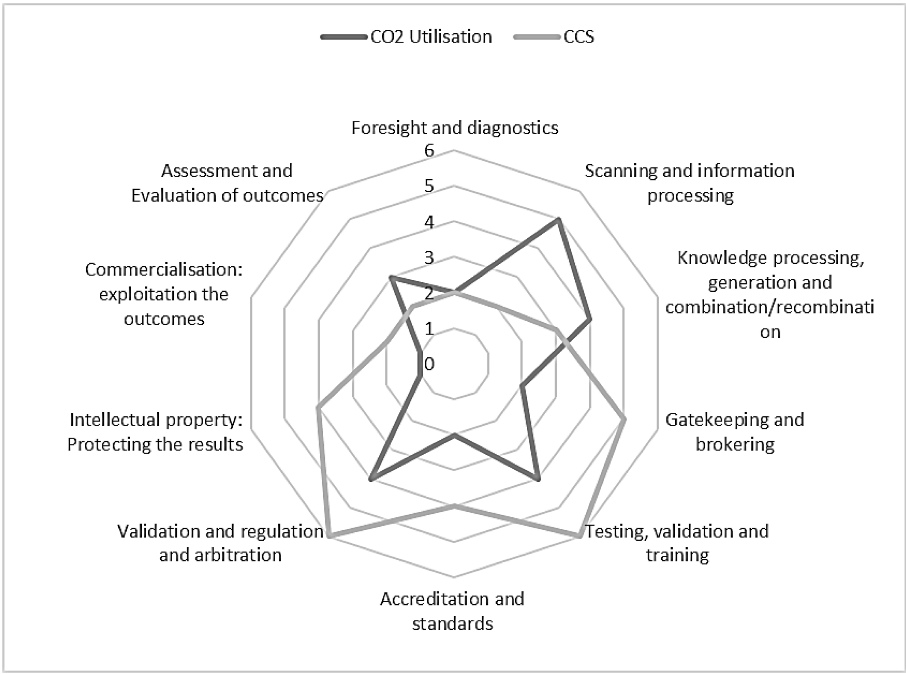

Figure 4-5: Role and activity forms per technology

The various expressions of roles and categories based on Howell's framework can be compared on a technology level. Figure 4-6 give overviews about the comparison of CO_2 utilisation and CCS intermediary's roles and activities: on the abscissa are the differences in the maximum number of reported codes per Howells' category, case and field of technology; negative numbers represent more reported codes in the field of CO_2 utilisation and positive numbers represent more reported codes in the field of CCS. There are considerable more activities (2-3) in the categories protection of results, validation, regulation and arbitration, testing, validation and training, and gatekeeping and brokering of CCS intermediaries. Protection of results indicate the importance of intellectual property (IP) ownership for the internal value creation (see internal value creation). The categories validation, regulation and arbitration, and testing, validation and training reflect the activation that has been taken place in case 3 and 4 to create and capture more value beyond the knowledge generation. More activities in gatekeeping and brokering reflect the broad member base and its leverage for synergetic complementation, e.g., via networking. Furthermore, this broad and longstanding (established and consolidated) membership of the CCS intermediaries indicate little need for new partners and provide explanation for considerable more activities in the field of CO_2 utilisation in the category scanning and information processing (see Figure 4-6).

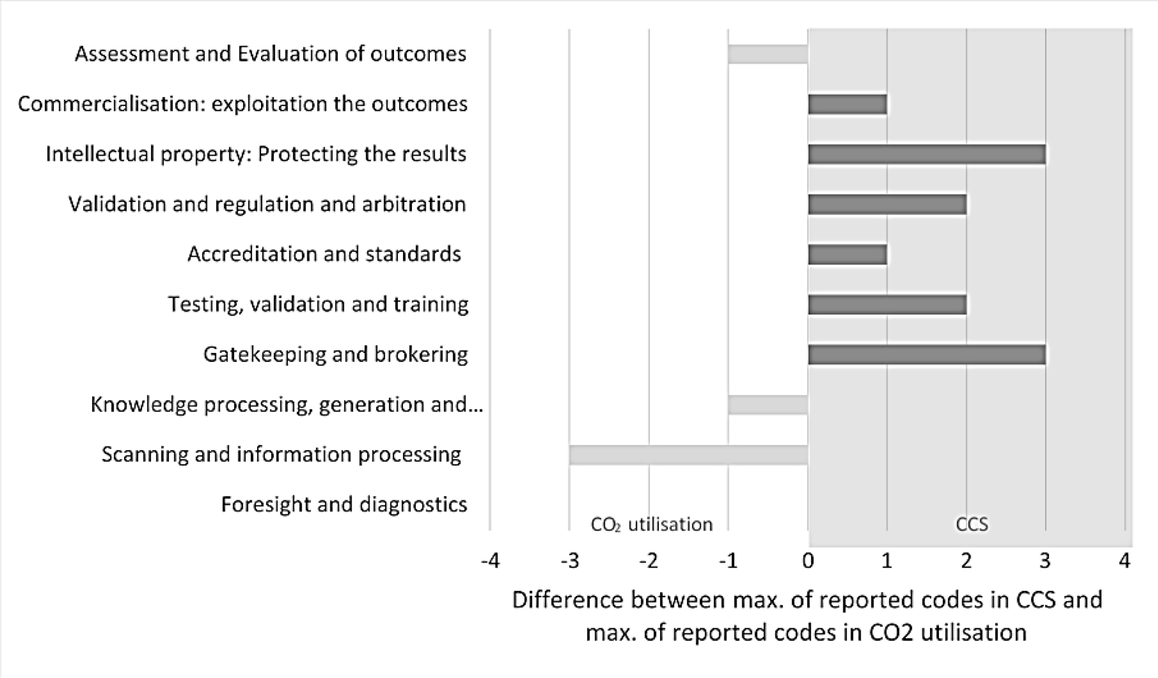

Figure 4-6: Role and activity comparison per field of technology: CO_2 utilisation vs CCS

4.5.2 Survival

The survival of innovation intermediaries is determined by drivers and challenges. There are at least four dimension that influence the survival: (i) neutrality, (ii) technological context, (iii) shared consensus, and (iv) internal value creation.

4.5.2.1 Neutrality

The tensions of government involvement (initiation and constraints), the sources of funding, objectivity (governance, technology, decision making), and top-down changes are presented in this section.

Case 3 and 4 received the initial funding via a policy incentive aiming to address market failures or counteract the financial crisis. Their evolution was driven by the endeavour of the organisation and its members to be financially self-sustaining and not dependent or constraint by volatility of or obligations from government (see Table 4-6 in Appendix 4.11.4). How the members perceived the dependence on public funding were thereby one of the main drivers for case 3 to become financially independent (see Table 4-6 in Appendix 4.11.4).

The number of funding sources is also linked to financial independence. A single source of funding exposed case 1 to the risk of being depended on the agenda setting of a single funder. The mix of funding sources in case 2, 3, and 4 helps to diversify this risk and sustain business operations over time. Case 2 gives evidence that such a diversification was intended when setting up the organisation to be entitled to attract public and private funding (see Table 4-6 in Appendix 4.11.4).

On the one hand, both organisations in case 3 and 4 appoint board members based on relevant skills and experiences within and beyond their membership to gain objectivity in decision making. Case 2 has a similar approach and achieves objectivity by unbiased expertise in its advisory board. On the other hand, a lack of objectivity biased the decision-making process throughout the existence of case 1 due to singular interest of the participating partners. Other potential conflicts of interests in the governance structure in case 1 and 2 were avoided by getting external advice to optimise the structure (see Table 4-6 in Appendix 4.11.4).

Moreover, objectivity towards technology was one of the driving forces in case 2 and 3 to gain credibility for advocating for a holistic field of technology (see Table 4-6 in Appendix 4.11.4).

By contrast, case 1 had a narrow focus on certain technologies in the field of CO_2 utilisation and a single-sided representation of industry in its membership. This focus and membership helped to agree upon and initiate the programme, but limited case 1's capacities to advocate as the opinion representation is not unbiased (see Table 4-6 in Appendix 4.11.4).

The role that the external advisors played in case 1, however, was not well defined. Moreover, a series of organisational and personnel changes of a lead partner (e.g., because of conflict of interest) resulted in changes of the composition of managing and decision-making bodies over time (see Table 4-6 in Appendix 4.11.4). Challenges in this regard arose from top-down decision making from the funder and subsequently lead partner to strategically realign towards business creation and introduce new metrics to measure success. These measures implied to operate on a timescale as near-term as possible (create businesses within 1-3 years) in a field of technology with long development times (5+ years) (see Table 4-6 in Appendix 4.11.4). These changes on multiple levels simultaneously led to de-prioritisation of the re-structuring process of the governance (see Table 4-6 in Appendix 4.11.4). Furthermore, the intermediary needed to adapt to the top down decision making by changing its activities and imposing these changes its members/partners.

4.5.2.2 Technological Context

The context of the innovation intermediary is primarily given by the addressed field of technology. Themes in this dimension were about proximity to the technology, the potential of the technology, and conditions of policy, market and technology.

A rationale for the geographic focus of case 2 is the proximity to the technology and its associated ability for hands-on interaction (see Table 4-6 in Appendix 4.11.4).

