The Role of Collaboration in Emerging Industries: The Case of Smart Grids in the UK

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Under the supervision of
Dr Aija Leiponen
Dr Ilze Kivleniece
Professor Markus Perkmann
Declaration of originality

I hereby confirm that this dissertation is the result of my own work and that I am its sole author. Nonetheless, I acknowledge that I have benefitted from the advice and guidance of my supervisors. Additionally, while the words in this dissertation are my own, the first chapter was shaped by discussions with my colleague Laurens Vandeweghe. Finally, all the ideas and concepts developed in this dissertation build extensively on previous research and I have been as rigorous as I could in adequately referencing the work of others.

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Acknowlegements

I don’t think I was fully aware of all the challenges I would have to overcome to complete my PhD dissertation. It has been a long journey full of good and bad moments but, above all, it has been a learning experience that has made me grow as a person and as a researcher.

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Abstract

This dissertation explores the initial stages of emergence of a new industry over three chapters. Emerging industries offer innovating firms substantial opportunities; however, the technological and cognitive uncertainty, lack of legitimacy, fierce competition and often institutional misalignment that characterise this initial period, make it challenging for firms to navigate. Furthermore, it is important for innovating firms to understand the complex dynamics that take place during the initial stages of industry emergence because they influence later developments of significant material interest, such as technological standards.

The first chapter reviews the literature on the emergence of new industries and develops a research agenda that guides the two empirical chapters that follow. A considerable body of work has focused on understanding the process by which new industries emerge and develop, identifying three phases in this process, each with distinct challenges and opportunities. However, this literature does not specifically address the transformation of established industries triggered by pervasive digitalization. Two unique characteristics of digital innovations, generativity and convergence, have significant implications for the dynamics associated with technological change and industry emergence. First, ecosystems gain strategic importance because the focus of innovation shifts from the firm level to the ecosystem level, and second, the heterogeneity of actors that need to get involved in the development of a digital innovation increases, adding complexity to some of the process associated with nascent industries, such as creating a collective identity. Following a review of the literature on new industry emergence and ecosystem dynamics, I identify new challenges to the emergence of new industries that form following the introduction of a digital innovation, and develop a framework for future research.

The second chapter explores the role of collective actors in the emergence of a new industry triggered by a digital innovation focusing on how that role changes over time and on how innovating firms strategically engage with their activity as the industry evolves. Drawing from an inductive case study of the development smart grids in the UK, I find that initially, collective actors legitimise the case for
change in the incumbent system and develop a collective understanding of the new industry. During this early phase, innovating firms engage with collective actors to “make space” for their novel technology by educating and promoting their vision of the new industry. In the second stage, collective actors theorise value ecosystems and develop a supportive institutional infrastructure. During this stage, innovating firms turn their attention to providing evidence of the value of their technology and removing barriers to its adoption.

The third chapter investigates the determinants of the collaboration strategies of new technology firms in emerging industries with ecosystem structures. Through an inductive, longitudinal study of the collaborative innovation activities of 16 new firms developing smart grid technologies in the UK, I identify four distinct collaboration strategies that vary in timing and scope. I propose that these four collaboration strategies are driven by a new firm’s resource munificence and its dependence on ecosystem innovation for its novel technology to create value.

This dissertation contributes to the literature on emerging industries in two ways. First, it extends co-evolutionary models of industry emergence by identifying new mechanisms of interaction between institutional and technological processes. Second, it highlights the changing role of collective actors as the industry progresses which dictates the opportunities for firms to engage with their activity. Finally, this dissertation extends theories of cooperative innovation behaviour by identifying factors, both internal and external to a firm, that make depth and breadth of collaboration beneficial to its innovation activity.
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**Thesis Overview**

This dissertation aims to increase our understanding of the initial stages of the emergence of a new industry. I specifically pay attention to the mechanisms that connect the technological, social and institutional processes that co-evolve as the industry emerges (Pacheco, York, & Hargrave, 2014; Van de Ven & Garud, 1993) and to the strategic action of firms in their attempt to influence the development of the new industry. It is important for innovating firms to understand these dynamics because, during this complex period, they need to make strategic decisions regarding which type of technical and institutional activities to engage in (Van de Ven & Garud, 1993). Furthermore, previous research on the emergence of new industries demonstrates the path-dependent nature of both technology and institutional developments, suggesting the importance of understanding what happens early on as it influences later developments of significant material interest, such as technological standards (Van de Ven & Garud, 1993).

The traditional focus of the literature on technology management has been on the period surrounding the emergence of a dominant design, where firm strategic action plays a significant role. Firms aim to influence the selection of a dominant design by creating bandwagons around their products, developing interfirm networks or achieving institutional support (Dowell, Swaminathan, & Wade, 2002; Kaplan & Tripsas, 2008; Rosenkopf & Tushman, 1998; Suarez, 2004). During the initial stage of industry emergence, firm strategic action has been considered in relation to the timing of entry to maximise possibilities of firm survival, and in relation to making a technological choice at the moment of entry (Christensen, Suárez, & Utterback, 1998; Kapoor & Furr, 2015). However, we do not have a comprehensive understanding of how strategic actors navigate this complex environment characterised by technological uncertainty, unformed markets, fierce competition between the incumbent technological order and the emerging one, and often institutional misalignment (Agarwal & Tripsas, 2008; Anderson & Tushman, 1990; Santos & Eisenhardt, 2009). This dissertation, therefore, focuses on the early stages of industry emergence, pre-dominant design, and on the strategies of innovating firms to shape the evolution of the new industry.
First, I review the literature on emerging industries to develop a research agenda. A large body of work has focused on understanding the process of industry emergence and the distinct technological and competitive dynamics across the various stages of the industry life cycle. This literature identifies three phases in the emergence of a new industry demarcated by two main events, the emergence of a collective understanding of the new industry and its products, and the convergence of the industry on a dominant design. However, these predominant models of technological change and industry evolution were mostly developed based on traditional manufacturing sectors and do not specifically consider the new challenges introduced by digital technologies.

The emergence and rapid growth of the digital sector, which includes extraordinarily successful firms such as Apple, Google and Facebook, has shifted the focus of innovation from the firm level to the ecosystem level (Gawer, 2014). Furthermore, digital innovation brings together previously separate industries and requires the engagement of heterogeneous actors from different institutional backgrounds which increases the complexity of the process of industry emergence (Ozcan & Santos, 2015; Yoo, Henfridsson, & Lyytinen, 2010). The first chapter of this dissertation, therefore, reviews the literature on technological change and industry evolution, identifies the new challenges to industry emergence introduced by the unique characteristics of digital innovation, and develops an agenda for future research.

My analysis suggests four main research avenues to improve our understanding of the dynamics of technological change and industry emergence in the context of digital innovation. First, a major challenge for the success of digital innovations is that they require other independent actors to innovate, who may or may not be motivated to do so (Dattée, Alexy, & Autio, 2018; Ozcan & Santos, 2015). Therefore, understanding how innovating firms effectively engage other relevant actors becomes of significant interest. Second, previous studies have shown that intermediaries, often in the form of collective actors such as standard setting bodies, were central in managing the tensions among heterogeneous actors that needed to reach an agreement for an emerging industry to progress (Lee, Hiatt, & Lounsbury, 2017). Future research could explore the role of collective actors as
intermediaries and coordinators of some of the processes associated with the emergence of digital industries, such as agreeing on an industry architecture or on a collective identity (Lee et al., 2017; Ozcan & Santos, 2015). Third, previous studies have shown that, in the context of platform technologies, start-ups face greater risks of failure during the early stages of the technology life cycle than diversifying firms (Chen, Qian, & Narayanan, 2017). Future work could focus on understanding how the increased risks created by ecosystem structures impact the strategies of new technology firms in emerging industries. Finally, the concept of dominant design in the context of industries with an ecosystem structure raises important questions that future research could address. For example, does a dominant design refer to the ecosystem architecture or to its governance structure? What is the role of complementor diversity in the battles for technological dominance? Or, how does the shift from number of complementors to variety interact with the emergence of the dominant design?

In the second chapter, I empirically explore the role of collective actors during the initial stages of the emergence of a new industry triggered by a digital innovation, and how innovating firms engage with their activity over time. I build on evolutionary models of technological and industrial change and on previous work that has demonstrated the crucial role of collective actors in supporting the emergence of a new industry by facilitating institutional change, mobilising resources, and legitimising the new industry (Aldrich & Fiol, 1994; Greenwood, Suddaby, & Hinings, 2002; Gustafsson, Jääskeläinen, Maula, & Uotila, 2016; Sine & Lee, 2009). Since the challenges, uncertainties and dynamics of industry emergence change over the life cycle and the role of collective actors is central in overcoming emergence challenges, this study asks the following research question: how do collective actors facilitate the emergence of a new industry during the early stages, pre-dominant design, and how do innovating firms engage with their activity over time?

Understanding how the role of collective actors changes over time is of strategic importance to innovating firms that need to make decisions regarding which type of technical and institutional activities to engage in as the new industry evolves (Van de Ven & Garud, 1993). This is of interest in industries with a technology base characterised by open complex technologies, that is, technologies
comprised of closed systems linked by open standards, such as telecommunications, where the influence of socio-political pressures are stronger (Tushman & Rosenkopf, 1992). Furthermore, empirical studies suggest that in this type of industries, firms that invest in engaging with collective actors may be able to influence the technological evolution of the industry (Bar & Leiponen, 2012; Leiponen, 2008).

To address the research question, I carried out an inductive case study of the emergence of smart grids in the UK from 2005 to 2014. This period covers the early stages of industry emergence, predominant design, when the influence of collective actors is greater (Rosenkopf & Tushman, 1998). This is an interesting context in which to explore the research question because smart grids are still in an early stage of development with technological standards, business models and consumer services still in flux (Erlinghagen & Markard, 2012). Furthermore, smart grids require a fundamental technical restructuring of the electricity system and both technological innovation and institutional changes will be necessary for their development (Kunneke, 2008). Finally, in the UK, a significant number of collective actors were created in relation to the development of smart grids.

Smart grids are not just about introducing an innovation into an existing industry. The following quote from “A Smart Grid Vision”, published by the Electricity Networks Strategy Group in November 2009, shows that smart grids require a transformation of the electricity industry: "It is essential to acknowledge that the vision [of smart grids] goes far beyond technology. Technology will play an important role in meeting the UK’s needs but regulatory, legal, commercial, market, industry and cultural change will also be critical."

I find that collective actors were central to facilitating the emergence of smart grids in the UK, and that both their role and the opportunities for innovating firms to engage with their activity changes over the life cycle. During the initial stage of industry emergence, collective actors legitimised the case for change in the incumbent system and developed a collective understanding of the new industry. Innovating firms engaged in educating and promoting their vision of the new industry to ensure a space for their technology in the collective understanding of the new industry. During the
second stage, collective actors focused on theorising value ecosystems and on developing an institutional infrastructure that facilitated the adoption of smart grid technologies. Innovating firms turned their attention to providing evidence of the value of their technology to remove barriers to its adoption.

This study contributes to co-evolutionary models of industry emergence by identifying the strategic action of innovating firms that participate in both institutional activity, via collective actors, and in collaborative innovation projects, as a mechanism of interaction between the development of the technological base of an industry and its institutional framework. In addition, this study suggests that small innovating firms aiming to influence the development of a new industry characterised by complex technologies, may use their technological capabilities to make up for their lack of market power.

In the third and last chapter, I empirically study the determinants of the collaboration strategies of new technology firms in their efforts to innovate. I focus on new technology firms because they are central actors in emerging industries (Powell, Koput, & Smith-Doerr, 1996; Schumpeter, 1934; Tushman, Michael L. & Anderson, 1986) and their limitations, particularly their lack of resources and legitimacy, often make collaboration with external partners a significant aspect of their innovation and survival strategy (Baum, Calabrese, & Silverman, 2000). Furthermore, in the context of industries with ecosystem structures, new firms face greater risks of failure during the early stages of the technology life cycle than incumbent or diversifying firms (Chen et al 2017). Therefore, the research question is **which are the determinants of the collaboration strategies of new technology firms innovating in ecosystem environments and the strategic trade-offs attached to each collaboration strategy?** Each collaboration strategy carries different strategic trade-offs and it is important for innovating firms to understand those if they are to efficiently allocate their valuable R&D resources. I adopt an ecosystem approach because it captures the interdependent nature of value creation in complex technological environments (Adner, 2017; Adner & Kapoor, 2010).
To address the research question, I carry out an inductive longitudinal study of the collaborative innovation activities of 16 new firms developing smart grid technologies in the UK. I find that a new technology firm’s resource munificence and the level of dependence on ecosystem innovation for its technology to deliver value, are the main determinants of their collaboration strategy. These two factors taken together give rise to four distinct collaboration strategies that vary in timing and scope. I contribute to the literature on cooperative innovation by identifying the circumstances, both internal and external to the firm, that make partnering broadly or intensely with a few key partners beneficial to an innovating firm.
References


Chapter One. The Emergence of New Industries: Review of the Literature and Research Agenda

Abstract
A significant body of work has focused on understanding the process by which new industries emerge and develop, identifying three phases in this process each with distinct challenges and opportunities. However, this literature does not specifically address the transformation of established industries triggered by pervasive digitalization. Two unique characteristics of digital innovations, generativity and convergence, have significant implications for the dynamics associated with technological change and industry emergence. First, ecosystems gain strategic importance and second, the heterogeneity of actors that need to get involved in the development of an innovation increases. Following a review of the literature on new industry emergence and ecosystem dynamics, I identify new challenges to the emergence of new industries that form following the introduction of a digital innovation and develop a framework for future research.