Even though most cases were initiated by governments and the potential of the technologies (e.g., keeping key industries in Europe, turning a waste into a resource) (see Table 4-6 in Appendix 4.11.4) positively affected the technology focus (e.g., by international agreements to favour certain technologies), effects by (i) market, and (ii) policy making, and (iii) technology development, were also reported to be negative in nature:

i. The demand for technological applications is necessary and partially non-existent. Suitable products and market acceptance are partially missing as well.
ii. The lack of policy support such as universal carbon price or accountability of carbon capture in emissions trading systems and dependencies such as on the price of petroleum challenged the focus on concerned technologies (see Table 4-6 in Appendix 4.11.4). Furthermore, this focus was negatively affected by room for interpretation in national implementation of supranational legislation and ineffective coordination between executive authorities to align agendas (see Table 4-6 in Appendix 4.11.4) or between funding programmes to avoid redundant technology funding.
iii. Long technology development times (5+ years) and a lack of technology success stories mismatched the expectations of funders (e.g., to have economic, environmental and social returns simultaneously) and industry (e.g., decrease failure rate of projects) (see Table 4-6 in Appendix 4.11.4).

However, the lack of success stories in commercialising the technology and the consequent lack of buy-in from the industry lead to case 2's opportunity recognition and focus on CO_2 utilisation in the first place.

4.5.2.3 Shared Consensus

This dimension is specified by themes about multi-stakeholder relationships, buy-in of partner, partner alignment, mix of partners, and expectation management.

Case 2 perceived the collaboration of relevant actors from policy, technology, and markets as key to achieve its objectives. But multi-stakeholder relationships can also be a source of challenges. Case 1 was set-up in an area of tension between different triple helix actors (university, industry, and government) within a PPP, however, the governance structure did not reflect a true triple helix as the government pillar was merely represented by the funder making top-down decisions.

Another perceived key element for the success of an intermediary was attributed to the team and it individuals by case 1. Especially the buy-in of the partners was critically reflected upon in case 1: the buy-in of the partners was generally missing, and a shared vision and a team spirit were absent (see Table 4-6 in Appendix 4.11.4). The relationship between the intermediary and its partners in case 1 remained transactional rather than evolved to the desired impact relationship. However, case 1 and 2 give also examples on how buy-in was (planned to be) achieved: Project facilitation via annual partner meetings was driven by the wish to activate and motivate a sub-community of a lead partner in case 1 (see Table 4-6 in Appendix 4.11.4). Furthermore, case 2 took advantage of its ownership model to release its members from liability (e.g., for capital-intensive demonstration projects) to incentivise its membership.

Other challenges that arose in case 1 were in the field of partner alignment. Partner objectives and interests diverged (e.g., climate-impact via immediate commercialisation vs competitive advantage via advocacy vs research sponsorship via grant money) and were difficult to align – especially after the self-sufficiency requirements were introduced. There was an inability to group and apply for third party funding with the current mix of partner (see Table 4-6 in Appendix 4.11.4). In case of an alignment, the process took a long time (see narrow technology focus). Case 1's narrow focus on a certain technology in the field of CO_2 utilisation was agreed upon in workshops with the programme-initiating partners; but, as only a few partners were involved in this process a consensus across all relevant stakeholder was impaired.

This narrow focus within the field of technology (see neutrality) in combination with a narrow membership of few industry representatives and research organisations constraint the ability to formulate and represent (advocate) a joint opinion for this field of technology towards policy maker. Furthermore, the mix of partner in case 1 limited its ability to adapt to the new top-down requirements to be financially self-sustaining (see Table 4-6 in Appendix 4.11.4).

Overall, the contribution of the intermediary and the contribution of its partners was not clearly defined (see Table 4-6 in Appendix 4.11.4). This lack of clarity led to several challenges in managing expectations of the involved stakeholders. On the one hand, the funder in case 1 introduced new KPIs that move away from pure knowledge generation towards business creation to encourage a more value for money attitude within the membership where the intermediary expected its project partners to engage in exploitation activities. On the other hand, the project partners expected ongoing funding to carry on their R&D as integral incentives of being part of the programme (see Table 4-6 in Appendix 4.11.4).

4.5.2.4 Internal Value Creation

This section is about how an innovation intermediary manages to create value internally. Themes in this regard are: size of funding. vertical integration, complementing activities and relationships, competencies and knowledge, leadership, self-organisation, exploitation management (value creation), enlightenment, and communication and involvement.

The intended evolution of case 1 to financial self-sustainment via private (e.g., membership fees) and public money (e.g., grant money) posed a discrepancy between the available money and the monetary requirements for R&D in this field of technology (see Table 4-6 in Appendix 4.11.4), let alone the monetary requirements to grow (e.g., broaden scope of technology and industry). Cuts in the budget of case 1 limited also the capabilities to incentivise new and existing partners.

Case 3 and 4 evolved (case 3) or plan to evolve (case 4) from knowledge generation and sharing to advising and advocating or operating facilities based on the accumulated knowledge over time. Both cases capture thereby more value in terms of applying knowledge for advocacy and consultancy (case 3) or for the operation of demonstration facilities (case 4) (see Table 4-6 in Appendix 4.11.4).

Both cases benefit from their broad membership and fall back on vast networks for advocacy or research and demonstration. Furthermore, the two cases are in a synergetic relationship and benefit from one another (see Table 4-6 in Appendix 4.11.4). Case 2's focus on technology development as an early stage intermediation is due to the fact that later stage intermediation needs a steady supply of new technologies to commercialise and to deploy. Vice versa early stage intermediation needs the money and partnerships from later stage intermediation. Moreover, case 1 and case 2 reported further activities to engage in complementing relationships either alongside a specific value chain or with various key actors in science and industry.

There was an absence of knowledge on various levels in case 1: First, technical knowledge to objectively assess the technologies in the field (e.g., understand its potential at the beginning of the intermediation process, methodologies to properly assess technologies). Second, market knowledge to understand the different fields of application in various industries. Third, policy knowledge to fully engage in advocacy. Last, product development knowledge to create internal value for the intermediary from the various project outcomes. The realisation of that absence and the consequent involvement of external expertise was late (see Table 4-6 in Appendix 4.11.4). Although, existing competencies and knowledge in case 1 and case 2 pre-determined the economic niche/scope of the intermediary at the beginning.

These competencies were also the rationale for the two cases to (attempt to) take on a leadership role as they would combine all relevant knowledge in science/technology and industry/market for the intermediation of this field of technology. Furthermore, case 4 perceived the leadership as key in achieving it objectives. However, case 1 failed to become a thought leader due to a lack of self-organisation and management.

Overall, there was a lack of (self-)organisation and management in case 1 to become thought leader (see Table 4-6 in Appendix 4.11.4), to secure additional funding and sustain operations, and to untap potential to create synergies by e.g., sharing project partner's existing infrastructure. The continues strategic re-alignment between lead partners and funder (top-down) left little room for decision making on the organisational level (bottom-up) of case 1; leaving the programme management caught up in implementing the top-down requirements at the expense of managing the stakeholder. Moreover, the absence of key personnel led to an underperformance of roles such as facilitator to leverage on the connections between the project partners and to operationalise synergetic effects between them.

The new metrics discouraged pure knowledge generation and those partners that mainly engage in research activities: Project-based activities in the domain of technology development and research were challenged to fulfil the new funder KPI's on business instead of knowledge generation and mainly seized to exist after the termination of the programme in case 1 (see Table 4-6 in Appendix 4.11.4). Furthermore, new partners were mainly assessed on their capability to preserve some of the programme's outcomes rather than carrying on or even scaling-up (broadening the technology focus) activities such as knowledge generation.

Case 1 was rather limited in its value creation by inabilities in exploitation management: It was neither able to leverage on the project outcomes by develop products for the intermediary to generate revenue to meet the requirement to become self-sustaining (find a working self-sustaining business model) (see Table 4-6 in Appendix 4.11.4) nor to incorporate user-centric aspects in this project exploitation. The absence of a formal technology transfer role such as a dedicated product manager for case 1 led to a lack of exploitation of the project outcomes.

IP is another area within the exploitation efforts of case 1. The partner, not the intermediary holds the IP of project outcomes. The partners' attitude towards competition had a direct effect on the openness of innovation and restraint it rather than to embrace it.

Enlightenment in case 1 has been taken place in form of social acceptance projects to create awareness about the risks and opportunities of the technology in order to counteract irrational fears in society and to educate about the technology. Education is also perceived by case 4 as a key factor to successfully fulfil its objectives. Moreover, the standardisation efforts for the assessment of the technology was motivated by incapability of e.g., investors to make qualified decisions about the technology. Similarly, unbiased, evidence-based expertise were also driven by requirements for competent decision making.

The last theme is communication and involvement. The knowledge dissemination capabilities of case 1 were limited by time constraints to engage, e.g., in more round table discussions or breakfast meetings and by a lack of traction of communication channels, e.g., online learning platforms. This also affected the identification process of partners to sustain project outcomes after case 1' termination (see Table 4-6 in Appendix 4.11.4). Similarly, interaction with policy maker was rather out of scope due to a lack of understanding for advocacy in the field of technology: neither the role of the technology nor the role of case 1 were fully understood. It follows that few policy discussions lead to an underperformance of actionable recommendations for stakeholder such as decision maker, opinion former and representatives of the civil society. Furthermore, the communication with budget owners and open innovator was challenging due to their limited understanding about the technology. Likewise, there was a conflict around the involvement of the end customer (drop in-solution vs active involvement of customer via tool-kit solution) (see Table 4-6 in Appendix 4.11.4).

4.6 **Discussion**

The discussion will focus on the guiding research question which targets the evolution of innovation intermediaries over time and the survival factors involved as they evolve. As presented in the literature review section, the evolution of intermediaries over time and thus their survival is not particularly discussed in the intermediary literature (cf. Kivimaa 2014; Martiskainen and Kivimaa 2017). However, the evolution and survival of intermediaries over time is a particularly important aspect in facilitating sustainability transitions since such transitions require far reaching *changes* in existing technological, material, organisational, institutional, political, economic and socio-cultural dimensions which takes several decades and even centuries to materialise (Kivimaa 2014; Hodson and Marvin 2010). Thus, sufficiently long and sustained intermediation activities are necessary to influence sustainability transitions. On the contrary, intermediaries of a temporary nature are also more likely to avoid getting locked in to current technologies, practices and institution and thus can challenge old and existing structures with new ideas (Kivimaa 2014). Thus, current research findings suggest to a mix of established intermediaries with stable intermediation roles and new entrants which can challenges existing practices as potentially healthy (cf. Kivimaa and Martiskainen 2018).

From our empirical studies, we described the evolution of intermediaries based on four themes: (a) characteristics, (b) scope, (c) objectives, and (d) roles and activities. Furthermore, we identify at least four dimensions of intermediaries which influence their longevity over time. These dimensions are: (i) neutrality, (ii) technological context, (iii) shared consensus, and (iv) internal value creation. All dimensions represent thereby either the internal, external or both domains of an innovation intermediary. The internal domain is covered by the internal value creation and the ability of the entity to manage its internal resources purposefully adapt its resource base to external influences. The dimension of technological context embodies these influences and presents the external domain. Both, neutrality and shared consensus are

dimensions that bridge the external and internal domain via interactions of the internal entity with external stakeholders.
In the following section the authors discuss the evolution and the four dimensions of survival.

4.6.1 Describing the Evolution

An intermediaries' roles and activities change over time to adapt to evolving structures and conditions (cf. Hakkarainen and Hyysalo 2016). The cases in this study went through changes over time to stay operational and cater for the shifting needs and requirements of its stakeholders. However, not only the roles and activities evolved but also objectives, scope and characteristics altered. The characteristics (source of funding, governance structure, and type of ownership model) tend to move on the continuum from public to private (Perry and Rainey 1988), whereas the scope tend to evolve alongside the maturity of the technology and/or intermediary. Given the maturing of intermediaries and the accumulation of resources (especially knowledge), objectives become more ambitious to cover more parts of the value chain. This goal to increase the added value over time is also reflected in the evolution of the roles and activities: moving from information screening and knowledge generation towards demonstration (testing, validation), negotiating, exploitation (incl. IP), and advocacy (see Figure 4-6). Thus, the intermediary meets the requirement to differentiate itself from other similar service providers on the market (cf. Kivimaa and Martiskainen 2018).

4.6.2 Neutrality

Kivimaa (2014) also argues that the neutrality of intermediaries i.e. independence from public administration and politics, finance, or technology neutrality is particularly important for their success and longevity. In particular, intermediaries which are not dependent on other organisations e.g., public authorities for funding can also easily build trust among companies and key stakeholders as they are perceived as being neutral in their intermediation activities.
We found that financial independence was one of the key drivers for the intermediaries in our sample. Particularly case 1 struggled to become financially self-sustaining and thereby failed to ensure its future operations. To develop intermediation activities that can be sustained over a period of time, it be necessary for intermediaries to secure a stable financing (Hodson and Marvin 2010). The stability of the funding is particularly important because, such a situation reduces the risk of intermediaries seeking their own interests and survival at the peril of the interests of their clients or target group. And as Hodson, (2010) discusses, intermediaries with stable financial support are less likely to risk the priorities of intermediation to be involved in chasing funding for their own survival which often have associated targets, objectives, and commitments which may not be in line with the target of the intermediary and its clients.
Thus, depending on other actors for financial support can limit the degree of freedom an intermediary has to set its own agenda and act freely as pointed out in other previous literature (e.g., Klerkx and Leeuwis 2009).
Furthermore, sustained broad based financial support also means that, key persons in the intermediary can be retained, trained and incentivised over time and their intermediation activities are thus sustained and committed to the intermediary organisation. We showed that the top-down decision-making lead to a series of challenges in governing the intermediary. Obtaining technology neutrality, e.g., via external supervision and advise or an unbiased understanding of technology and membership was one of the key drivers in our cases to gain legitimacy.

4.6.3 Technological Context

The context of an intermediary depends on the technology the intermediary is focussing on and the stage in which this technology is: development, demonstration or diffusion (e.g., Sarkar

1998). Our findings indicate the relevance of context for the cases' fields of technology with regard to technology itself, market and policy. Mejía-Dugand (2015) argues that a new technology has to interact not only with other technological systems but also with human systems. Hence, there are several layers of context such as the political, cultural, geographic context and market structure that define the conditions a technology must manage (e.g., Heiskanen and Matschoss 2017; Kanda 2017). The political context is expressed by different policies that affect the technology or the intermediary. Policy interventions and regulatory pressure are also be discussed as a lever to overcome barriers for sustainability-oriented innovation (e.g., Parker et al. 2009; Kneller and Manderson 2012). Bocken et al. (2014) points out that regulatory change may enable more sustainable business models in the future. However, these interventions can lead to further dependencies and challenges in the neutrality of an intermediaries. Consequently rapidly changing policy context can directly affect the activities of intermediaries as they have to repackage their activities for each new policy changes and funding opportunity (Kivimaa and Martiskainen 2018). Legitimacy through the acceptance of the technology are of upmost importance in the field of CCS (e.g., Kraeusel and Möst 2012; Dütschke et al. 2016) and cannot be neglected in the field of CO_2 utilisation (c.f. Jones et al. 2017). In CO_2 utilisation CO_2 could be considered as a resource, whereas CCS deals with CO_2 as a waste/emission. Nevertheless, the geographical context in form of resource availability and waste streams is equally important.

The market structure is interwind with the political context in both fields of technology. The price of CO_2 effects both areas. Furthermore, CO_2-based products must compete with fossil-based products and therefore depend on the price of petroleum. Regulatory frameworks can therefore directly impact these technology, e.g., with demand-pull policies (e.g., Peters et al. 2012).

CO_2 utilisation and CCS are in a similar technological context. However, there are differences from the maturity and the application of the technology. CO_2 utilisation is mainly in the technology development phase and mainly finds application as a resource efficiency technology. CCS is mainly in the demonstration phase and mainly finds application as a CO_2 mitigation technology. The technological context needs to be acknowledged by all actors in the respective field of technology. Especially, the funder and initiator need to develop a contextual understanding to make establish structures that enable the intermediary to sustain its business operations over time.

The different technology or innovation phases, for example, are also reflected in the funding requirements of an intermediary's clients. Polzin et al. (2016) links the financial resource mobilisation activities of intermediaries to the phase in the innovation cycle to address phase-specific barriers with various public and private financial instruments (sources of finance). They argue that many barriers occur at the transition from the research and demonstration phase to the commercialisation and diffusion phase (ibid.). Hence, when policy makers grant innovation intermediary the mandate to operate in the technology deployment, those intermediaries may enhance eco-innovation (ibid.). Public and private instruments that needs to be mobilised are usually also reflected by the different innovation phases. Whereas public funding is more prominent in the early stage (research and demonstration phase), private funding gets more relevant in later stages (commercialisation and diffusion phase) (e.g., Chertow 2000). This transition from public to private is also reflected in the realm of (sustainable) entrepreneurship (e.g., Englund et al. 2017). Our findings support this line of argumentation: the intended change in the source of finance (from public to private) in case 1 mismatched the innovation phase of CO_2 utilisation (mainly research and demonstration). It is therefore crucial for decision maker to not only understand the field of technology and the corresponding innovation phases but also to set feasible parameters, e.g., KPIs and to implement an appropriate funding scheme for the intermediary.

4.6.4 Shared Consensus

Another factor that influences the longevity of intermediaries is the degree of shared consensus and alignment between key stakeholders (Laur et al. 2012). We discovered that a shared consensus was largely absent and an alignment of stakeholders challenging due to diverging interests and expectations in case 1. Murphy et al. (2015) found that alignment positively affects the value creation in cross-sectoral collaboration such as joint efforts of multiple industries in the field of CCS or CO_2 utilisation (cf. Styring and Jansen 2011). In particular, for intermediaries, such as those who create arenas for networking and exchange between different types of stakeholders, an established common vision is the basis for engaging the stakeholders in such intermediation activities. The common vision thereby "[…] represents the degree to which the members of the network share an understanding of and perspective on the achievement of the network's activities and results." (Expósito-Langa et al. 2015, p. 294). Furthermore, organisations with a shared vision benefit more from internal (absorptive capacity) and external (network positioning) resources (ibid.).

Sharing consensuses with the broader community and other key stakeholders of the intermediaries is important for creating legitimacy, and visibility for the intermediary and also in attracting clients and members (cf. Hodson and Marvin 2010). And as Barrie et al. (2017) argue a triple helix structure with the representation of actors form government, industry and academia within an intermediary can offer mechanisms to reach consensus in multi-stakeholder relationships. In view of case 1, we found that a triple helix structure was inherited by the intermediary, but there was an imbalance in the decision-making power and representation of each actor. Furthermore, intermediaries such as cluster initiatives seem to rely on enthusiastic individuals who seek to align interests between the changing needs of the target group (e.g., clients – companies, projects), key players (actors who have a critical role as resource providers, agenda setters), and also the support group (e.g., governmental organizations, academic institutions, regional development agencies) by continually developing and adapting their activities (Laur et al. 2012). And for longevity, it is equally important to align and share consensus on current needs and expectation as well as evolving ones in-line with the expectations of various stakeholders.

4.6.5 Internal Value Creation

Intermediaries have been typically characterised in the literature as actors who facilitate the innovation activities of others e.g., companies (Howells 2006), and create spaces for others to act (Martiskainen and Kivimaa 2017). However, in order for intermediaries to exist and successfully create value for their clients, they need to generate internal value for themselves. This internal value creation is also particularly important for ensuring the long-term survival of intermediaries and sustaining their key facilitating roles in innovation systems (Silva et al. 2018). In this case, "internal value" refers to the sum of both financial and non-financial values generated from their clients by intermediaries (Silva et al. 2018, p. 71). The direct internal value for intermediaries is the financial benefits they claim from their clients in case of private intermediaries, membership fees from e.g., cluster-based intermediaries, research grants and so on. We observed that case 1 was challenged to expand its single source of funding and failed to leverage its project outcomes, whereas the other cases could rely on a mix of funding streams.