1. Introduction
Emerging industries offer innovating firms substantial opportunities and have received increasing attention in the literature (Giarratana, 2004; Kapoor & Furr, 2015; Sine & Lee, 2009; Suarez, Grodal, & Gotsopoulos, 2015). An emerging industry is a “newly formed or re-formed industry that has been created by technological innovations, shifts in relative cost relationships, emergence of new consumer needs, or other economic and sociological changes that elevate a new product or service to the level of a potentially viable business opportunity” (Porter, 1980).

Often, during the early stages of industry emergence, market leader positions are established (Gustafsson, Jääskeläinen, Maula, & Uotila, 2016) such as in the mobile telecommunications industry (Rice & Galvin, 2006). Entrepreneurs can take advantage of the ambiguity and lack of structure that characterises new industries to establish dominant positions in the nascent market (Santos & Eisenhardt, 2009). However, emerging industries also present significant challenges for firms.
Innovating firms not only compete against each other but also against the incumbent system (Van de Ven & Garud, 1989). This competition extends beyond the market place into the institutional space as companies battle to gain support for their proposed technologies (Van de Ven & Garud, 1989).

Given the significant opportunities and risks associated with emerging industries, an understanding of their dynamics should support strategic decision-making in relation to timing the entry into a new industry, making technological choices at the time of entry, selecting collaboration partners for R&D activities, participating in the development of the institutional context to support their technologies and strategic positioning in the technology battles that precede the selection of industry standards (Kapoor & Furr, 2015; Suarez, 2004; Suarez et al., 2015; Van de Ven & Garud, 1993).

A large body of work has focused on understanding the process of industry emergence and the distinct technological and competitive dynamics across the different stages of the industry life cycle. The literature identifies three phases in the emergence of a new industry demarcated by two main events, the emergence of a collective understanding of the new industry and its products, and the convergence of the industry on a dominant design. However, these predominant models of technological change and industry evolution were mostly developed based on traditional manufacturing sectors and do not specifically consider the new challenges introduced by digital technologies.

First, the emergence and rapid growth of the digital sector, which includes extraordinarily successful firms such as Apple, Google and Facebook, has shifted the focus of innovation from the firm level to the ecosystem level (Gawer, 2014). Second, digital innovation brings together previously separate industries and requires the engagement of heterogeneous actors from different institutional backgrounds which increases the complexity of the process of industry emergence (Ozcan & Santos, 2015; Yoo, Henfridsson, & Lyytinen, 2010). The aim of this chapter, therefore, is to review the literature on technological change and industry evolution, identify the new challenges to industry emergence introduced by the unique characteristics of digital innovation and develop an agenda for future research.
My analysis suggests four main research avenues to improve our understanding of the dynamics of technological change and industry emergence in the context of digital innovation. First, a major challenge for the success of digital innovations is that they require other independent actors to innovate that may or may not be motivated to do so (Dattée, Alexy, & Autio, 2018; Ozcan & Santos, 2015). Therefore, understanding how innovating firms effectively engage other relevant actors becomes of significant interest. Second, previous studies have shown that intermediaries, often in the form of collective actors such as standard setting bodies, were central in managing the tensions that arise among heterogeneous actors that need to reach an agreement for an emerging industry to progress (Lee, Hiatt, & Lounsbury, 2017). Future research could explore the role of collective actors as intermediaries and coordinators of some of the processes associated with the emergence of digital industries, such as agreeing on an industry architecture or on a collective identity (Lee et al., 2017; Ozcan & Santos, 2015). Third, previous studies have shown that, in the context of platform technologies, start-ups face greater risks of failure during the early stages of the technology life cycle than diversifying firms (Chen, Qian, & Narayanan, 2017). Future work could focus on understanding how the increased risks created by ecosystem structures impact the strategies of new technology firms in emerging industries. Finally, the concept of dominant design in the context of industries with an ecosystem structure raises important issues that future research could address. For example, does a dominant design refer to the ecosystem architecture or to its governance structure? What is the role of complementor diversity in the battles for technological dominance? Or, how does the shift from number of complementors to variety interact with the emergence of the dominant design?

2. Traditional Frameworks of Industry Emergence

An influential framework for illustrating how technologies and industries evolve is the life cycle approach (Anderson & Tushman, 1990; Utterback & Abernathy, 1975). This body of work is based on the principle that technological change follows an evolutionary process of variation, selection and retention and these underlying forces determine the progression of industries (Anderson & Tushman, 1990; Utterback & Abernathy, 1975). In this framework, a technological discontinuity or
breakthrough sets off an era of ferment characterised by high levels of technical experimentation, variation and uncertainty. This technological uncertainty is resolved when the emergent industry converges on a dominant design, that is, a specific technological path which achieves dominance among alternative competing paths leading to a period of incremental technical change until a new technological discontinuity starts the cycle all over again (Anderson & Tushman, 1990; Utterback & Suarez, 1993).

The proposal that products and processes follow a consistent pattern of evolution was first developed by Utterback and Abernathy in their seminal 1975 paper. They distinguish between innovation in the product (new technology or combinations of technology) and in the process (equipment, work force, physical inputs, etc. required in the production of a product or service) and develop a conceptual model that relates innovation to product and process evolution (Utterback & Abernathy, 1975).

Utterback and Abernathy (1975) identify three stages in the evolution of a process. The first phase, which they term uncoordinated, is characterized by high product diversity, unstandardised operations and inefficiency in the process. This is followed by a segmental phase during which the process becomes more specialised, efficient, integrated and rigid. This development requires the emergence of a few stable designs. During the final or systemic phase the process becomes highly integrated and developed and is costly to change. These three phases approximately correspond to the three phases of the product lifecycle. During the early phase, performance-maximising, there is a high rate of product change, innovation is driven by new market needs, and markets are not clearly defined. During the second phase, or sales maximising, some product designs begin to dominate and rate of product innovation decreases. Finally, the product becomes standardised and competition revolves around product price. Innovations during this cost-minimising phase are primarily incremental (Utterback & Abernathy, 1975).

Building on the work of Utterback and Abernathy (1975), Anderson and Tushman (1990) developed an evolutionary model of technological change. They propose that evolutionary processes of variation, selection and retention determine the evolution of technologies. Each technological cycle
consists of two distinct phases, one era of ferment and one of incremental change. Breakthrough innovations initiate an era of ferment which is characterised by competition among different variants or designs of the breakthrough technology until a single configuration is selected as the dominant design. The emergence of a dominant design initiates the second phase of the cycle where the selected designs continue evolving in an incremental way until a new breakthrough innovation or discontinuity starts a new technology cycle (Anderson & Tushman, 1990).

Figure 1: A technology cycle, adapted from (Tushman, Anderson and O'Reilly, 1997)

The development of a technological discontinuity and the emergence of a dominant design, are also the moments when managerial action and firm strategic behaviour are crucial. During those periods, companies can have a stronger impact on shaping market rules and innovation patterns and firms that proactively attempt to influence technological cycles are more likely to sustain competitive advantage as technology evolves (Tushman, Anderson, & O'Reilly, 1997).

The life cycle framework has been empirically demonstrated by Utterback and Suarez (1993) in a number of U.S. manufacturing industries including typewriters, automobiles, television sets, transistors, integrated circuits, calculators and supercomputers. They also observed that the industries studied showed similar patterns of firm entry and exits which were linked to the state of technological evolution in the industry. Initially, small entrepreneurial firms enter the nascent industry at a moderate pace which is later followed by a rapid wave of entry (Utterback & Suarez, 1993). Once the
industry converges on a dominant design, however, the number of firms decreases until the industry is dominated by a few large firms (Utterback & Suarez, 1993).

Two recent studies expand the life cycle model by considering the impact of cognitive factors on the dynamics of technology evolution. Kaplan and Tripsas (2008) develop the concept of “technological frames” to refer to how actors make sense of a technology, that is, how they understand the new technology and its uses (Kaplan & Tripsas, 2008). They suggest that the technological frames of different actors, such as producers, users and institutional actors, shape technology evolution indirectly by guiding their actions (Kaplan & Tripsas, 2008). These technological frames are rooted in the knowledge accumulation of actors and direct key decisions that impact a technological trajectory such as which technology to invest in, which technology to adopt or which technology to give institutional support to (Kaplan & Tripsas, 2008). Actors can strategically act to try and shape technological frames often creating technology user groups or industry associations to influence the frames of others in the new field (Kaplan & Tripsas, 2008).

Suarez, Grodal and Gotsopoulos (2015) also focus on the evolution of the understanding of the new industry and its products by different stakeholders and its influence on technology developments. They propose the concept of dominant category or “the conceptual schema that most stakeholders adhere to when referring to products that address similar needs and compete for the same market space” (Suarez et al., 2015: 438). A dominant category is negotiated and represents a collective vision of what most stakeholders understand the new industry to be and once it emerges it guides subsequent technological experimentation (Suarez et al., 2015).

The existing literature, therefore, identifies three phases in the process of emergence of a new industry, an initial phase, also termed embryonic or precursor phase, a co-evolutionary phase and a phase of incremental growth (Anderson & Tushman, 1990; Gustafsson et al., 2016; Kaplan & Tripsas, 2008; Suarez et al., 2015). These three phases are demarcated by two main events, the emergence of a collective understanding of the new industry and its products, that is, a dominant category or collective technological frame, and the convergence of the industry on a dominant design. The
following sections provide an overview of each of the phases and associated dynamics focusing mainly on the earlier stages before a dominant design emerges and the industry enters the growth stage.

2.1. The initial stage of the era of ferment
The initial stage of industry emergence is characterised by high ambiguity, unclear product definitions and low legitimacy (Aldrich & Fiol, 1994; Hargadon & Douglas, 2001; Santos & Eisenhardt, 2009). During this stage, the incumbent industrial order or technological system is being challenged but the emerging one is still undefined (Gustafsson et al., 2016; Van de Ven & Garud, 1989, 1993). The main challenges that firms face during this initial stage is cognitive uncertainty, which constrains their ability to communicate effectively with stakeholders about the new technology or activity, lack of a coherent collective identity, low legitimacy and often institutional misalignment (Aldrich & Fiol, 1994; Freeman & Perez, 1988; Suarez et al., 2015).

During this phase, there is no industry as such, and its meaning and boundaries are being negotiated by diverse stakeholders that may have a different understanding of what the new industry represents and the need that it addresses (Kaplan & Tripsas, 2008; Suarez, F et al., 2015). These different visions of the industry will initially co-exist until an agreement is reached among stakeholders on the meaning of the new industry (Kaplan & Tripsas, 2008; Suarez, F., 2004).

This initial phase in the emergence of a new industry is often triggered by a technological innovation that challenges the incumbent system (Tushman & Anderson, 1986). Tushman and Anderson (1986) studied the minicomputer, cement and airline industries from their birth through 1980 and found that technological breakthroughs occur rarely and typically after a long period of incremental technological change. They note that technological breakthroughs have an important impact on the competitive environment and classify them as “competence-destroying” or “competence enhancing” based in the effect they have on the competencies of existing firms (Tushman & Anderson, 1986). Competence-destroying discontinuities are the most rare and require new skills, abilities and
knowledge and have the potentially to change the distribution of power within an industry creating opportunities for new entrants (Tushman & Anderson, 1986).

Nonetheless, other factors beyond a technological innovation can lead to the creation of a new industry. Institutional changes including new regulations, new practices as well as changes in meanings and understandings can open opportunities for entrepreneurs that can then gain momentum and develop into new industries (Russo, 2001, 2003; Sine & Lee, 2009). These changes at the broader institutional level are often initiated and managed by collective actors, such as social movement organisations and industry associations (Greenwood, Suddaby, & Hinings, 2002; Lounsbury, Ventresca, & Hirsch, 2003; Sine & Lee, 2009; York, Hargrave, & Pacheco, 2016).

For example, the emergence of the independent power sector in the U.S. was facilitated by a number of institutional shifts prompted by regulatory changes (Russo, 2001, 2003). These regulatory changes forced incumbent utilities to buy electricity from independent power producers, thus reducing transaction costs and entry barriers for firms wishing to enter the new field (Russo, 2001). The following establishment of a trade association ensured that the interests of the nascent industry were taken into account as the institutional framework developed (Russo, 2001). Likewise, in the state of California, the emergence of the wind energy industry was enabled by the convergence of availability of natural resources, a favourable institutional environment that lowered the risks of the new activity through tax incentives, and the existence of an industry association that could participate in the policymaking process supporting the wind industry (Russo, 2003).