Other internal values that can be generated from the intermediation process include the development of new knowledge that intermediaries can generate from working on different projects or with different companies through cooperation, reciprocity and information sharing. Such accumulated knowledge is important in their intermediation activities and particularly when transferred from one client to another for effective intermediation. Our findings show that knowledge has been generated and accumulated in all cases, but especially intermediaries

in the field of CO_2 utilisation did not (yet) fully apply the knowledge, e.g., for advocacy or plant operation (see case 3 and 4). Furthermore, our findings show the absent of relevant knowledge on several levels in case 1. And as Geels and Deuten (2006) discusses, by accumulating knowledge from different intermediation activities, intermediaries are able to create, maintain and distribute generic abstracted knowledge that can be used within a broader technological field of on a global scale. Particularly in addressing long-term, systemic and strategic issues related to sustainability transitions, intermediaries need a variety of technical, policy and local knowledge which need to be constantly developed and integrated.
Moreover, intermediaries through their activities develop networks with several stakeholders including companies, and such networks can be particularly important when seeking partners for collaborations and providing support services for innovation development. We found that efforts to increase the membership and to interact with relevant stakeholder was hindered by limitations in the communication, and a lack of (self-)organisation and management in case 1. Contrary to these obstacles, we discovered that case 3 and 4 managed to leverage their network and to engage in a synergetic relationship with other intermediaries in their field of technology. Case 1 gives empirical evidence for a tension between sustainability and cooperative arrangements (cf. Koppenjan 2015) as it failed to align the various objectives and requirements from funder and (lead) partners to get economic, environmental and social impact in the near term. Case 4 on the other hand managed to sustain its business by evolving from an initiated PPP to a private organisation over a period of 11 years. This findings supports Koppenjan (2015) who identified tensions between sustainability and cooperative arrangements, especially when public budgets are shut down over time and private investments are required to step in. Furthermore, those cooperative arrangements to form intermediary initiatives between public and private entities (Kivimaa 2014) such as PPPs mostly *fail* because of the absence of a positive business case or positive return on investment (Akintoye et al. 2008; Hodge et al. 2010). Yaqub and Nightingale (2012) advocate for a more active management approach in PPP for difficult, time-consuming and costly developments such as CCS and CO_2 utilisation.
Intellectual property can be another source of internal value creation for intermediaries. Beside neutrality (Kivimaa 2014), IP ownership is argued to be another source of legitimacy (cf. Johnson 2008). We found a lack of IP ownership in the field of CO_2 utilization intermediaries (case 1 and 2) that can limit the intermediary's capacities to act as arbitrator (Johnson 2008).

4.7 **Conclusion**

4.7.1 Strategies and Recommendation

There are four dimensions influencing the survival of innovation intermediaries in this work to derive recommendations for policy makers and innovation intermediaries. Even though the empirical setting in this study focussed on CO_2 utilisation and CCS, recommendations are not limited to current and future actors in these specific fields of technology (this may be also true for pure networking associations and conference providers when they decide to broaden their activities). Stakeholders with a similar need for coordination between a technology's sustainability effect and market impact, may also gain a better understanding on potential factors influencing the evolution and survivability of intermediaries that engage in this area of tension.
Policy makers should consider the nature of sustainability-oriented innovation and technology when formulating their requirements (e.g., KPIs) for innovation intermediaries. This requires specific knowledge about targeted fields of technologies. Especially the technology development time and cost should be acknowledged and reflected in dedicated requirements for sustainability-oriented innovation intermediaries. These dedicated requirements will help

to align (a) activities to meet the requirements of the policy maker and (b) activities to meet the objectives of the intermediary. Aligned activities will thereby increase the neutrality of the intermediary. Furthermore, policy makers in triple helix arrangements should move beyond making top-down decisions by imposing their requirements onto initiated intermediaries to engaging in the triple helix coordination by being part of these intermediaries.

Intermediaries should be aware of relevant expertise in their fields of technology, market and policy. Both internal knowledge that is built up and maintained and external knowledge that is acquired from partners or third parties should retain its neutrality. This neutrality will make intermediaries' voices heard better when advocating and will help to gain legitimacy in alignment processes. Moreover, intermediaries in a triple helix setting should engage all triple helix actors to reach consensus and legitimacy for long-term decision making. Effective self-organisation and management will not only help in the alignment of partners, but also in the creation of internal values. Intermediaries should cater for the stakeholder demands and expectations of different stakeholders by striking a balance between them using multiple value propositions.

4.7.2 Theoretical Implications and Future Research

This study syntheses four dimensions influencing the survival of innovation intermediaries over time. Although the authors are aware that there might be more, the identified aspects neutrality, technological context, shared consensus and internal value creation contribute to the literature by creating a greater understanding of an intermediary's survival. Moreover, we show that not only the roles and activities, but also the characteristics, scope and objectives of innovation intermediaries evolve. Research in the field of innovation intermediaries and their roles and activities have a rather static nature. This study, however, shows that intermediaries and their intermediation activities are not static but dynamic and intermediaries have to make strategic decisions to survive over time.

The authors took advantage of the termination of one of the cases during the data collection and consequently acknowledge the focus on the survival part in this study. A longitudinal study in the same field of technology with a single in-depth case can reveal further insights into the evolution of an intermediary and its roles and activities by differentiating the four aspects, investigating interactions between the aspects or identifying further dimensions. Nevertheless, the diversity in this study allowed for comparison and valuable insights across similar fields of technologies, countries and maturity of intermediaries and technology.

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4.11 **Appendix**

4.11.1 Excerpt from Semi-Structured Interview Guide for Intermediaries

Table 4-3: Excerpt from semi-structured interview guide

Category	**Item**	**Evolutionary aspect**
Background and intro	What is your personal background: training and work experiences?	
	What are your position and responsibility within your organisation [intermediary]?	Since when are you with your organisation?
Overview	Private vs public	
Funding	How is the current funding of your organisation? Private vs pubic	How did the funding change over time?
Governance	How is your organisation governed? Private vs public	How did the governance change over time?
Ownership (legal form)	What is the current ownership/legal for of your organisation? Public vs private	How did the ownership change over time?
Operational area	In what location is your organisation active?	
Level of activities	At what level is your organisation active? System vs individual/project	How did the focus on a level change over time?
Innovation phase	At what innovation phase is your organisation active? Development vs diffusion	How did the focus on an innovation phase change over time?
Objective/Goal		
	What are the objectives and goals of your organisation?	Did they change over time? How did they change over time?
Roles/Activities		
	What are the key roles your organisation was taking to meet those objectives/goals	Did they change over time? How did they change over time?
	What are concrete activities that your organisation carries out to meet those objectives/goals	Did they change over time? How did they change over time?

4.11.2 Cases' Evolution Theme and Survival Dimension Codes

Table 4-4: Overview of cases' evolution and survival

#	Evolution Themes/ Survival Dimension	Code Themes	Code (Categories)	Case Reference
	Characteristics (source of funding)	Financial self-sustainability	(1) phase out of initial public funding, (2) self-sustainment of business operations	Case 3, case 4, case 1*
	Characteristics (Governance structure)	Governance composition	(1) changes in governance structure, (2) personnel changes in programme management, (3) personnel changes in steering committee	Case 1
	Characteristics (Ownership model)	Private ownership	(1) evolving to private, not-for-profit organisation	Case 4
	Scope	Deployment focus	(1) shifting focus away from development and demonstration towards deployment	Case 3
	Objective	Knowledge dissemination	(1) desire to shift from knowledge generation to knowledge dissemination*	Case 1*
	Objective	Reassessment of objectives	(1) critically questioning status quo, (2) reassessing initial objectives and focus	Case 1
	Objective	Active knowledge application	(1) (desire to) shift to an active application of existing knowledge	Case 3, case 4*
	Roles & activities	Activation: advising and advocating	(1) shifting from presenting status quo of technology to actively advising decision maker, (2) shifting from knowledge sharing to knowledge application via advocating	Case 3
	Roles & activities	Activation: operating facilities	(1) desire to shift from knowledge generation to knowledge application via operating demonstration facilities*	Case 4*
	Roles & activities	Project facilitation	(1) active project facilitation after change in programme management	Case 1
	Roles & activities	Project evaluation	(1) evaluation shift from knowledge generation to business creation	Case 1
	Roles & activities	Funding brokerage	(1) desire to evolve from funding provider to funding broker*	Case 1*
	Roles & activities	Communication channel	(1) planned relaunch of online platform to gain better traction to educate about technology*	Case 1*
	Roles & activities	User centric project exploitation	(1) started to develop methodology-based toolkit for potential end-user*	Case 1*
	Roles & activities	External expertise	(1) planned acquisition of external expertise to address lack of expertise in technology, processes, and industry*	Case 1*
1	Neutrality	Intervention by government	(1) address market failure, (2) counteract the financial crisis, (3) reporting obligations, (4) decision-making constraints, (5) short, 4-5 years legislature with unknown outcome of upcoming elections, (6) membership feels uneasy due to constraints and volatility	Case 4, case 3
2	Neutrality	Funding sources	(1) mix of funding sources to diversify risk and avoid dependence, (2) dependence on single source of funding, (3) organisations legal entity entitles for public funding, (4) ensure sustainment of business operations via ownership	Case 4

#	Evolution Themes/ Survival Dimension	Code Themes	Code (Categories)	Case Reference
3	Neutrality	Objectivity	(1) board members beyond membership, (2) board members based on required skills and experience, (3) independent board, (4) lack of objectivity in strategic decision making, (5) potential conflict of personal interests, (6) evidence-based decision making, (7) external experts advise governance structure, (8) narrow technology focus, (09) loosing big picture, (10) inability to advocate	Case 3, case 4, case 1, case 2
4	Neutrality	Top-down change	(1) requirement to operate on a timescale as near-term as possible in a field of technology with long development times, (2) top-down introduction of new success metrics, (3) multiple changes in parallel: strategic focus, success metrics, governance; (4) de-prioritisation of governance re-structure, (5) fluctuation of personnel, (6) unclear role of external consultants	Case 1
5	Technological context	Proximity to technology	(1) hands-on interaction with technology	Case 2
6	Technological context	Technology potential	(1) keeping key industries in Europe, (2) turning a waste into a resource, (3) international agreements favour technology	Case 1, case 3
7	Technological context	Functioning markets	(1) need for demand, (2) suitable products, (3) and acceptance	Case 1
8	Technological context	Policy support	(1) ETS not in favour of technology, (2) dependency on prices, (3) room for interpretation in national implementation, (4) coordination between funders/initiators to avoid redundancies, (5) effective integration of executive authorities	Case 1, case 3
9	Technological context	Technology development	(1) high project failure rates, (2) no buy-in of industry, (3) lack of success stories, (4) long technology development times (5+ years)	Case 2
10	Shared consensus	Multi-stakeholder relationship	(1) lack of government representation in triple helix approach, (2) collaboration of policy, technology, and market is key	Case 1, case 2
11	Shared consensus	Buy-in of partner	(1) lack of a shared vision, (2) inability to create team spirit, (3) transactional rather than impact relationship, (4) individuals in a team are key, (5) partner assembly to bring community together, (6) release members from liability during capital-intensive projects	Case 1, case 4
12	Shared consensus	Partner alignment	(1) inability to group and apply for external funding, (2) partner objectives and goals diverge, (3) long alignment processes, (4) partner workshop to set technology focus	Case 1
13	Shared consensus	Partner mix	(1) mix of partner limits (introduced) evolution, (2) narrow membership leads to inability to adequately represent opinion	Case 1
14	Shared consensus	Expectation management	(1) unclear contribution of intermediary and its partners, (2) partners do not take part in exploitation of technology, (3) partner expect ongoing funding (unfulfilled), (4) partner expectations diverge	Case 1
15	Internal value creation	Size of funding	(1) discrepancy in available funding supply and R&D demand, (2) lack of funding to incentives new partners	Case 1

#	Evolution Themes/ Survival Dimension	Code Themes	Code (Categories)	Case Reference
16	Internal value creation	Vertical integration	(1) capture more value by operating research/demonstration outcomes/facilities in the future, (2) advocate by applying generated knowledge	Case 4, case 3
17	Internal value creation	Complementary activities and relationships	(1) complementing close relationship to another intermediary, (2) interdependency of early and late stage intermediation, (3) existing knowledge network, (4) desire to collaborate alongside the value chain to complement competencies, (3) reach out to various actors in the technology field to acquire new partners	Case 4, case 2, case 3, case 1
18	Internal value creation	Competencies and knowledge	(1) pre-determination of organisation's or initiative's niche/scope by existing competencies, (2) lack of understanding of technology (potential), processes, and industry, (3) underdevelopment of methodologies to access technologies, (4) lack of policy understanding for advocacy	Case 1, case 2
19	Internal value creation	Leadership	(1) technical and market background enables to lead, (2) combination of scientific and industry perspective enables leadership, (3) leadership is key	Case 2, case 1, case 4
20	Internal value creation	(Self-)organisation and management	(1) failed to become a thought leader, (2) lack of self-organisation to secure external/additional funding, (3) untapped potential to use/share one partner's existing infrastructure, (4) ongoing strategic (re-)alignment leaves little room for (bottom-up) decision making on the organisation's level, (5) difficulties in operationalising synergetic effects between projects, (6) need to showcase that new KPIs are met at the expense of ongoing knowledge generation,	Case 1
21	Internal value creation	Exploitation management	(1) lack of product manager/developer in or initiative, (2) lack of time to exploit project outcomes, (3) no formal technology transfer, (4) lack of self-sustaining business models, (5) IP with partners not intermediary, (6) openness of innovation is limited by partners' attitude towards competition	Case 1
22	Internal value creation	Enlightenment	(1) create awareness and educate to overcome fear, (2) education is key, (3) lack of industry-wide standards to understand effectiveness of technology for decision making	Case 1, case 4
23	Internal value creation	Communication and involvement	(1) communicate to non-technical budget owner to increase understanding about technology, (2) involvement of end customer, (3) lack of external communication and traction of communication channels, (4) identifying partners to sustain project outcomes, (5) lack of policy interaction, (6) underperformance of actionable recommendation	Case 1
	intended/planned			

4.11.3 *Roles and Activities per Case*

Table 4-5: Overview of roles and activities of innovation intermediaries in study (adapted from Howells 2006; Johnson 2008)

Category	Case 1	#	Case 2	#	Case 3	#	Case 4	#
Foresight and diagnostics	Event representation to identify needs within the system/technology, narrowing down the technology focus	2	Database based technology to scout and scan for new technologies and partners; Scientific Advisory Board to ensure good practise on the process and to discuss innovation/new technologies; technology implementation roadmap	2	Organisation keeps aware about technologies passive observer	2	Roadmap overview of national and international efforts (documentation)	1
Scanning and information processing	Event representation and meetings to identify and acquire potential partner; call for project proposals(; internal and external proposal expert evaluation)	5	Database based technology to scout and scan for new technologies and partners; Scientific Advisory Board to ensure good practise on the process and to discuss innovation/new technologies	1	Gather information, e.g., project experience, lessons learnt	2	Initiate interdisciplinary research project with various partners	1
Knowledge processing, generation and combination/recombination	Project: Dissemination of project knowledge outcome via reports, conferences and scientific publications; generating knowledge economic, ecological and social aspects of technology to increase understanding Partner assembly to spark new ideas, facilitate synergies, and	4	Reporting on website (reports, webinars, slides) and representation at events to disseminate market and technology expertise	3	Compiling, buying (commissioning) and generating knowledge, e.g., project experience, lessons learnt to disseminate it via a report; facilitate knowledge collaborations between peer projects by 'embedded'	3	Interdisciplinary research portfolio that enables sub-projects within research projects; publication of studies to inform governments	2

Category	Case 1	#	Case 2	#	Case 3	#	Case 4	#
	enable co-creation within and across initiative; website, mailing list, personal contacts and online learning platform to share knowledge outcomes				knowledge managers (documentation)			
Gatekeeping and brokering	Project: Connecting emitters and utilisers Community-wide cross-pollination and interaction of problem bringer and solution provider or need and opportunity, Grant Agreement as foundation of further bilateral agreements	2		1	Informing about ongoing contracts, contracting types and negotiations as well as incorporating knowledge sharing requirements into agreements; negotiating to finance new/follow-up projects (documentation)	3	New consultancy projects or contract research are undertaken through organisation by seconding organisation's researchers and/or contracting services through collaboration agreements; providing member and project agreements; matching CO2 sinks and sources in studies; negotiate agreements and with partners funding with funders/government (documentation)	5
Testing, validation and training	Project: laboratory incubation space/programme; hackathon; collaborative technology development and testing Funder level: Partner 1 professional education programme for innovation/entrepreneurship	4	Investment thesis to enable creative technology ideas via collaboration	1	Highlight testing and demonstration project in annual reports (documentation); provide online map/database of ongoing and past projects (website)	0	Interdisciplinary research portfolio to validate and demonstrate safe operation; adapting best practise from relevant industries; commercial arm for technical, education and training services (documentation)	6
Accreditation and standards	Collaborative project: LCA/TEA guide as standard for technology assessment and evaluation; evidence-based best practice for technology screening	1	Collaborative project: LCA/TEA guide as standard for technology assessment and evaluation; applying industry standards in	2	Best practice guidance documentation to be integrated into standards; informing about industry-recognised standards and new international standards (e.g., for CO2 transportation) and	3	Adapting best practice from relevant industries; advocate for best practice manuals; promote technology standardisation via networks (documentation)	4

Category	Case 1	#	Case 2	#	Case 3	#	Case 4	#
			assessment (documentation)		advocating for them (documentation)			
Validation and regulation and arbitration	Project: social acceptance study to eliminate irrational fears and scenario-based policy study; report on status quo of technology to create awareness Early stage dialogue with policy makers	4	Rapport to policy/decision makers to support the system	2	Advice decision makers and opinion formers on science, engineering, economic and legal issues with a communication and advocacy strategy that is based on commissioned/compiled knowledge;	6	Negotiating/liaising existing regulations and informing new legislation in regards to the technology operation; creating public outreach with research facilities in local communities and dedicated community liaise officer	2
Intellectual property: Protecting the results	Project: all IP remains with project partners; Grant Agreement as foundation of further bilateral agreements	1		0		0	IP is governed by project agreements; IP identification via IP disclosure forms; management and maintenance via IP database and register; organisation holds ownership with agreed project shares for project partners; project partner support the filing for a patent; informing about ongoing patenting (documentation)	4
Commercialisation: exploitation the outcomes	Project: understanding market development/potential and identify market opportunities Provision of seed funding, too little in comparison to development costs → guidelines to attract private capital	1	Market study to assess market potential and convince collaborators and investors	1	Deployment analysis and strategies via funding	2	Market research to measure success (public acceptance) of own operations; funding of demonstration projects; commercial arm for technical, education and training services (documentation)	2
Assessment and Evaluation of outcomes	Project: technoeconomic and environmental assessments of technology and methodology development Project assessment on 4 KPI areas (climate, funder	3	Techno-economic and environmental assessments of technology and methodology development	1	Economic analysis on costs	1	Techno-economic and cost studies that are published nationwide; strategic planning	2