A change in the regulatory environment was also one of the main factors leading to the emergence of the management consulting sector in the U.S. (David, Sine, & Haveman, 2013). In the 1930s, the expansion of American businesses had led them to rely on commercial banks for advice on how to manage efficiently increasingly complex operations. However, in 1933, the Glass–Steagall Act separated commercial and investment banking and precluded banks and accounting firms to act as business advisors opening opportunities for other firms to take on that role (David et al., 2013).
In their study of the U.S. electricity power industry, Sine and David (2003) demonstrate that environmental jolts, such as blackouts and the 1973 oil embargo, mobilised actors and initiated field-level search processes for solutions. The result was institutional changes that eventually led to the emergence of the independent power sector (Sine & David, 2003). Environmental activists took advantage of the crisis caused by the 1973 Saudi oil embargo to raise the issue of increasing environmental damage caused by a fossil-fuel based power industry and simultaneously advocated renewable energy technologies as a solution (Sine & Lee, 2009). The environmental movement mobilised its members to promote wind energy and to participate in the development of a regulatory environment to support renewable energy technologies (Sine & Lee, 2009). Sine and Lee’s (2009) study of the emergent U.S. wind energy sector empirically demonstrates the importance of large scale social movements in facilitating the emergence of new industries (Sine & Lee, 2009).

A further example of social movements promoting institutional change and enabling the development of a new industry is the case of the U.S. for-profit recycling industry (Lounsbury et al., 2003). This case shows the importance of the non-profit recycling movement in de-institutionalising the prevailing waste management solution, incineration, by drawing public attention to its harmful health implications, and in engaging both grassroots activists and mainstream institutional players in building the infrastructure necessary for the emergence of the recycling industry (Lounsbury et al., 2003).

Cultural changes have also shown to create entrepreneurial opportunities that can develop into new areas of activity. The emergence of the commercial whale-watching industry in North America would not have been possible without a macro cultural change in how whales where conceptualised and perceived by the general public (Lawrence & Phillips, 2004). Lawrence and Phillips (2004) refer to two widely known stories, those of Moby Dick and the Hollywood production Free Willy to illustrate this change. Nonetheless, this cultural change was not sufficient in itself and the emergence of this new industry also required the action of local actors (Lawrence & Phillips, 2004).

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Finally, strategic action of individuals or collectives can bring about institutional change and lead to the creation of new fields. Kodak, for example, used discursive strategies to influence how the public understood a new technology, the roll-film camera (Munir & Phillips, 2005). By influencing the social context of a technology, Kodak was able to transform photography from a highly specialised professional activity to a mundane activity that could be easily introduced into any part of life, furthermore, capturing life’s important moments became a must (Munir & Phillips, 2005). This change of perception of photography from an activity available only to a few professionals to a popular activity available to all benefited Kodak immensely (Munir & Phillips, 2005). This study is interesting because it shows that the technological evolution of an industry can be influenced by the meanings purposefully created around a new technology (Munir & Phillips, 2005).

However, strategic action to impact the institutional context in emerging fields can be complex as power and resources are distributed and there are a variety of views among the different stakeholders of what the main issues and perceived solutions are (Maguire, Hardy, & Lawrence, 2004). Given the specific characteristics of emerging fields, strategic actors that intend to promote a process of institutional change in support of a new area of activity must develop arguments that speak to the interests of a wide number of stakeholders, use political tactics to form coalitions with these stakeholders and support practices aligned with the values of diverse stakeholders (Maguire et al., 2004).

Nonetheless, firms that take advantage of the opportunities offered by a new technological innovation or by a change in the institutional context that creates a new area of activity face a crucial constrain during the formative years of a new industry, that is, the lack of legitimacy which restricts their access to valuable resources, such as capital, skilled workers and government protection (Aldrich & Fiol, 1994). Aldrich and Fiol differentiate between two types of legitimacy, cognitive legitimacy, or how widespread the knowledge of a new activity is, and socio-political legitimacy, or to what extent that new activity conforms to existing rules and norms and is accepted by key stakeholders (Aldrich & Fiol, 1994).
Legitimacy requires a coherent identity for the new sector (Clegg, Rhodes, & Kornberger, 2007; Georgallis, Dowell, & Durand, 2018). Early entrepreneurs in the nascent business coaching industry in Australia, engaged in discursive strategies to develop a collective identity for the new industry and establish the legitimacy needed for growth (Clegg et al., 2007). Furthermore, a coherent identity may also increase the chances of a new industry receiving institutional support (Georgallis et al., 2018). The negotiation of a collective identity, however, is a complex process and firms often need to make concessions in order to reach an agreement on an identity that resonates with a heterogeneous group of actors (Lee et al., 2017). This collective identity is a result of the efforts of the different firms that participate in the new activity and it is not until this identity is formed and legitimised that individual firms start claiming their uniqueness within the field (Navis & Glynn, 2010).

Other strategies that firms pursue to legitimise a new area of activity include generating acceptance by imitating incumbent systems, establishing the value of the new activity, making claims, obtaining external endorsements and developing affiliations with external actors (Clegg et al., 2007; David et al., 2013; Khaire, 2014; Sine, David, & Mitsuhashi, 2007).

In their excellent discussion of the early years of the emergence of electric lighting, Hargadon and Douglas (2001) show how, initially, the electric lighting system was designed to imitate some of the features of gas lighting while presenting differences at the same time (Hargadon & Douglas, 2001). The aim of this strategy was to locate the innovation within existing meanings and behaviours so that actors could make sense of and understand the new ideas by connecting them to accepted schemas and scripts (Hargadon & Douglas, 2001). Making a new idea or product understood is a pre-requisite for cognitive legitimacy (Khaire, 2014).

Invoking familiarity to generate acceptance was also observed in the early years of the U.S. broadcasting radio industry where the legal framework of the waterways was adopted to coordinate the radio spectrum (Leblebici, Salancik, Copay, & King, 1991). Likewise, in the Indian high-end fashion industry, early designers created mainly traditional Indian garments to promote acceptance of the new industry (Khaire, 2014).
In her study of the emergence of the high-end fashion industry in India, Khaire (2014) also highlights the importance of establishing the worth of a nascent industry in order for it to be legitimised (Khaire, 2014). Early entrepreneurs, as well as other field-level actors that emerged with the new activity, such as educational institutions, media and retail outlets, participated in defining the boundaries of the industry, making the industry and its products understood and establishing standards that enabled consumers to compare and judge the new products (Khaire, 2014). These distributed activities led to the construction of worth of the new industry which contributed to the establishment of legitimacy (Khaire, 2014).

Cultural support can also lead to the legitimation of a new industry, as demonstrated by the case of the Danish wind industry (Andersen & Drejer, 2008; Lounsbury & Glynn, 2001). During the early 1970s, the formative years of the industry, narratives of an environmentally friendly and free energy source which would generate employment, helped the wind energy movement gain public and institutional support, enabling the industry to attract capital and skilled workers (Andersen & Drejer, 2008). In emerging industries, this cultural support can often come from outside of the field (David et al., 2013).

In the early US car industry, claim making through reliability contests led to the legitimation of the automobile as a viable means of transport (Rao, 2004). These demonstration events, organised by clubs and car enthusiasts, offered the entertainment of a race alongside the practical testing and comparison of the different makes of cars, proving their reliability and safety to various audiences and increasing the visibility and understanding of the new technology (Rao, 2004).

Finally, external endorsements and affiliations with established actors are powerful mechanisms to increase the credibility of a new activity or technology and legitimise it (David et al., 2013; Navis & Glynn, 2010; Sine et al., 2007). As an example, in the early US independent power sector, new ventures that obtained external certification were more likely to secure sufficient resources to become operational than those that did not get the external certification (Sine et al., 2007). Similarly, James McKinsey, a pioneer in the field of management consultancy, was connected to the University of Chicago which increased his credibility (David et al., 2013).
This initial phase of a new industry culminates with the emergence of a collective identity, or collective understanding of the new industry, which resolves the cognitive uncertainty that characterises this early phase and allows stakeholders to communicate effectively about the new activity (Kaplan & Tripsas, 2008; Suarez et al., 2015).

2.2. The co-evolutionary phase of the era of ferment

During this phase of industry emergence, the co-ordinated efforts of many actors leads to the creation of a social, economic and political infrastructure necessary to support the emerging industry (Van de Ven & Garud, 1993). This infrastructure co-emerges and simultaneously guides and constrains subsequent technology development (Van de Ven & Garud, 1993). Furthermore, this phase is characterised by intense competition between different technological designs which leads to the convergence on a dominant design and the establishment of the technological basis of the industry (Anderson & Tushman, 1990; Gustafsson et al., 2016).

Numerous actors both from the public and private sectors make significant contributions to create each of the components of an industrial system required to support the entire technological community (Van de Ven & Garud, 1993). This industrial system comprises (1) institutional arrangements that legitimate, regulate and standardise a new technology, (2) resource endowments, including financial arrangements and competent labour, and (3) technical economic activities of applied R&D, manufacturing, marketing and distribution by private entrepreneurial firms to commercialise the innovation for profit (Garud & Van de Ven, 1987; Van de Ven & Garud, 1989, 1993). The development of the institutional arrangements, resource endowments and technical economic activities are highly interdependent and co-produce each other over time (Van de Ven & Garud, 1993). During this stage, rival firms often cooperate through industry councils, technical committees and trade associations, to collectively develop the infrastructure that supports the emerging industry as a whole (Van de Ven & Garud, 1993).

A collective organisation, the Danish Wind Mill Owners’ Association, was central to the emergence of the wind turbine industry in Denmark. By engaging with this Association in the design of wind
turbines, Danish wind turbine manufacturers were able to capture design features that were important to users, resulting in turbines with enhanced safety and reliability (Garud & Karnøe, 2003). Furthermore, Danish wind turbine manufacturers also worked closely with the engineers at the Danish Wind Turbine Test Station to create an industry certification which facilitated access to government subsidies (Garud & Karnøe, 2003). By engaging with other actors, technology entrepreneurs in Denmark were able to benefit from distributed skills and resources thus enabling a new industry to flourish (Garud & Karnøe, 2003). In contrast, these interactions and engagement of distributed actors did not take place in the US, where the wind turbine industry failed to emerge (Garud & Karnøe, 2003).

A further example of the significance of diverse groups and associations in facilitating the co-emergence of the different elements of an industrial infrastructure is the nanotechnology industry (Woolley, 2014). In this case, collective organisations contributed to overcoming the limitations of established institutions by providing access to information, enabling knowledge creation and transfer, securing public resources and coordinating the advancement of the field (Woolley, 2014).

The development of coalitions around different technologies or technological designs and battles for technological dominance is another central characteristic of this co-evolutionary phase (Gustafsson et al., 2016; Suarez, 2004). Firms will position themselves strategically during this phase and may aim to create bandwagons around their products, develop interfirm networks, incentivise the development of complementary assets such as distribution channels and supply chain relationships, or gain institutional support (Agarwal & Tripsas, 2008; Dowell, Swaminathan & Wade 2002; Kaplan & Tripsas, 2008; Rosenkopf & Tushman, 1998; Suarez, 2004).

Considerable effort has gone into trying to understand what factors influence the selection of a technological variant as a dominant design given the evidence that it is not just technological superiority (Anderson & Tushman, 1990). The dominance of the QWERTY keyboard or of the VHS video tapes over Betamax are classic examples (Christensen, Suárez, & Utterback, 1998). Several studies have shown that economic factors, such as the existence of network externalities or economies
of scale; social factors, such as development of technological communities and networks; as well as institutional and political factors, can all influence which design wins the battle for technological dominance (Dowell et al., 2002; Rosenkopf & Tushman, 1998; Suarez, 2004).

The emergence of a dominant design resolves the technological uncertainty that characterises the era of ferment and establishes the technological basis of the new industry allowing the industry to progress into the growth stage or era of incremental change (Anderson & Tushman, 1990; Gustafsson et al., 2016).

2.3. The era of incremental change

The establishment of a dominant design is a key event in the development of an industry that marks the end of the emergent phase (Anderson & Tushman, 1990). This transition has a profound impact on the competitive dynamics of the industry and on the focus of the innovation activity that now shifts to the development of incremental changes along the technological path established by the dominant design and to innovation in the production process (Anderson & Tushman, 1990; Christensen et al., 1998; Suarez et al., 2015). A dominant design can be defined as the product configuration that achieves dominance among competing ones (Anderson & Tushman, 1990; Suarez 2004). Anderson and Tushman studied of 16 discontinuities and found that dominant designs or industry standards were mostly developed by collaboration between incumbents and new entrants, highlighting the importance of both new ideas and institutional leverage in the process of setting industry standards (Tushman & Anderson, 1986). They propose that dominant designs emerge as the interplay between technical, political, social and organisational factors and highlight the importance of the actions of individual, organisations and interfirm networks in shaping the development of industry standards (Tushman & Anderson, 1986).

Empirical work has documented the firm “shake-out” that takes place in a new industry once it has converged on a dominant design (Christensen et al., 1998). Following the rapid entry of firms that takes place during the early stages of industry emergence, once the industry converges on a dominant design, the number of firms decreases due to competitive pressures until the industry is dominated by
a few large firms (Utterback & Suarez, 1993). This work highlights the importance of technology evolution as the driving force behind changes in the competitive structure and population dynamics of an industry pointing to the timing of entry in relation to technology evolution as a key strategic decision which will determine the success and survival of a firm in a new industry (Suarez & Utterback, 1995). Empirical work suggests that entering an industry early, before a dominant design is established, increases the possibility of firm survival because firms have time for technological experimentation and to accumulate collateral assets (Suarez & Utterback, 1995). However, entering an emerging industry too early is highly risky as the meaning of the industry is not yet defined (Suarez et al., 2015). Therefore, there is an optimal window of opportunity for entry into a new industry which is demarcated by the emergence of a dominant category and the emergence of a dominant design (Suarez et al., 2015).

During the phase of incremental change, economies of scale gain greater importance which benefits larger firms and is typically associated with a decrease in prices (Agarwal & Tripsas, 2008). Finally, the industry reaches an “equilibrium” of firms, so that the number of firms stabilises with low entry and exit rates, incremental innovation dominates as is mainly carried out by large firms, growth rates and prices stabilise and complementary assets become well-established (Agarwal & Tripsas, 2008).

3. Digital Innovation and Ecosystem Dynamics

The emergence of the digital sector, with firms like Google, Apple or Amazon becoming some of the fastest growing firms, has opened unprecedented opportunities for innovating firms. At the same time, the pervasive introduction of digital innovations into established industries is having a profound effect on their structure and competitive dynamics (Yoo et al., 2010). It is therefore crucial for both innovating and established firms to understand the dynamics of an industry that emerges around a digital innovation, and the dynamics triggered by the introduction of a digital innovation into an established industry. I follow Yoo, Henfridsson and Lytyinen and define digital innovations as “new combinations of digital and physical components to produce novel products” that offer new functionalities, such as an e-book, a digital camera, a smart phone or a digital television (Yoo et al.,
A core characteristic of digital innovations is their layered, modular architecture which results from embedding digital components into physical artefacts (Yoo et al., 2010). This architecture is a hybrid between the layered architecture of digital technologies and the modular architecture of some physical products, and confers digital innovations its unique characteristics of generativity and convergence (Yoo, Lyytinen, & Majchrzak, 2012; Yoo et al., 2010).

Generativity refers to the capacity of digital technologies to generate unprompted change driven by large, varied, and hierarchically independent audiences (Yoo et al., 2012; Zittrain, 2006). This generativity has enabled third parties to build complementary innovations or add-ons to a product characterized by a digital component and, as such, change the functional capabilities of that product (Yoo et al., 2012). In fact, for many digital innovations, complementary innovation from third parties is required for them to be of value to the customer (Adner & Kapoor, 2010). Consider the examples of digital platforms, which core software only becomes valuable with the availability of complementary applications (Evans, Hagiu, & Schmalensee, 2008). Convergence, on the other hand, refers to the ability of digital technology to cross areas of activity by bringing together different user experiences from previously separate industries (Yoo et al., 2012). For example, a smart phone allows users to make a phone call, take photos, watch a film, read the news and listen to music, among other services (Yoo et al., 2012).

The significance of complementors in relation to digital innovation, and their role in adding to the functionality and value of a certain product, have fundamentally changed the structure of many industries into an ecosystem structure (Adner, 2017; Yoo et al., 2012). Therefore, one of the main implications of digital innovation is the increased strategic importance of ecosystems defined as “the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize” (Adner, 2017: 40).

The concepts of ‘business ecosystems’ and ‘innovation ecosystems’ were introduced into the management literature over 25 years ago and managerial and scholarly attention have only increased since then (Jacobides, Cennamo, & Gawer, 2018). This trend is arguably sustained by the continuous
diffusion of digital technologies across industry sectors and the associated spread in the emergence of platforms (Gawer & Cusumano, 2002; Yoo et al., 2010). In management research, the term ‘ecosystem’ has normally been used to refer to a network of interconnected organizations that are linked to or operate around a focal innovation (Adner, 2017; Adner & Kapoor, 2010; Jacobides et al., 2018).

An innovation that is embedded in an ecosystem structure carries ecosystem-specific dynamics. First, the set of partners in an ecosystem cover both production and use-side participants and their mutual relationships does not resemble classic firm-supplier relationships, nor the relationships within a value system or a strategic network (Jacobides et al., 2018). For example, providers of complementary innovations will often not be linked through contractual arrangements to the hub organization(s) within an ecosystem and for an ecosystem to emerge and sustain, coordination and alignment of these independent actors will be required (Adner & Kapoor, 2010; Kapoor & Lee, 2013) and will involve specific types of coordination risks and coopetition dynamics (Adner, 2006; Ansari, Garud, & Kumaraswamy, 2016; Hannah & Eisenhardt, 2017). Second, ecosystems are characterized by the presence of one or more hub organizations that use their prominence and power to engage members and pull together their dispersed resources and capabilities (Dhanasai & Parkhe, 2006; Gawer & Cusumano, 2002). The hub organization(s) would often define members’ roles, and establish standards and interfaces around the focal innovation (Dattée et al., 2018; Gawer & Cusumano, 2002). Third, innovation ecosystems often require the participation of heterogeneous actors from distinct industries (Ozcan & Eisenhardt, 2009; Ozcan & Santos, 2015; Santos & Eisenhardt, 2009). In the case of ecosystems that form around a digital innovation, this heterogeneity will be even greater because digital technologies often bring together previously separate industries (Yoo et al., 2012). The example of the e-book offers an illustration of the diversity of actors that engaged in the development of this digital innovation which required the participation of firms from the book retailing industry, publishing, consumer electronics, internet search engines, telecommunications and computer industries (Yoo et al 2010).
Taken together, these dynamics suggest that digital innovations, typically embedded in ecosystem structures, may follow different evolutionary patterns than traditional electro-mechanical innovation (Chen et al., 2017).

4. Discussion and Research Agenda

The unique characteristics of digital innovation, generativity and convergence, introduce new complexities that current frameworks for understanding the dynamics of technological change and industry emergence may not fully account for. First, the generativity property of digital innovations requires simultaneously paying attention to processes taking place at two distinct levels; within and across ecosystems, and to the interactions between those two levels. Second, the convergence aspect of digital innovation increases the heterogeneity of actors that need to participate in the process of developing a new product which may influence the dynamics of technological change across the two levels. In what follows I will elaborate on how these unique characteristics of digital innovation influence the evolutionary dynamics of technological change, using the life cycle framework as the basis of my discussion.

The era of ferment is traditionally characterized by technological uncertainty and experimentation, low legitimacy and competition between different designs. Digital innovation, however, will introduce new challenges. Initially, for an ecosystem to emerge, the focal firm introducing the digital innovation will need to engage other hierarchically independent actors that also need to innovate for the focal innovation to create value (Adner & Kapoor, 2010). This will require gaining commitments from independent actors which will only bear fruit once a threshold of commitments from key actors is achieved, creating a catch-22 dilemma (Dattée et al., 2018).

Related to the engagement of relevant actors, is the design of the ecosystem architecture which will govern value sharing among the different actors. Agreeing on an ecosystem architecture is a pre-requisite for ecosystem emergence and its establishment will be influenced by power struggles and competition for the bottleneck positions (Ozcan & Santos, 2015). Within ecosystem dynamics during
this phase will, therefore, be dominated by coopetitive pressures and the need for leadership within the ecosystem (Ansari et al., 2016; Gower & Cusumano, 2002; Hannah & Eisenhardt, 2017).

Previous research demonstrates that increased actor heterogeneity introduced by digital innovation may result in greater difficulties in developing effective collaborative relationships, and in power struggles that may compromise the emergence of the ecosystem (Lee et al., 2017; Ozcan & Santos, 2015).

Within this phase, across ecosystem dynamics will centre on category formation, developing a collective identity for the new category and battles for technological dominance (Navis & Glynn, 2010; Suarez et al., 2015). Increased actor heterogeneity will introduce tensions that impact the ability of a new category to achieve legitimacy (Lee et al., 2017). The case of the organic food industry in the US demonstrates that intermediaries in the form of a collective actor were crucial in managing the identity tensions that emerged between heterogeneous market actors, enabling the formation of a collective identity and legitimation of the new sector (Lee et al., 2017).

Regarding the emergence of a dominant design, we may need to reconsider its conceptualization in the context of digital innovations (Murmann & Frenken, 2006). Dominant designs have traditionally referred to the physical architecture of a product, and this conceptualization has also been adopted by ecosystem studies (Chen et al., 2017). However, in the context of digital innovation, the governance structure of the ecosystem could also be considered an integral part of a dominant design. For example, in the case of mobile operating systems, iOS, Android and Windows Phone all adopted the same governance structure with their complementors despite their product architecture being very different. Furthermore, in the context of technology battles, strategy studies have particularly focused on growing the number of ecosystem participants, without considering the role of variety and exclusivity of ecosystem members (Boudreau, 2012).

Finally, during the era of incremental change, traditional models would predict incremental innovation along an established technological path set by the dominant design, and a shake-out of firms due to competitive pressures (Agarwal & Tripsas, 2008; Christensen et al., 1998).
ecosystem dynamics during this phase, previous studies have shown that significant innovation can occur at the level of the complements leading to sustained levels of innovation across both the era of ferment and the era of incremental change challenging the presumption that incremental change dominates this phase (Lee & Berente, 2013). This raises new challenges for the focal firm that needs to motivate innovation within the ecosystem during this phase as innovation within an ecosystem tends to decline over time reducing its competitiveness (Boudreau, 2012). Across ecosystems, the possibility of “multi-homing” introduces new competitive dynamics, both for hub organizations and complementors, and may require reconsidering the firm shake-out that follows the emergence of a dominant design in the traditional models of technological change and industry evolution (Lee & Berente, 2013).

The figure below shows the new challenges that arise in the development of a new industry that emerges around a digital innovation and forms the basis for the future research agenda that follows.

**Figure 2: The emergence of digital industries: a framework for future research**

The dynamics of technological evolution drive changes in the focus of innovation activity, the competitive structure and population dynamics within an industry and have important implications for
firm strategy. Given the unique characteristics of digital innovation and their pervasive nature, understanding the dynamics triggered by a digital innovation warrants specific attention because they are not explicitly addressed by current models. Following from the above discussion, I identify five areas of future research that would improve our understanding of the dynamics associated with technological change and industry emergence in the context of digital innovation.

First, a major challenge for the success of digital innovations is that they require other hierarchically independent actors to innovate, who may or may not have an incentive to do so (Adner & Kapoor, 2010; Dattée et al., 2018; Ozcan & Santos, 2015). Therefore, the ability to engage other actors becomes a significant priority for innovators since their lack of engagement may result in the failure of the industry to emerge (Lee, Struben, & Bingham, 2018). Future research might focus on understanding how ecosystem leaders effectively engage relevant actors and whether new forms of collaboration may be required to achieve actor engagement.

Second, previous studies have mainly considered ecosystem architectures that have been designed by a hub organization. Digital innovations however, often require the convergence of different industries each with their corresponding leading firms which may have different ideas on how the new industry should be structured (Ozcan & Santos, 2015). When several industries converge, power struggles around reaching an agreement about an industry architecture can stall the development of the emerging industry (Ozcan & Santos, 2015). Further research could address the role of intermediaries, such as industry associations or other types of collective organisations, in facilitating an agreement on an industry architecture. Another interesting research avenue would be to focus on understanding which actors will accept non-leadership roles within an ecosystem that emerges around a digital innovation and under which conditions.

Third, the case of the organic food industry in the US suggests that collective actors such as standards associations may become more prominent in the process of industry emergence under circumstances of increased actor heterogeneity. A standards-based certification organisation was central in managing the identity tensions that emerged among the different actors involved in the US organic food industry.
(Lee, et al., 2017). A future research avenue could consider the role of collective actors as intermediaries during the early stages of the technology cycle in the context of digital innovation.

Fourth, recent research has demonstrated that ecosystem structures carry increased risks for new entrants demonstrating that technologies introduced by start-ups are more likely to exit a dominance battle when it takes place in the context of technologies with a platform structure (Chen et al., 2017). Given that new technology firms, or start-ups, already face significant challenges related to their lower levels of legitimacy and resources, further research could focus on identifying the strategies of start-ups during the early stages of industry emergence in the context of technologies with an ecosystem structure.