Category	Case 1	#	Case 2	#	Case 3	#	Case 4	#
	[knowledge transfer/adaption → business creation], financial sustainability, reputation) based on reporting induced by funders: internal and external evaluation and audits							

#: number of reported codes per category

4.11.4 Exemplary Interview Quotes

Table 4-6: Overview of exemplary quotes from interviews

Survival Dimension	Code Theme	Code (Categories)	Quote	Case Reference
Neutrality	Intervention by government	membership feels uneasy due to constraints and volatility	*"Our people [members] became aware of that all around the world and as we were starting to talk about our future they felt our future was in doubts. That was something we needed to deal with."*	Case 3
Neutrality	Funding sources	ensure sustainment of business operations via ownership	*"Moving from a [PPP] model to a competitive and sustainable business in the longer term, [case 4] reviewed and simplified the Constitution and Members' Agreement. For the business to seek a broader range of opportunities both domestically and internationally it was crucial that these changes reflected our company status and structure."*	Case 4
Neutrality	Funding sources	organisations legal entity entitles for public funding	*"The reason that we set it up as non-profit is to enable public money to come in."*	Case 2, Interviewee 2
Neutrality	Objectivity	evidence-based decision making	*"We don't have any preconceptions, as a board member I don't have any preconceptions, I don't have any biases towards any particular technology. But I do like to see is an evidence-based case whether a technology should be considered."*	Case 2, Interviewee 1, Advisory Board
Neutrality	Objectivity	evidence-based decision making	*"It is not our role to pick winners in there [the field of technology], in fact this is a poor way to go."*	Case 3
Neutrality	Objectivity	inability to advocate	*"Talking to policy makers at that time with the representation of only one industry stakeholder and twelve academic partners raises the question how heard you are and how valid is the opinion that you are representing in terms of advocacy to policy makers, who usually look for bigger representation of opinions."*	Case 1, Interviewee 2, Lead partner 1
Neutrality	Top-down change	fluctuation of personnel	*"[…] I just jumped in to something that was already there and tried to figure out how to create value for [lead partner 1]."*	Case 1, Interviewee

Survival Dimension	Code Theme	Code (Categories)	Quote	Case Reference
				2, Lead partner 1
Neutrality	Top-down change	requirement to operate on a timescale as near-term as possible in a field of technology with long development times	*“[...] our desire to operate on a timescale as near-term as short-term as possible. That is [the reason for the narrow technology focus]”*	Case 1, Interviewee 1, Lead partner 1
Neutrality	Top-down change	requirement to operate on a timescale as near-term as possible in a field of technology with long development times	*“[...] what kind of return we are having on the climate, a lot of that is way out in the future. That's tough. We need impact on a shorter time horizon.”*	Case 1, Interviewee 1, Lead partner 1
Neutrality	Top-down change	de-prioritisation of governance re-structure	*“[...] the steering committee, probably, was de-prioritised by us in terms of not being the most essential thing, where we wanted to work on together with [lead partner 2]. It was more on the metrics and the value for [lead partner 1] and understanding the success and measure the success of the [programme]. That is probably why we de-prioritised the governance.”*	Case 1, Interviewee 2, Lead partner 1
Technological context	Technology potential	turning a waste into a resource	*“Because the more that you can make money from CO_2 rather than have to deal with it as a waste, the easier it becomes to deploy.”*	Case 3
Technological context	Technology potential	keeping key industries in Europe	*“There are these competing viewpoints: on the one hand [CO_2 utilisation] is this incredible technology that's chemically and from an energy perspective more efficient than photosynthesis and that has the potential to be carbon negative and replace fossil resources in important materials like plastics and chemicals. And it is also from an industrial standpoint an interesting way to keep key industries - like chemicals, like steel making, like cement - in Europe, because without some sort of CO_2 capture those industries will have to leave Europe.”*	Case 1, Interviewee 1, Lead partner 1
Technological context	Policy support	dependency on prices	*"On the other hand, [CO_2 utilisation] is a technology that really plays on the margins, doesn't have the volumes that CCS has. Its existence is really dependent on some bigger things like the price of petroleum and the price of carbon.”*	Case 1, Interviewee 1, Lead partner 1
Technological context	Policy support	effective integration of executive authorities	*“The challenges we tend to see would be more around where you don't have an effective either integration or coordination between DGs in the case of the Commission, but departments or ministries in other parts of the world. If you don't get a sensible connection between environment policy and energy policy that is when you start getting the problems.”*	Case 3

Survival Dimension	Code Theme	Code (Categories)	Quote	Case Reference
Technological context	Technology development	high project failure rates	*"If you are talking to a company, which is a very good company […] 97% of their projects die, they don't make it to the market. And these are guys who know their stuff."*	Case 2, Interviewee 2
Shared consensus	Buy-in of partner	lack of a shared vision, inability to create team spirit	*"There was no vision. There was no 'what we want to push with this thing?'. There were objectives, like you said, but the vision and why we are all combined, why we are all together: the glue of the team was missing. We were not a team. That is what I am learning in these public funded projects. It is difficult to create a team spirit."*	Case 1, Interviewee 2, Lead partner 1
Shared consensus	Buy-in of partner	partner assembly to bring community together	*"[…] this changed with [interviewee 1] joining - so that the project would be aware of the other projects and there could be ideally synergies created between the projects."*	Case 1, Interviewee 2, Lead partner 1
Shared consensus	Partner alignment	inability to group and apply for external funding	*"[…] we were never able to group ourselves as a group and do something together to go for bigger funding."*	Case 1, Interviewee 2, Lead partner 1
Shared consensus	Partner mix	mix of partner limits (introduced) evolution	*"One of the things that [the funder] is most concerned about, most interested in is new business creation. One of the things that become clear over the last 12-18 month is that the path towards new business creation in the [CO_2 utilisation] space is - at least given our current partner mix - pretty limited. […] That was one of the considerations in looking at why the next phase didn't happen."*	Case 1, Interviewee 1, Lead partner 1
Shared consensus	Expectation management	unclear contribution of intermediary and its partners	*"[…] we needed to look at the more long-term objectives and we started to ask ourselves: what is the added value to this whole discussion; how can we serve the partners right; and what we can get back from the partners."*	Case 1, Interviewee 2, Lead partner 1
Shared consensus	Expectation management	partner expect ongoing funding (unfulfilled)	*"[…] that was where it was difficult to match partner wishes and our requirement of becoming self-sustainable"*	Case 1, Interviewee 2, Lead partner 1
Shared consensus	Expectation management	partner expect ongoing funding (unfulfilled)	*"[…] the research colleagues had their wishes that suddenly - due to the repositioning - were not fulfilled anymore."*	Case 1, Interviewee 2, Lead partner 1
Internal value creation	Size of funding	discrepancy in available funding supply and R&D demand	*"[The] programme has - what we consider at [lead partner 1]- a significant amount of funding in total. But if we relate that to what is necessary to develop,*	Case 1, Interviewee

Survival Dimension	Code Theme	Code (Categories)	Quote	Case Reference
			to commercialise technologies in the chemical industry or the materials industry where [CO_2 utilisation] is used, it's a rounding error compared the many many millions that are needed to take something from even a high level of technological development in the laboratory and scale it up to pilot or industrial/commercial scale."	1, Lead partner 1
Internal value creation	Vertical integration	capture more value by operating research/demonstration outcomes/facilities in the future	*"We envisage a transition from a pure research organisation to an organisation that - given our experience - is more and more moving the actual operation of CCS projects as they potentially come off line."*	Case 4
Internal value creation	Complementary activities and relationships	complementing close relationship to another intermediary	*"I see the two organisations as complementary. We have obviously pretty close relationship, because I know most the senior people there and they know us, and they are members of ours and we have given them money. Pretty obviously it is a comfortable relationship. But we are different. They employ almost exclusively scientists and I almost exclusively don't employ scientist. That is how it works."*	Case 3
Internal value creation	Competencies and knowledge	lack of understanding of technology (potential), processes, and industry	*"We realised too late that we need somebody external, unbiased, that would help [the lead partner 1] to understand the technical part of it."*	Case 1, Interviewee 2, Lead partner 1
Internal value creation	(Self-)organisation and management	failed to become a thought leader	*"We never thought of organising ourselves. There is that [CO_2 utilisation] conference, but we never came up with the idea why don't we present yearly the newest results that are coming out from all the studies, the systemic studies there. The though leadership piece was definitely missing."*	Case 1, Interviewee 2, Lead partner 1
Internal value creation	(Self-)organisation and management	need to showcase that new KPIs are met at the expense of ongoing knowledge generation	*"The KPIs have changed: the whole knowledge generation KPI - the knowledge transfer and knowledge adoption. That KPI doesn't exist anymore. That makes pure research projects pretty tough. [...] Projects that happen essentially in the laboratory or at someone's desk. We get less credit from our funder for those kinds of activities. That is one of the reasons we are at this point: we are re-evaluating how we engage on the topic."*	Case 1, Interviewee 1, Lead partner 1
Internal value creation	Exploitation management	lack of product manager/developer in organisation or initiative	*"I think we lack a product developer in the team. [...] Somebody that recognises there is a value [in the project outcomes]. Maybe also together with the research universities. Let's build this as a service. Why did we never think about that? Honestly, we didn't have the time."*	Case 1, Interviewee 2, Lead partner 1
Internal value creation	Communication and involvement	identifying partners to sustain project outcomes	*"That is a key topic for us right now: figuring out who we can partner with, how we - in some ways - can pass the torch on some of our work and make sure that the knowledge is shared more broadly."*	Case 1, Interviewee 1, Lead partner 1

Survival Dimension	Code Theme	Code (Categories)	Quote	Case Reference
Internal value creation	Communication and involvement	involvement of end customer	*"One of the things we are doing in the next [programmes] is have toolkits that we can sell to different cities and regions that they would pay for and ultimately, we can cover some of the cost if not make some revenue."*	Case 1, Interviewee 1, Lead partner 1

5 OVERALL CONCLUSIONS

In this section, overall conclusions are given. First, Section 5.1 shows how all three articles are connected by building on the managerial statements and the overall framework; thereby including the articles' implications in a framework of conclusions. Second, in Section 5.2, all conclusions are brought together by providing brief answers to the research questions. Moreover, propositions for future research are developed to encourage testable hypotheses in a maturing technological field of growing empirical data. Lastly, the overall conclusions end with a reflection on this PhD project's generalisability and limitations and provide further outlook for future research in Section 5.3.