Finally, given the major strategic relevance that current literature places on the impact of a dominant design on the innovation and competitive dynamics of an industry, further work is needed to deepen our understanding of how dominant designs are conceptualized as well as their relevance in the context of digital technologies (Murmann & Frenken, 2006; Suarez et al., 2015). Some interesting questions would be: does a dominant design refer to the ecosystem architecture or to its governance structure? What is the role of complementor diversity in the battles for technological dominance? Or, how does the shift from number of complementors to variety interact with the emergence of the dominant design?
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Theoretical approaches to industry emergence
References


Chapter Two. The Role of Collective Actors in Emerging Industries: The Development of Smart Grids in the UK

Abstract
This study explores the role of collective actors during the initial stages of industry emergence.

Through an inductive study of the initial stages of the smart grid industry in the UK, I find that collective actors were central to facilitating the emergence of the new industry and that both, their role and the opportunities for innovating firms to engage with their activity, changes over the life cycle. During the initial stage of industry emergence, collective actors legitimise the case for change in the incumbent system and develop a collective understanding, or collective technological frame of the new industry. Innovating firms engage in educating and promoting their vision of the new industry to ensure a space for their technology in the collective technological frame. During the co-evolutionary stage, collective actors focus on theorising value ecosystems and developing a supportive institutional infrastructure. Innovating firms turn their attention to providing evidence on the value of their technology to remove barriers to its adoption. Understanding this process is critical for innovating firms that need to make strategic decisions regarding their participation in technological and institutional activities during this complex and risky period.

1. Introduction
New industries that emerge as a result of technological change are characterised by high technological uncertainty, fierce competition between the incumbent technological order and the emerging one and often institutional misalignment (Aldrich & Fiol, 1994; Tushman & Anderson, 1986; Van de Ven & Garud, 1993). Emerging industries offer innovating companies substantial opportunities and have received increasing attention in the literature (Giarratana, 2004; Kapoor & Furr, 2015; Sine & Lee, 2009; Suarez, Grodal, & Gotsopoulos, 2015). The early emergence stage of an industry is the stage in which market leader positions are often established (Gustafsson, Jääskeläinen, Maula, & Uotila, 2016) such as in the mobile telecommunications industry (Rice & Galvin, 2006). Successful firms often
establish leadership positions during the early stages of industry emergence, before the market is clearly defined and structured (Santos & Eisenhardt, 2009).

However, emerging industries pose significant challenges for firms. New technologies not only compete against each other but also against the incumbent system (Van de Ven & Garud, 1989). Competition in the institutional space often precedes competition in the market place as companies battle to gain support for their technologies (Van de Ven & Garud, 1989).

The complexity of the different technological, institutional and social processes that interact during the early stages of the emergence of a new industry, leads firms to form or join collective actors, that is, organizations that represent collective interests and include industry and professional associations, standards councils and working groups (David, Sine, & Haveman, 2013; Sine, Haveman, & Tolbert, 2005; Van de Ven & Garud, 1993). Previous work has demonstrated the crucial role of collective actors in supporting the emergence of a new industry by facilitating institutional change, mobilising resources, and legitimising the new industry through theorising, framing and agreeing on technological standards (Aldrich & Fiol, 1994; Greenwood, Suddaby, & Hinings, 2002; Gustafsson et al., 2016; Sine et al., 2005; Sine & Lee, 2009). However, none of these studies follows the activities of collective actors over the different stages of emergence of a new industry. Since the challenges and uncertainties around the emergence of a new industry change over the different stages and collective action is important in overcoming those challenges, it is likely that the role of collective actors will change from one stage to the other. Furthermore, the opportunities for innovating firms to engage with the work of collective actors may also be different as the new industry progresses. We therefore need a deeper understanding of how the role of collective actors evolves over time, and how organisations in the emerging industry engage with their activity over the life cycle.

Given the central role of collective actors in industry emergence, understanding how their role changes over time is of strategic importance to innovating firms that need to make decisions regarding what type of technical and institutional activities to engage in as the new industry evolves (Van de Ven & Garud, 1993). This is particularly important in the context of industries with a technology base.
characterised by open complex technologies, that is, technologies composed of closed systems linked by open standards (Tushman & Rosenkopf, 1992), such as telecommunications or electricity. Empirical studies suggest that in these type of industries, firms that invest in engaging with collective actors may be able to influence the technological evolution of the industry (Bar & Leiponen, 2012; Leiponen, 2008). Furthermore, this effect is stronger during the early stages of industry emergence, pre-dominant design (Rosenkopf & Tushman, 1998).

Based on the theoretical gap identified, this study poses the following research question: **how do collective actors facilitate the emergence of a new industry during the early, pre-dominant design, and how do innovating firms engage with their activity over time?**

To answer the research question, I carried out an inductive case study of the emergence of smart grids in the UK from 2005 to 2014. This period covers the initial stages of industry emergence when the influence of collective actors is greater. This is an interesting context in which to explore the research question because smart grids are still at an early stage of development with technological standards, business models and consumer services still in flux (Erlinghagen & Markard, 2012). Furthermore, smart grids require a fundamental technical restructuring of the electricity system and both technological innovation and institutional changes will be necessary for their development (Kunneke, 2008). Finally, in the UK a considerable number of collective actors were created in relation to the development of smart grids and stakeholders believe they are central in facilitating their development.

Smart grids are not just about introducing an innovation into an existing industry. The following quote from “*A Smart Grid Vision*” published by the Electricity Networks Strategy Group in November 2009, shows that smart grids require the entire industry to transform: *It is essential to acknowledge that the vision [of smart grids] goes far beyond technology. Technology will play an important role in meeting the UK’s needs but regulatory, legal, commercial, market, industry and cultural change will also be critical.* ENSG *A Smart Grid Vision, November 2009.*
Findings from this study suggest that during the early stages of the emergence of a new industry characterised by complex technologies, the role of collective actors and the strategic opportunities for firms to engage with their activity changes over the life cycle. During the initial stage, collective actors contribute to legitimising the case for change in the incumbent system, and to developing a collective understanding of the new industry or collective institutional frame. During this stage innovating firms engage with collective actors to “make space” for their new technology in the emerging industry by educating other stakeholders on how their new technology can solve the industry’s challenges and by promoting their vision of the new industry. Once a collective understanding of the new industry emerges, the role of collective actors focuses on ensuring coordination across the value chain by theorising value ecosystems and developing a supportive institutional infrastructure to drive consumer adoption of smart grid technologies. During this stage, innovating firms engage with collective actors to provide evidence on the value of their technology and remove barriers to its adoption.

This study contributes to our understanding of the complex processes that take place during the early stages of industry emergence. It identifies the strategic action of technology firms that participate in both collaborative innovation projects and institutional activity, often via collective actors, as a mechanism of interaction between the development of the technological base of an industry and its institutional framework. It highlights the changing role of collective actors as the industry progresses, from legitimising the case for change and developing a collective technological frame of the new industry, to theorising value ecosystems and developing a supportive institutional infrastructure. Finally, this study suggests that small innovating firms aiming to influence the development of a new industry characterised by complex technologies, may use their technological capabilities to make up for their lack of market power.
2. Theoretical background

2.1. Evolutionary models of industry emergence

Traditional models of technology evolution propose that technologies and industries evolve following a consistent pattern with two distinct phases. The initial phase, or era of ferment, is triggered by a technological discontinuity which is followed by a period of technological uncertainty and experimentation (Anderson & Tushman, 1990; Utterback & Abernathy, 1975). During this early phase, social, technological and political factors lead to the emergence of a dominant technological trajectory among several competing ones (Anderson & Tushman, 1990; Suarez, 2004). The influence of socio-political factors on the evolution of the underlying technological base of an industry is stronger during the era of ferment, and in industries based on open, complex technologies where the end product comprises multiple interdependent component technologies linked via interfaces (Rosenkopf & Tushman, 1998; Tushman & Rosenkopf, 1992).

The emergence of a dominant design resolves the technological uncertainty of the era of ferment and enables the industry to move to the next phase, the era of incremental change, where technological progress takes place along a selected technological trajectory until a new technological discontinuity starts the cycle all over again (Anderson & Tushman, 1990). This life cycle framework has been empirically demonstrated by Utterback and Suarez (1993) in a number of U.S. manufacturing industries including typewriters, automobiles, television sets, transistors, integrated circuits, calculators and supercomputers (Utterback & Suarez, 1993).

Recent studies have extended the life cycle framework by identifying an important event that needs to take place during the era of ferment to facilitate the emergence of a dominant design, that is, the development of a collective technological frame or a dominant category (Kaplan & Tripsas, 2008; Suarez et al., 2015). Kaplan and Tripsas (2008) develop the concept of “technological frames” to refer to how actors make sense of a technology, that is, how they understand a new technology and its uses (Kaplan & Tripsas, 2008). Suarez, Grodal and Gotsopoulos (2015) define a dominant category
as “the conceptual schema that most stakeholders adhere to when referring to products that address similar needs and compete for the same market space” (Suarez et al. 2015, p.439).

Two distinct phases can therefore be identified during the early stage of industry emergence, or era of ferment, an initial stage and a co-evolutionary stage, which are demarcated by the emergence of a dominant category or collective technological frame (Gustafsson et al., 2016; Kaplan & Tripsas, 2008; Suarez et al., 2015). During the initial stage, the incumbent order or technology is challenged yet the new order is not clearly defined (Gustafsson et al., 2016; Kaplan & Tripsas, 2008; Suarez et al., 2015). The meaning and even the existence of the new industry is still uncertain and there is a lack of common understanding about the new industry among stakeholders (Suarez et al., 2015). Several market categories or technology frames may emerge to reflect that variation in how the new industry and its products are understood by different stakeholders (Kaplan & Tripsas, 2008; Suarez et al., 2015). For example, in the early automobile industry the car was referred to as “electric buggy, horseless carriage, automobile or motorcycle” (Rao, 2008; Suarez et al., 2015).

In addition to individual actors’ technological frames, a field-level meaning system, or collective technological frame, may emerge over time as a result of the interactions of different actors with competing technological frames (Kaplan & Tripsas, 2008). Kaplan and Tripsas (2008) highlight the contested nature of the process of emergence of a collective technological frame given that, once it emerges, it will guide subsequent technology development efforts (Kaplan & Tripsas, 2008). The concept of collective technological frame builds on the concept of field-level frames developed by Lounsbury et al. (2003). Field frames are political constructions that provide meaning to fields of activity and can be altered as a result of political action. The study of the emergence of the US recycling industry highlights the political struggles over meanings that actors in an emerging field engage in (Lounsbury, Ventresca, & Hirsch, 2003).

Suarez, Grodal and Gotsopoulos (2015) suggest similar dynamics during the era of ferment of technology and industry evolution. At the beginning of the life cycle, the number of new categories introduced into the emerging field grows until, eventually, as some categories become increasingly
supported by industry participants, the field converges on a “dominant category” (Suarez et al., 2015). The emergence of a dominant category is a negotiated process that precedes the emergence of a dominant design (Suarez et al., 2015). Although these two concepts are related, a dominant category is a socio-cognitive construct that responds to the need of stakeholders to communicate in relation to the emerging industry (Suarez et al., 2015). A dominant design, however, is material and therefore, needs to be technologically feasible (Anderson & Tushman, 1990; Dowell, Swaminathan, Wade, 2002; Klepper, 1997; Suarez et al., 2015; Utterback & Suarez, 1993).

A firm that enters the industry during this initial stage faces great uncertainty as the industry itself has not been clearly defined and the required functionality of the new products is being negotiated, often by collective actors (Kaplan & Tripsas, 2008; Suarez et al., 2015). During this stage, firms will aim to ensure that the characteristics of their product become the cognitive referent for the industry, or will need to reposition its products at considerable risk (Santos & Eisenhardt, 2009; Suarez et al., 2015). The dominant category, or collective technological frame, will guide future technological activity (Suarez et al., 2015).

The emergence of a dominant category or collective technological frame resolves the cognitive uncertainty surrounding the new industry and marks the beginning of the co-evolutionary stage, during which, the co-evolution of technology, institutional and social developments enable the progression of the industry (Anderson & Tushman, 1990; Powell & Grodal, 2005). During this phase, firms have a shared understanding of the new industry and can meaningfully exchange information with other stakeholders about their novel technologies (Suarez et al., 2015). Firms can therefore focus on technology experimentation that is consistent with the shared perception of the new industry (Suarez et al., 2015). This phase is characterised by competition between different technology designs, strategic positioning by firms and collective action which will eventually lead to the emergence of a dominant design (Anderson & Tushman, 1990; Gustafsson et al., 2016).
2.2. The role of collective actors in industry emergence

The emergence of a new industry is shaped by technological, institutional and social forces that interact and mutually influence each other (Garud & Karnøe, 2003; Garud & Rappa, 1994; Pacheco, York, & Hargrave, 2014; Van de Ven & Garud, 1989, 1993). The complexity of the early phases of industry emergence, drives firms to cooperate in the development of the infrastructure required to support the new industry, often through forming or joining collective actors (Van de Ven & Garud, 1993). Collective actors can be broadly defined as organizations that represent collective interests, and include industry and professional associations, standards councils and working groups (David et al., 2013; Sine et al., 2005; Van de Ven & Garud, 1993, Wijen & Ansari, 2007).