5.1 Valley of Death and Multi-Level Considerations

5.1.1 Overcoming the Valley of Death

Within this doctoral thesis, several barriers to and drivers for the commercialisation of radical cleantech are identified. Whereas Article 1 approached these barriers and drivers mainly from a new venture perspective, Article 2 introduced the investor perspective to complement the capital demand side of the valley of death with the capital supply side. With Article 3, barriers to and drivers for an ongoing intermediation were investigated to allow a brokerage along the innovation process of radical cleantech, i.e., supply and demand, and niche and system levels. An increase in returns by means of reducing a venture's costs or increasing revenue can flatten the valley of death, while risk reduction measures decrease the risk of investment (see Figure 5-1). Additional capital supply from support systems can further fill the valley to ease a traverse (see Figure 5-1). Ensuring the ongoing intermediation by setting the right course in the evolution of an innovation intermediary can lead to the stabilisation of existing support systems and to a role model function for the design of future dedicated support systems.

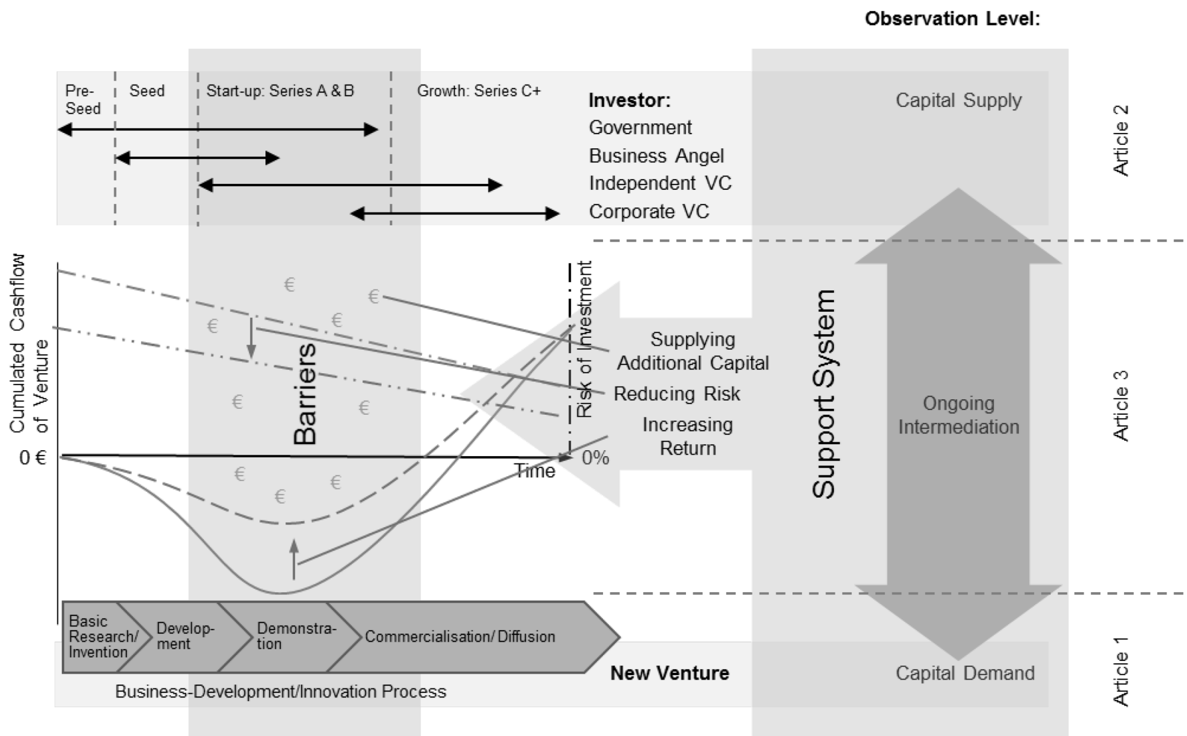

Figure 5-1: Overcoming the valley of death (adapted from Murphy and Edwards 2003)

5.1.2 Conclusions on Multiple Levels

The three frameworks that have been developed in the articles are embedded in the overall framework of this doctoral thesis covering internal dimensions of the niche and intermediary levels and the external dimensions of the niche, intermediary and system levels (see Figure 5-2).

Article 1 identified the barriers and drivers of successfully commercialising CO_2 utilisation via SE. The perception of new ventures (internal dimension) was thereby triangulated from the point of view of larger incumbents (part of the external dimension). Both new ventures and larger incumbents are niche actors taking on a niche perspective. However, a support system approach was chosen to cover the relevant factors to overcome the identified barriers, thereby allowing one to derive implications for actors not only at the niche level but also at the intermediary and regime levels.

A similar approach was carried out in Article 2, where the perceptions of investors (internal dimension) and investment experts (part of the external dimension) provided the basis for the development and assessment of strategies for early-stage, radical cleantech venture investments. In addition to recommendations at the niche level for investors, new ventures and service providers, implications for public authorities and intermediating service providers are provided at the regime and intermediary levels.

The perspective in Article 3 was on the intermediary level, where primarily the innovation intermediaries' perception (internal dimension) – in triangulation with third-party data (part of the external dimension) – described and identified evolution themes and survival dimensions. Nevertheless, the regime level is also addressed here in terms of implications for policy makers involved in the intermediation process.

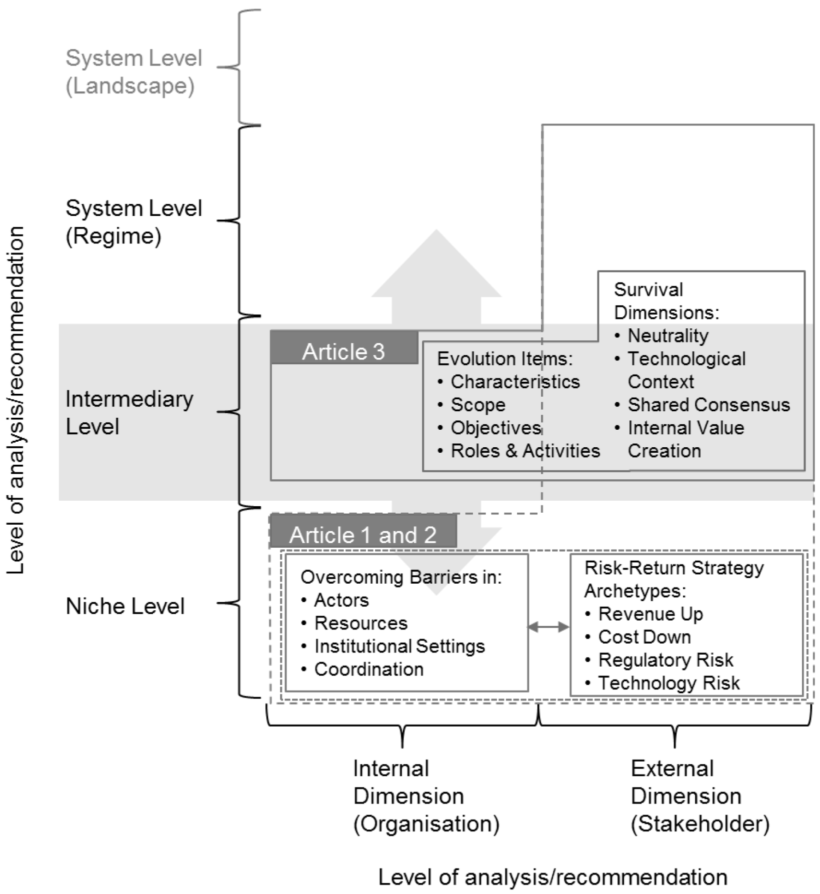

Figure 5-2: Overall conceptual framework with conclusions

Overall, the contribution of this thesis is greater than the sum of its parts (articles) because it conceptualises the MLP with the intermediary level and internal and external dimensions. Furthermore, it suggests that the valley of death should be approached from multiple perspectives and by multiple stakeholders mobilising capital and decreasing capital intensity.
In the next section, the previously framed conclusions of each article will be summarised in light of the research questions in order to lead into Section 5.3 via propositions for future research.

5.2 Research Answers and Propositions

Three research questions have been developed and answered in the course of this PhD project. In the following section brief answers and propositions for future research are presented. Propositions have been fruitfully suggested in Article 2, and this approach is now applied to the results of Articles 1 and 3 to complement the overall conclusions.

5.2.1 What are the Barriers and Drivers for the Successful Commercialisation of Strong Sustainability-Oriented New Technology Ventures? (Research Question 1)

A series of external, internal and cross-linkage barriers and drivers affect the successful commercialisation of new CO_2 utilisation ventures as a form of radical cleantech (or strong-sustainability-oriented technology) venture. The commercialisation of these radical cleantech ventures thereby shows an increased complexity in comparison to conventional innovation. This result is because of multiple focal points in sustainability (environmental, social and economic) leading to additional barriers and drivers when trying to meet all sustainability dimensions both within the organisation and via the many stakeholders that necessarily include representatives from society, industry and research. The interplay of sustainability effect with market impact for a sustainability transition is part of this complexity, and new ventures must navigate these dimensions. Hence, the following proposition is developed for near-term market impacts:

> Proposition 1-1: Sustaining (while avoiding lock-in effects) rather than disrupting industries will impact the sustainability transition in the near future because radical SOI will otherwise not be diffused.

Moreover, the identified barriers and drivers can be mapped with the crucial elements of a support system for SE: actors, resources, institutional setting, and system coordination. Stakeholders from the entire value chain, such as new ventures, larger incumbents and SMEs (as partner, supplier, service provider or customer), intermediaries, and policy makers, are called into action to jointly overcome barriers and facilitate drivers. The next proposition, therefore, reads as follows:

> Proposition 1-2: The barriers to the successful commercialisation of radical cleantech can be addressed by dedicated support systems that are coordinated effectively.

5.2.2 What Strategies can and have Successfully Improved the Risk-Return Ratio of Early-Stage Hardware-, Material- or Chemical-Based Clean Technology Venture Investments? What is their Potential Effect and who are the Players Involved in their Implementation? (Research Question 2)

Overall, 19 out of the 27 identified strategies are perceived as increasing the likelihood of a positive investment decision in early-stage, radical cleantech ventures. These strategies either affect the perceived risk or return of the investment by decreasing regulatory and technology risks and increasing a venture's revenue or reducing a venture's cost. This risk-return ratio appears to be the common denominator for investment decision-making for radical cleantech or even investments in general. Thus, the following proposition is suggested:

> Proposition 2-1 (as stated in Article 2): Strategies aiming at improving the investor-perceived risk-return ratio of cleantech investments can be clustered and evaluated by their potential to decrease technology and regulatory risk and improve return via cost reduction and revenue increase.

Furthermore, the identified strategies target multiple implementation levels where action is required to bridge the valley of death. Thus, the involvement of stakeholders goes beyond policy makers introducing various measures and includes investors, ventures and service providers. To address such an implementation complexity, the following proposition is made:

> Proposition 2-2 (as stated in Article 2): A holistic approach aiming at improving the risk-return ratio of cleantech investments should consider strategies targeting the venture, investors, public authorities (policies), service providers (e.g., incubators) and customers.

Implementing the 19 potent strategies are perceived as shifting the decision-making process towards a positive investment outcome. The combination of strategies (on different or the same implementation levels) might create synergetic effects that boost the attractiveness of an investment case even further. However, not all investment cases will become positive by following the identified strategies because the focus on financial returns is (still) predominant in the decision making of dedicated (for-profit) cleantech VC investors. Hence, there is a necessity for venture financing beyond VC investments. The following three propositions capture these observations:

> Proposition 2-3a (as stated in Article 2): Strategies targeted at the risk-return perception of cleantech investors evaluating cleantech investments have been successful in the past and can lead to increased investments in the future, provided they are applied more often and by the right stakeholders.

> Proposition 2-3b (as stated in Article 2): Strategies targeted at the risk-return perception of cleantech investors can incrementally improve the risk-return perception, but "extreme cases" require new financing models that go beyond the strategies developed in this article.

> Proposition 2-3c (as stated in Article 2): Even for cases with extremely poor risk-return perception, applying the strategies as identified in this research will lead to an improvement in the risk-return ratio.

5.2.3 How do Innovation Intermediaries Evolve Over Time and what are the Survival Factors in that Evolution? (Research Question 3)

Not only do the activities and roles of intermediaries change over time (cf. Hakkarainen and Hyysalo 2016) but also their characteristics, scope and objectives. The innovation intermediary must constantly adapt to changes in its environment. In particular, government-initiated intermediaries or PPP in general are often faced with becoming financially self-sustaining following governmental initiation. Thus, intermediation in the field of sustainability appears to be exposed to the tension between profitability and sustainability (cf. Koppenjan 2015).

However, acknowledging the four survival factors identified in Article 3 may help in dealing with this particular tension. Thus, the following proposition is developed:

> Proposition 3-1: There are at least four elements (neutrality, technological context, shared consensus, and internal value creation) that influence the survivability of innovation intermediaries in radical cleantech covering the internal perspective of the intermediary, its external environment and their interplay.

Furthermore, dealing with resource depletion or climate change is of great relevance for society; consequently governments, as society's democratically elected representatives, have a mandate to rise to these challenges by effectively allocating capital (e.g., financing of technology and market development), creating fair market conditions (e.g., charge for detrimental impacts on the environment and society or counterbalance subsidies of fossil-based technologies). Fair market conditions also refer to sound technology assessments to create a necessary understanding for the establishment of fair requirements or KPIs when designing support systems or initiating intermediation in radical cleantech fields. Consequently, the following proposition is suggested:

> Proposition 3-2: A better understanding of the potential (e.g., development times or environmental footprint) of radical cleantech via standardised assessment methodologies will lead to better decision making for initiating and sustaining an intermediation process or support systems for SOI.

5.2.4 SE to Enable CO_2 Utilisation? (Pivotal Question)

SE is clearly part of the equation in bringing CO_2-based products to the market. In particular, the radicality (in the context of SOI) of new ventures' technologies ensures a substantial sustainability effect. However, the markets where CO_2-based products can be applied are still niche-sized, and thus, the market impact is rather limited. Hence, other innovators such as larger incumbents should also play an enabling role, as previously discussed in SE research (cf. Schaltegger and Wagner 2008; Hockerts and Wüstenhagen 2010). With activities and efforts by both groups of innovators, a transition from fossil- to CO_2-based products in mass markets, such as polymers or aviation fuels, is more likely to occur, bringing society a step closer to closing the carbon loop.

Furthermore, financial returns both in cleantech investments (Article 2) and the self-sustainment of government-initiated intermediaries (Article 3) predominate, compared to environmental or social returns. Hence, innovators should try to develop business cases by focussing on improved product performance when applying or advertising a technology and the price competitiveness of CO_2-based products, compared to conventional, often fossil-based, alternatives.

5.3 **Generalisability, Limitations, and Outlook for Future Research**

The qualitative research approaches in this PhD project were justified for the purpose of exploring SE as a means of examining radical cleantech and make valuable contributions in theory and practise. However, the generalisability of these contributions should be carefully considered, as most observations concern specific cases and specific contextual settings. Nevertheless, the empirical setting was carefully chosen to abstract the technological context to other radical cleantech ventures that combine core attributes, such as research-, capital-, and risk-intensity with long technology development cycles in similar institutional settings and geographies. In addition, triangulation on different levels such as data and methodology further increased the validity of the results and allowed us to draw from rich empirical data. In the future, the growing number of new ventures in the field of CO_2 utilisation and other radical cleantech ventures with maturing technologies will enable larger sample sizes. Thus, quantitative research can further enhance our understanding of the role SE plays in the diffusion of radical cleantech by testing hypotheses derived from the propositions of this PhD project. Furthermore, longitudinal studies can unveil the specific success factors of these venture types. Building on the articles of this PhD project, the following three impulses for future (quantitative and longitudinal) research can be given: (i) Quantitative studies on new CO_2 utilisation ventures over an extended period will build on Article 1's insights and identify the specific success factors of new radical cleantech ventures and allow for further comparisons between more distinct contexts by exploiting growing data sources. (ii) Article 2 provided a solid theoretical foundation, with 27 strategies that pave the way for longitudinal studies to measure the success of these and further strategies and to explore the interplay of strategy combinations. (iii) Article 3 encourages another longitudinal approach where single in-depth case studies within the same field of technology can expand our understanding of the evolution and survival of innovation intermediaries.

Furthermore, future research could shift its emphasis from single or dual considerations of sustainability dimensions to economic, environmental and social aspects at once. This thesis and its applied frameworks such as MLP and valley of death focus rather on technology innovation instead of on social innovation (see, e.g., Witkamp et al. 2011 for MLP). Sequential considerations to align and combine the sustainability dimensions in SE for radical cleantech innovation (see, e.g., Belz and Binder 2017) could help maintain focus on both aspects. The sustainability dimensions are intertwined with the sustainability effect and the market impact that are necessary for a sustainability transition (e.g., Hockerts and Wüstenhagen 2010; Hörisch 2016; Schaltegger et al. 2016). For example, it is a challenge for cleantech innovation in exclusive niches with high sustainability effects to reach mass markets with high volumes due to conservative market behaviour, while cleantech innovation for mass markets tend to sustain the status quo or even create lock-in effects with incremental improvements in certain industries. Scholars from entrepreneurship, innovation management, and technology development must acknowledge the limitations that come with imbalances on either side (sustainability effect vs market impact) in order to contribute to dealing with (global) societal challenges such as resource depletion and climate change.

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7 PUBLICATION LIST

7.1 Article 1

Kant, Marvin (2018): Overcoming Barriers to Successfully Commercializing Carbon Dioxide Utilization.

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7.2 Article 2

Kant, Marvin; Michelfelder, Ingo (2018): Strategies to Bridge the Valley of Death!? How to Improve the Risk-Return Ratio of Hardware-, Material- or Chemical-Based, Early-Stage Cleantech Venture Investments

Later version submitted to *Research Policy* with the title 'Strategies to Bridge the Valley of Death – How to Improve the Risk-Return Ratio of Radical, Early-Stage Cleantech Venture Investments'

7.3 Article 3

Kant, Marvin; Wisdom, Kanda (2018): Innovation Intermediaries: What Does it Take to Evolve and Survive Over Time?

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