Previous studies suggest that during the initial stages of industry emergence collective actors have an important role in triggering institutional change in support of the new industry. For example, the emergence of the cochlear implant industry required changes in the way new technologies were evaluated and this new evaluation rules were developed by trade associations (Van de Ven & Garud, 1993). In the US, the actions of environmental organisations were key drivers of the regulatory changes that created a favourable tax environment for wind developers, supporting the growth of the early wind power industry (Sine & Lee, 2009). Likewise, the for-profit recycling industry in the US benefitted from the educating activities of non-for-profit recycling organisations which enabled the cultural change necessary for the for-profit recycling business to flourish (Lounsbury et al., 2003). Finally, during the early stages of the high definition television industry in the US, the framing efforts of the NAB, the industry association representing the interests of broadcasters, were critical to overturning regulatory action that would have compromised the emergence of high definition television in the US (Dowell et al., 2002).

Collective actors also contribute to legitimising a new industry (Aldrich & Fiol, 1994). Professional associations were crucial to the legitimisation of the management consulting field by identifying the problems faced by the accounting profession and proposing solutions (Greenwood et al., 2002). In the process that led to the legitimization of the US wind power industry, environmental organisations
had a vital role in developing a hybrid logic that combined economic and environmental motives for supporting wind energy and, therefore, appealed to a broad set of stakeholders (York, Hargrave, & Pacheco, 2016). Trade associations are also central in the legitimisation of a new industry by enabling the emerging industry to settle on technology standards and facilitate industry growth (Aldrich & Fiol, 1994; Anderson & Tushman, 1990).

Previous studies have demonstrated the significant role of collective actors in facilitating the emergence and progression of a new industry. The focus of this work has been on understanding how collective actors trigger institutional change to support the emergence of the new industry, and legitimise the new industry through theorising, framing and agreeing on technological standards (Aldrich & Fiol, 1994; Greenwood et al., 2002; Gustafsson et al., 2016; Sine & Lee, 2009). However, we do not have a full understanding of how the role of these groups evolves over the different stages of industry emergence. Given that the uncertainties and challenges to industry emergence vary over the life cycle, and that the activities of collective actors are often aimed at resolving uncertainty and influencing the direction of the emerging industry, it is likely that they carry out different activities as the industry progresses.

Previous work has suggested that firms that engage with collective actors may be able to influence the technological evolution of an industry (Leiponen, 2008; Rosenkopf & Tushman, 1998). In their study of wireless telecommunications, Bar and Leiponen (2012) suggest that firms may invest in committee activities to develop standard specifications that favour their technological solutions and thus facilitate competitive positioning after commercialisation (Bar & Leiponen, 2012). If indeed engaging with collective actors allows firms to shape the emerging industry and benefit from that participation, it is important for innovating firms to understand how the role of those collective actors changes over time to make strategic decisions regarding the allocation of their limited resources to technological and institutional activities during the initial stages of industry emergence. Understanding how collective actors shape the industry during the different phases of emergence and the impact their activity has at
the field and organisational level, will point to areas where firms should focus their efforts to leverage their resources and navigate this complex and risky period.

This study aims to build upon the literature on industry emergence reviewed above. Based on the theoretical gap identified, I propose the following research question: how do collective actors facilitate the emergence of a new industry during the early stages, pre-dominant design, and how do innovating firms engage with their activity over time?

3. Data and methods

3.1. Research design and setting
The research design is an inductive case study of the emergence of smart grids in the UK from 2005 to 2014 (Eisenhardt, 1989). This method is appropriate because the focus of this study is to gain an in-depth understanding of the complex dynamics that take place in emerging industries and the contextual conditions are important (Yin, 1994). Furthermore, my aim is to extend existing theory which can also be accomplished from case study evidence (Eisenhardt, 1989; Greenwood & Suddaby, 2006; Yin, 1994).

The empirical setting is the development of smart grids in the UK from 2005-2014. The smart grid is an emerging industry, which in functional terms is part of the electricity sector but requires technological components and know-how that originate from the ICT sector (Battaglini, 2009; Erlinghagen & Markard, 2012). This is a particularly relevant context in which to study the dynamics of industry emergence because smart grids are not just about new technologies, as well as requiring a fundamental technical restructuring of the electricity system, institutional changes will also be necessary for their development (Kunneke, 2008). Furthermore, given their early stage of development and their technological complexity, socio-political forces will be important, thus providing a unique case to observe the activity of collective actors and the engagement of firms with their work (Eisenhardt, 1989; Yin, 1994). The period selected is appealing because during those years the field was still in an early stage of development with technological standards, business models and
consumer services in flux (Erlinghagen & Markard, 2012). This period is sufficiently long to observe longitudinal patterns yet recent enough to allow the collection of detailed data as events unfold (Santos & Eisenhardt, 2009).

The availability of data was another important reason to study the emergence of smart grids in the UK. In 2005 and 2010, a number of regulatory incentives in the UK triggered the formation of an innovation network formed by approximately 400 R&D projects and 47 smart grid demonstration projects. Given that these projects were partially funded with public money, information on them had to be reported regularly and made publicly available. In addition, information on the activity of the main collective actors, identified by interviewees, was also publicly available on their websites. These websites provide information on the activity of the collective actors, as well as access to all their deliverables and minutes or summaries of their meetings.

Finally, the boundaries of the field studied were defined by the innovation network formed by the innovation projects funded through the 2005 and 2010 regulatory incentives. All these R&D and demonstration projects are led by UK electricity distribution network companies (DNOs) and since new grid technology cannot be fully proven in the laboratory or on a simulator (SmartGrids, 2006), when a level of development is reached, unproven technologies need to be trialled on an electricity network. Therefore, by focusing on the innovation projects of the DNOs, owners and operators of the UK electricity distribution network, I am able to capture most of the applied innovation activity for the development of smart grids taking place in the UK during the observation period.

To conclude, the emergent nature of the smart grid industry, the availability of data on collaborative innovation projects as well as on the activity of collective actors, and the need for institutional changes for smart grids to develop, makes this a rich context in which to explore the role of collective actors in an emerging industry.
3.2. **Background**

3.2.1. **The UK electricity system and decarbonisation pressures**

The electricity system consists of four interconnected activities: generation, transmission, distribution, and retail or supply. The strategic importance of the electricity infrastructure and the interdependent nature of the four activities had led to the organisation of electricity utilities around publicly-owned, vertically-integrated structures (Jamasb & Pollitt, 2011). However, in the 1990s, many countries around the world saw a wave of liberalisation of the electricity sector that comprised a restructuring of the utilities, the introduction of competition, a regulatory reform and privatisation of major electricity assets (Jamasb & Pollitt, 2008).

In the UK, the liberalisation of the electricity sector in the 1990s resulted in the vertical unbundling of the generation, transmission, distribution and retail functions. Competition was introduced in electricity generation and supply, and electricity wholesale and retail markets were created, triggering the entrance of new players in both areas (Jamasb & Pollitt, 2011). The separation of electricity distribution and supply led to the creation of distribution network operators (DNOs), regional regulated monopolies whose activities are overseen by Ofgem (Office of Gas and Electricity Markets), an independent regulator (Jamasb & Pollitt, 2011).

The figure below, taken from the Smart Grid Capabilities Development Programme report published by the UK Energy Research Centre, shows the traditional UK electricity value chain.

![Conventional electricity value chain](image)

**Figure 3**: Conventional electricity value chain. Source UK Smart Grid Capabilities Program, UKERC, 2011

The electricity system that emerged from liberalisation was formed by mostly large, centralised power stations fuelled predominantly by coal, gas and oil, electricity networks characterised by one-way
power flows, and uncontrolled electricity demand (ENA, 2011). This electricity system has remained largely unchanged since the 1990s (Jamasb & Pollitt, 2008). Nonetheless, recent developments in EU and UK energy policy prompted by climate change concerns, will result in increased penetration of low carbon technologies that will create technical pressures on the current electricity networks and require them to become more flexible and controllable (Gross et al., 2008; Kunneke, 2008; Strbac, 2008).

<table>
<thead>
<tr>
<th>Year</th>
<th>Major EU and UK Energy Policy Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>The Rio Conference on Environment and Development. Resulted in the Framework Convention on Climate Change (FCCC), which was adopted and signed by 162 countries. This was the first international framework that aimed at reducing the threat from global warming and called for nations to stabilise CO2 emissions by 2000 at 1990 levels.</td>
</tr>
<tr>
<td>1997</td>
<td>The Kyoto Protocol. International agreement linked to the FCCC which set internationally binding emission reduction targets for industrialised countries.</td>
</tr>
<tr>
<td>2000</td>
<td>Climate Change the UK Programme. Launched following the UK’s commitment to the Kyoto Protocol. Aimed at reducing CO2 emissions by 19% below 1990 levels in 2010 and measures included the increase of electricity provided by renewable sources to 10% by 2010.</td>
</tr>
<tr>
<td>2003</td>
<td>Our Energy Future Creating a Low Carbon Economy. UK Energy White Paper which recognised the need for energy policy to address environmental challenges, specifically the threat of climate change. Stated the ambition of the UK and other developed countries to cut emissions of greenhouse gases by 60% by around 2050.</td>
</tr>
<tr>
<td>2006</td>
<td>EU Renewable Energy Directive. Required the European Union (EU) to fulfil at least 20% of its total energy needs with renewables by 2020 through the attainment of individual national targets. The UK target was set at 15% of total energy to come from renewables by 2020.</td>
</tr>
<tr>
<td>2007</td>
<td>An Energy Policy for Europe. Set highly challenging targets for carbon dioxide (CO2) emission reductions at 20% from 1990 levels by 2020 and 80% from 1990 levels by 2050.</td>
</tr>
<tr>
<td>2008</td>
<td>Climate Change Act (CCA). The UK becomes the first country in the world to have legally binding carbon budgets with the objective of achieving carbon reductions of 34% by 2020 and at least 80% by 2050 (both below 1990 levels).</td>
</tr>
<tr>
<td>2009</td>
<td>The UK Low Carbon Transition Plan, National Strategy for Climate and Energy. White Paper that sets out the UK’s first comprehensive low carbon transition plan to 2020. Aims to produce 30% of electricity from renewable sources by 2020 and deliver emission cuts of 18% on 2008 levels by 2020.</td>
</tr>
<tr>
<td>2009</td>
<td>Smart meter roll-out. Government announces major roll-out of electricity and gas smart meters to domestic and small and medium sized businesses throughout the UK by 2020 to reduce energy use and pave the way for a low-carbon &quot;smart grid&quot;.</td>
</tr>
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</table>

Table 1: EU and UK main energy policy events
3.2.2. Smart grids

The smart grid is an emerging industry, which in functional terms is part of the electricity sector but requires technological components and know-how that originate from the ICT sector (Battaglini, 2009; Erlinghagen & Markard, 2012). The field is still in an early stage of development with technological standards, business models and consumer services still in flux and many firms trying to find their role and establish their business (Erlinghagen & Markard, 2012; Giordano & Fulli, 2012).

Traditional electricity transmission and distribution networks were built to utilise the output of conventional fossil-fuel power generation plants. They are designed for the unidirectional flow of electricity from large generators to centres of demand (Teh, Goujon, Bortuzzo, & Rhodes, 2011). The smart grid is an advanced electricity network infrastructure characterised by a two-way flow of information and in many cases also a two-way flow of electricity (Erlinghagen & Markard, 2012). It incorporates information and communication technologies to traditional electricity network technologies to understand and intelligently respond to changing conditions in both electricity generation and demand (Teh et al., 2011). Smart grids enable new forms of energy generation and consumption as well as new services and business models (Erlinghagen & Markard, 2012).

Typical smart grid architectures consist of three layers: a hardware layer, a communication layer and a software or application layer. The hardware layer consists of the traditional transmission and distribution hardware plus “intelligent” sensors that collect information about the status and operations of the hardware (Erlinghagen & Markard, 2012). The communication layer allows gathering data from distributed end devices (e.g. metering data) and sending signals to the end device (two-way communication) (Erlinghagen & Markard, 2012). The third layer is the software or application layer that allows for aggregation and analysis of the collected data (Erlinghagen & Markard, 2012). A meter data management system (MDM) is an example of a software solution. Finally, all three layers need to be integrated into an end-to-end solution to allow for the system to work seamlessly (Erlinghagen & Markard, 2012).
3.2.3. Innovation incentives in the UK electricity distribution networks

Following the liberalisation of the UK electricity sector in the 1990s, annual expenditure by distribution network operators (DNOs) on research and development (R&D) plummeted from approximately £12 million in 1989/90 to £1 million by 2003/4 (Jamasb & Pollitt, 2015). To encourage DNOs to increase their innovation activity, in 2005 Ofgem introduced two incentives, the Innovation Funding Incentive (IFI) and the Registered Power Zones (RPZ).

The IFI provided funding for innovation projects aimed at the technical development of the distribution networks to deliver value to consumers (EDF-Energy, 2006). The IFI mechanism allowed DNOs to spend 0.5% of their revenue on innovation projects and recover between 70-90% of the project expenditures from its customers (EDF-Energy, 2006). IFI projects did not need to be approved by Ofgem but each DNO needed to report its IFI projects annually (EDF-Energy, 2006). RPZs, on the other hand, were specifically aimed at developing and demonstrating new ways of connecting generation to distribution systems. DNOs could apply for up to 2 RPZ per year and the additional revenue from RPZ schemes could not be greater than £0.5 million (EDF-Energy, 2006).

In 2010, the IFI was extended for 5 additional years and the RPZ was superseded by the Low Carbon Networks Fund (LCNF). The LCNF made £500 million available to DNOs over 5 years (2010-2015) to trial novel technologies and new commercial arrangements to facilitate the UK’s transition to a low-carbon economy (Ofgem, 2010). The main objective of the LCNF was to give DNOs the opportunity to understand the impact of the UK climate change initiatives on the electricity networks and to trial innovative technical and commercial solutions to manage the connection of larger amounts

Figure 4: Traditional versus smart grid architecture from Erlinghagen and Markard 2012.
of renewable generation technologies (Ofgem, 2010). The LCNF mechanism also encouraged DNOs to carry out their demonstration projects in collaboration with partners from the electricity industry and from other sectors, such as the telecommunications and information technology sectors (Ofgem, 2010).

The LCNF was divided into two tiers. The first tier consisted of £80 million available to DNOs over a five-year period for small-scale demonstration projects to trial new technologies and commercial arrangements that will prepare the networks for a low-carbon energy sector (Ofgem, 2010). There was no minimum or maximum size for first tier projects; however, each DNO had a maximum annual first tier allowance (Ofgem, 2010). The second tier consisted of £320 million to be allocated over five years for which DNOs competed to fund a small number of large “flagship” demonstration projects (Ofgem, 2010). From April 2010 to March 2015, the LCNF supported 40 first tier projects and 23 second tier projects with budgets totalling £29.5 million and £220.3 million respectively (Frame, Bell, & McArthur, 2016).

3.3. Data collection
This study draws upon two main sources of data: 47 stakeholder interviews and archival materials. The archival materials are comprised of: (i) the IFI annual reports of the six UK DNOs filed yearly with Ofgem from 2005-2014. These reports include individual information on each of the IFI projects, including the name of the project, its aim, collaborators, R&D providers and project progress; (ii) LCNF Tier 1 project registration reports and project closedown reports; (iii) LCNF Tier 2 project reports, including a detailed project proposal, six-monthly progress reports and project closedown report; (iii) Reports, deliverables and summaries or minutes of meetings of the stakeholder groups organised by DECC and Ofgem, including the Smart Grids Forum (SGF), the Energy Networks Strategy Group (ENSG) and the Embedded Generation Working Group (EGWG); (iv) Response documents to public consultations of Ofgem and DECC between 2005-2015; (v) Websites of trade associations for membership information.
Data collection began with 22 semi-structured interviews to stakeholders. The aim of these interviews was to set the boundaries of the case study and to focus the research question. The questions to interviewees were directed at understanding what was driving the emergence of smart grids in the UK, which were the different actors involved, how were the different actors trying to shape the emergence of the new field and what were the main challenges to the emergence of smart grids in the UK. Key questions from the interviews included: what are smart grids? What are the main drivers for their development? Which are the key stakeholders that need to get involved for smart grids to develop? How do the different actors try to influence the development of smart grids? Which stakeholder groups are involved in the development of SG? And, what are the main challenges to the development of smart grids in the UK?

The interviewees were selected, initially, based on access and then using a snowball approach with the objective of capturing a variety of perspectives. Stakeholder groups interviewed included the government, the regulator for the electricity networks (Ofgem), distribution network operators, the UK transmission network operator, electricity suppliers, technology providers, information and communication firms, environmental groups, consumer groups and energy experts. The interviews lasted between 30 and 90 minutes and most were recorded and transcribed. There were a few instances where the interviewee requested that the interview not be recorded or expressed concerns mainly related to confidentiality, in which case notes were taken and a formal write up was carried out shortly afterwards (Miles, Huberman, & Saldana, 2013). This initial work allowed me to set the boundaries of the case, focus the research question and direct subsequent data collection (Miles et al., 2013).
The exploratory phase of this research identified two main activities as the most relevant for influencing the development of smart grids in the UK, the first one was participating in the collaborative innovation projects led by the DNOs, and the second one was engaging with the activities of a number of stakeholder groups whose work was expected to influence the development of the institutional context in which smart grids were emerging. Following this phase, I carried out eight additional interviews to better understand the work of these stakeholder groups. One of those interviews was with a member of the Smart Grids Forum, the most influential group, who had been involved in the development of smart grids since 2001. That interview, which lasted 70 minutes and was fully recorded and transcribed, focused predominantly on the history of the main industry-government stakeholder groups that preceded the Smart Grids Forum, their aims and their main activities. Overall, these interviews allowed me to identify the most influential stakeholder groups and their activities. The findings from these interviews were corroborated by archival data and by

### Table 2: Stakeholders interviewed

<table>
<thead>
<tr>
<th>Organization</th>
<th>Stakeholder Group</th>
<th>Interviewees</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECC</td>
<td>Government</td>
<td>1</td>
</tr>
<tr>
<td>Ofgem</td>
<td>Regulator</td>
<td>1</td>
</tr>
<tr>
<td>National Grid</td>
<td>Electricity networks</td>
<td>1</td>
</tr>
<tr>
<td>UK Power Networks</td>
<td>Electricity networks</td>
<td>1</td>
</tr>
<tr>
<td>Energy Networks Association</td>
<td>Electricity networks</td>
<td>1</td>
</tr>
<tr>
<td>EdF Energy</td>
<td>Electricity supplier</td>
<td>1</td>
</tr>
<tr>
<td>Elster</td>
<td>Technology provider</td>
<td>2</td>
</tr>
<tr>
<td>Sentec</td>
<td>Technology provider</td>
<td>2</td>
</tr>
<tr>
<td>Smarter Grids Solutions</td>
<td>Technology provider</td>
<td>1</td>
</tr>
<tr>
<td>IBM</td>
<td>Technology provider</td>
<td>1</td>
</tr>
<tr>
<td>Cable and Wireless</td>
<td>Communications</td>
<td>1</td>
</tr>
<tr>
<td>Electralink</td>
<td>Data services</td>
<td>1</td>
</tr>
<tr>
<td>The Climate Change Group</td>
<td>NGO</td>
<td>1</td>
</tr>
<tr>
<td>Sustainability First</td>
<td>NGO</td>
<td>1</td>
</tr>
<tr>
<td>The Committee on Climate Change</td>
<td>Policy advisor</td>
<td>1</td>
</tr>
<tr>
<td>UKERC</td>
<td>Research centre</td>
<td>2</td>
</tr>
<tr>
<td>The Grantham Institute for Climate Change</td>
<td>Research centre</td>
<td>1</td>
</tr>
<tr>
<td>Chiltern Power</td>
<td>Energy consultant</td>
<td>1</td>
</tr>
<tr>
<td>PPA Energy</td>
<td>Energy consultant</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22</strong></td>
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</tr>
</tbody>
</table>
further interviews carried out at the Low Carbon and Innovation Conference in 2015, thus allowing for triangulation of the data.

The next phase involved understanding the activity of the different stakeholder groups and how firms engaged with that activity. For that purpose, I collected data on the different groups and created a database that included the technological and institutional activity of each firm that participated in the innovation projects (an example of a company table can be found in Appendix 1). Information on the stakeholder groups identified by the interviews was available from the National Archives which contains a section dedicated to government information published on the web, the UK Government Web Archive1. That information includes terms of reference and membership of each group, description of the groups, information on work streams, meeting summaries, specific projects carried out, outputs and annual reports. The Smart Grid Forum2, identified as the most influential group, has a dedicated website which contains information and documents related to its activity and that of its 9 work streams which includes, smart grids forum (SGF) membership list and profile of 8 of its members and the organisations they represent, minutes of the 18 meetings held by the (SGF), 4 annual reports of its activity up to 2015, terms of reference of the work streams, deliverables of the work streams and support documents delivered by consultants.

The information from the IFI and LCNF reports was used to create a database of all the R&D and demonstration projects of the six UK DNOs from 2005 to 2014. This database of over 500 collaborative innovation projects includes information on project name, project size, start date, end date, project description, project aim, technology area, type of innovation, number of participants, names of other participants and project outcome. Of all the innovation projects collected, 352 included collaboration with private firms. These projects were then reorganised around each firm, resulting in a database of all the collaborative R&D and demonstration projects funded by the IFI and

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1 http://webarchive.nationalarchives.gov.uk

the LCNF mechanisms for 132 firms. The information on the innovation activity of these 132 firms was then supplemented with their engagement with collective actors.

In the final phase of this study, I wanted to increase my understanding on how innovating technology firms could access both the collaborative innovation projects and the collective groups, what were the benefits of engaging with the innovation projects as well as with the collective groups and how firms moved from the innovation activity to the institutional activity and vice versa. For this purpose, I complemented my data with 18 short interviews with technology companies that participated in the innovation projects. These interviews were carried out between then 24th and 26th of November of 2015 at the Low Carbon Networks and Innovation Conference in Liverpool. These companies were selected to provide a representation of both large and small companies, established and new entrants that were participating in the smart grid innovation projects. During these interviews I asked innovating firms how they accessed the collaborative innovation projects, what it meant for them to participate in the collaborative innovation projects, whether they engaged with any of the collective actors identified, how they had accessed those groups, what were the benefits of participating in those groups and whether participating in those groups gave them any advantage in accessing cooperative innovation activity. All these interviews were recorded, transcribed and coded.
Table 3: List of interviewees at the 2015 LCNI Conference

<table>
<thead>
<tr>
<th>Technology Firm</th>
<th>Interviewees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smarter Grid Solutions</td>
<td>3</td>
</tr>
<tr>
<td>Elimpus</td>
<td>1</td>
</tr>
<tr>
<td>Hubnet Consortium</td>
<td>1</td>
</tr>
<tr>
<td>Nortech</td>
<td>1</td>
</tr>
<tr>
<td>Netcontrol/Radius</td>
<td>1</td>
</tr>
<tr>
<td>Power Plus Communications</td>
<td>1</td>
</tr>
<tr>
<td>Fundamentals</td>
<td>1</td>
</tr>
<tr>
<td>CGI Logica</td>
<td>1</td>
</tr>
<tr>
<td>Locamation</td>
<td>1</td>
</tr>
<tr>
<td>EMS</td>
<td>1</td>
</tr>
<tr>
<td>Kelvatek</td>
<td>1</td>
</tr>
<tr>
<td>EA Technology</td>
<td>1</td>
</tr>
<tr>
<td>GE Energy</td>
<td>1</td>
</tr>
<tr>
<td>Siemens</td>
<td>1</td>
</tr>
<tr>
<td>Lucy Electric</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>18</td>
</tr>
</tbody>
</table>

3.4. Data analysis

The data analysis proceeded as follows. The first step consisted of a theme analysis of the exploratory interviews to develop an understanding of the main developments in the field. As a result, an interim case report was written consolidating the views of the interviewees on their understanding of smart grids, the main drivers for their development, the key stakeholders that needed to engage, how firms tried to influence their development and the main challenges to the development of smart grids in the UK (Miles et al., 2013). I shared the interim case report with all interviewees and requested feedback from them.

Following this exploratory phase, it emerged that collective actors were central to the progression of the emerging field and that firms tried to shape the emergence of the new industry by participating in both innovation projects and collective groups. I then focused on understanding the role of the main stakeholder groups identified by the interviews. For this purpose, I developed a “data bank” formed by all the archival materials related to stakeholder groups, including annual reports, terms of reference
of the main groups as well as of the work streams, and reports delivered by the different work streams (Greenwood et al., 2002). Using these extensive materials on the stakeholder groups as well as the data from the exploratory stakeholder interviews, I developed a chronological account of the activities undertaken by the different stakeholder groups, which organisations participated in them, why they were established, when, which work streams had they created, what outputs they had produced and what impact they had. I then supplemented this account with the analysis of the later interviews to firms participating in the innovation projects, which had been coded using first, descriptive coding and subsequently, second order coding to uncover patterns of interaction between institutional and innovation activities (Miles et al., 2013; Saldaña, 2015).

4. Findings

Societal pressures related to climate change led the UK to commit to stringent CO2 reduction targets. The UK’s broader strategy towards the achievement of these targets included a significant increase in low carbon generation technologies which posed technological, institutional and commercial challenges for the incumbent electricity system. The emergence of the concept of smart grids, approximately in 2009, was a response to these challenges and it aimed to transform the way in which electricity in the UK is generated, distributed and consumed. The development of smart grids requires new technologies, new regulatory frameworks, new commercial arrangements, new actors and new relationships between actors. Their development started approximately in 2005 and is still ongoing well over a decade later.

Smart grids are not just about introducing innovation into an existing industry. The following quote from the report published by the Electricity Networks Strategy Group in November 2009, “A Smart Grid Vision” shows that smart grids require the entire electricity industry to transform: "It is essential to acknowledge that the vision [of smart grids] goes far beyond technology. Technology will play an important role in meeting the UK’s needs but regulatory, legal, commercial, market, industry and cultural change will also be critical." Electricity Networks Strategy Group, A Smart Grid Vision, November 2009.
From a purely technological perspective, smart grid technologies are those that enable increased levels of “intelligence” in the electricity networks which allow the networks to automatically respond to changes in electricity generation and demand. Smart grid technologies address a specific need in the electricity networks for increased automation, control and responsiveness, which is achieved by combining traditional electrical engineering components with information and communication technologies.

Smart grids can therefore be considered an emerging industry, defined by Porter as a “newly formed or re-formed industry that has been created by technological innovations, shifts in relative cost relationships, emergence of new consumer needs, or other economic and sociological changes that elevate a new product or service to the level of a potentially viable business opportunity” (Porter, 1980).

The main findings of this study focus on the activities of the collective actors, in the form of industry-government groups, created by the UK government (DECC3) and the regulator of the electricity networks (Ofgem). The first group created in relation to the development of smart grids was the Embedded Generation Working Group (EGWG), followed by the Distributed Generation Coordinating Group (DGCG), the ENSG (Electricity Networks Strategy Group) and, finally, by the Smart Grids Forum (SGF). Table 4 below includes the main activities carried out by collective actors during the emergence of smart grids in the UK between 2005 and 2014.

The findings of this study are organised around two distinct phases in the early stages of emergence of smart grids in the UK. The initial stage covers the period 2005-2010, and the second period, from 2010-2014, coincides with the co-evolutionary stage, although I do not capture the emergence of a dominant design. Nonetheless, towards the end of the observation period, technology leaders were starting to emerge and standardisation activity was ongoing.

3 DECC: Department for Energy and Climate Change.
Table 4: Main activities of collective actors

4.1. 2005-2010: Initial industry emergence stage

The need to transform the energy system was triggered by environmental pressures to reduce CO2 emissions in response to climate change concerns. These societal pressures resulted in the UK committing to highly ambitious CO2 reduction targets which required a significant increase in the amount of electricity generated by renewable energy sources. While most conventional, carbon-based...
generation plants are connected to the electricity transmission network, renewable energy generation technologies are often connected to the electricity distribution network and are also referred to as embedded or distributed generation (DG). Since the traditional electricity industry was designed around large, carbon-based generation plants, the required increase in renewable generation challenged the technological, commercial and institutional arrangements of the incumbent system. During this initial stage in the emergence of smart grids, the need for change in the incumbent system is established and followed by a search for solutions and the development of a collective understanding of the meaning of smart grids.

4.1.1. Legitimise the case for change

Increasing societal and institutional pressures towards a sustainable, low carbon energy system that challenged the incumbent industrial arrangements led the UK government and regulator to invite the electricity industry elite, formed by senior industry figures and strategic thinkers, to convene in a government-industry group and address those challenges. The first government-industry group created for this purpose was the Embedded Generation Working Group (EGWG). The group’s main objective was to understand the technical and institutional limitations of the electricity system to achieve the UK’s targets for low carbon generation. These targets had been set by the government in The UK Programme for Climate Change following the UK’s adoption of the Kyoto Protocol, and aimed to increase the electricity generated from renewable sources from 2.8% of total electricity generated in 1999 to 10% by 2010. The members of the EGWG represented the Government, the regulator (Ofgem), electricity customers, suppliers, generators and network operators (full membership list can be found in appendix 2).

The group carried out its activities during the years 2000 and 2001 and published a main report which made three central arguments. First, it established that change was needed in the electricity industry for the Government targets to be achieved:
“If Government’s targets for higher levels of CHP⁴ and renewable plant by 2010 are to be achieved, distribution networks will have to be capable of accommodating far more generators connected directly to their networks than we have now. (These are known as ‘embedded’ generators).

[...] Present regulatory framework, financial incentives and network design approaches are not conducive to all of the above.” Embedded Generation Working Group, Network Access Issues, Main Report and Appendices, January 2001.

Second, it connected the need for the electricity industry to change to broader environmental goals:

“The Government’s central energy policy objective is to ensure secure, diverse and sustainable supplies of energy at competitive prices. Its environmental priorities are influenced by global and international factors, including international agreements and EU policies to which the UK is committed. These include legally binding targets for the reduction of greenhouse gases, and in particular carbon dioxide emissions.” Embedded Generation Working Group, Network Access Issues, Main Report and Appendices, January 2001.

Third, it developed an understanding of the specific technological and institutional issues which needed to be addressed so that the governance of the electricity networks did not disadvantage distributed generation and recommended the review of the regulatory framework under which distribution network companies operated.

In late 2001, the Distributed Generation Coordinating Group (DGCG) was created to continue with the work that the EGWG had started. Both the EGWG and the DGCG addressed mostly issues related to the governance of the electricity networks that were disadvantaging the connection of distributed generation. The DG CW was successful in bringing together DG developers and electricity networks to reach consensus around network access issues for distributed generators. Furthermore, the DG CW also worked closely with developers of distributed generation to understand their problems connecting to the networks which resulted in a number of technical reports:

"The DGCG completed some 25 projects across a broad range of subjects, delivering tangible outputs. Examples include: a common connection guide for all DNOs; a new Engineering Recommendation for microgeneration; new Engineering Technical Reports (published by the Energy

⁴ CHP: Combined heat and power generators.
Networks Association) addressing DG connection issues; the review of Engineering Recommendation P2/5; a study of ancillary services in distribution systems; a system of reporting DG activity (now managed by the ENA); and the launch of the Technical Architecture study looking at the more strategic issues of network development." ENSG 2005 Annual Report.

The work of the EGWG and DGWG was important because first, it established the need for change and, second, for the first time since the industry was privatised in 1990, it brought together stakeholders from across the value chain in stakeholder groups formed to address the challenges of the industry, which “created a sense of joint ownership of the issues and a commitment to achieving balanced and realistic solutions” ENSG, 2005 Annual Report. These early groups were crucial for legitimising the change process, which they did by engaging elite influential players in the stakeholder groups that made policy recommendations, connecting the need for change to broader environmental goals and by bringing stakeholders across the value chain to work together on understanding why change was required and what aspects of the incumbent system needed to be reviewed.

4.1.2. Develop a collective technological frame of the new industry

As larger amounts of renewable generation technologies started to connect to the distribution network, the technological challenges increased. The Government and regulator realised that technological innovation in the electricity networks was necessary or they could become a bottleneck for the achievement of the UK’s carbon reduction targets. In 2005, the Government and regulator created the Electricity Networks Strategy Group (ENSG) to advise the government on issues related to the development of the electricity networks.

“The case for establishing the ENSG is that both the transmission and distribution networks are fundamental enablers for the development of the low carbon generation base sought by the Government.” Electricity Networks Strategy Group, Annual Report 2005.

The members of the ENSG were senior figures and strategic thinkers from electricity distribution, transmission and supply firms, and they could nominate members of the working groups (see Appendix 3 for membership of the ENSG and its working groups). Two working groups were established to carry out the detailed work and to manage the delivery of the projects, the Distribution Working Group (DWG) and the Transmission Working Group (TWG).

Although the ENSG takes over from the previous groups (the EGWG and the DGCG), its objectives go beyond identifying barriers to connecting distributed generation to the electricity networks, and this group starts to explore specific novel technological solutions to facilitate the integration of larger amounts of renewable generation into the networks.

“The ENSG is concerned with more than the removal of barriers. It must identify areas where work is required to produce networks suited to a low carbon future and to co-ordinate that work.” ENSG Annual Report 2005.

First, the DWG sought to understand the current state of innovation in network technologies and compiled a register of recently completed, ongoing and planned pilot and trial activities in novel network technologies in the UK and internationally. This group also commissioned expert reports on specific novel concepts in network technologies such as active network management, fault current limiters, network automation and dynamic ratings that could contribute to developing a low carbon electricity system. Through its activities, the DWG aimed to identify new technologies being developed that could potentially solve the technical challenges to the connection of renewable technologies to distribution networks and also technology gaps in the development of future low carbon electricity networks.

“A number of the TWG’s and DWG’s projects focus on new technologies and on R&D. Engagement with current R&D, pilots and trials can maximise the value of existing work, and avoid duplication. There is a considerable amount of detail to assimilate from R&D programmes in the EU and elsewhere, from projects sponsored by the DTI, and from RPZ and IFI initiatives.” ENSG Annual Report 2005.
This work formed the basis for the development of the different technology subsystems of the smart grid. Technology companies were not represented in the ENSG but could be invited to participate in the working groups. Four technology companies were part of the DWG: ABB, GE Energy, Econnect and EA Technology, as well as the co-founder of technology start-up Smarter Grids Solutions which was established in 2008.

In July 2008, the Electricity Networks Strategy Group (ENSG) was reconstituted to provide a high-level forum which brought together key stakeholders in electricity networks to support the government in meeting the long-term energy challenge of tackling climate change by reducing carbon dioxide emissions while ensuring secure, clean and affordable energy (ENSG 2008). The ENSG set up a Smart Grids Working Group (SGWG) which produced two crucial documents for the delivery of smart grids in the UK. In November 2009, the ENSG/SGWG published the smart grid vision for the UK which was aligned with the vision put forward by the European Technology Platform for Smart Grids\(^5\). This vision proposed an entirely different approach to managing the electricity networks where information and communication technologies played a major role in achieving a low carbon energy system. Furthermore, it involved transforming the electricity industry from a centralised top-down design where the consumer was just a sink for electricity use, to a decentralised internet-like design where the consumer was an active participant.

“A Smart Grid as part of an electricity power system can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies.

A Smart Grid employs communications, innovative products and services together with intelligent monitoring and control technologies to:

1. Facilitate connection and operation of generators of all sizes and technologies
2. Enable the demand side to play a part in optimising the operation of the system

\(^5\) The term smart grids was put forward by the Smart Grids European Technology Platform for the Electricity Networks of the Future, set up by European Commission in 2005.
3. Extend system balancing into distribution and the home
4. Provide consumers with greater information and choice of supply
5. Significantly reduce the environmental impact of the total electricity supply system
6. Deliver required levels of reliability, flexibility, quality and security of supply.”

Electricity Networks Strategy Group, A Smart Grid Vision, November 2009.

This report was followed in February 2010 by a route map or description of how smart grids could be delivered in the UK to contribute to the achievement of the government’s carbon targets (ENSG, 2010). This report had a direct impact on the future innovation activity by explicitly including the type of innovation projects that should be carried out: “the intention is to provide some high level foundations for the development of trials that will be able to assess challenges and construct and evaluate potential solutions.” Electricity Networks Strategy Group, A Smart Grid Routemap, February 2010. The trial projects proposed by the SGWG were developed based on existing innovation activity as well as the vision of smart grids developed which, taken together, led to identifying the technology areas that needed most innovation investment so that all the different subsystems of the smart grid would be fully developed and integrated.

During the observation period, DNOs established innovation projects in all the areas proposed by the ENSG which included: smart meter communication, active dynamic ratings, active voltage control, superconducting fault current limiters, active network monitoring, embedded storage, active network management, smart asset management, power flow optimisation through the use of power electronics, demand side management, integration with smart appliances, integration of electric vehicles and end-to-end solutions. By identifying the innovation needs for the development of smart grids, the ENSG was able to direct the innovation efforts of the DNOs and motivate the development of all the different technologies that were required for the development of smart grids.

The SGWG had 25 members which included; Intellect, the trade association representing the IT sector traditionally outside of the electricity system, two innovative smart grid technology companies, RLTec and Smarter Grid Solutions, the electricity network companies and the Renewable Energy
Association. The membership of this group shows that some firms outside of the traditional energy supply chain start to engage in the development of the institutional framework for the emergence of smart grids. Full member list of the ENSG and the SGWG can be found in appendix 2.

Until the end of 2009 when the ENSG published the vision for smart grids in the UK, there was no broadly accepted definition of smart grids. Interviews carried out in 2012 show that the definition published by the ENSG was the one that became widespread in the UK. As an example, interviewees from an electricity network operator and from a new technology firm both referred to this definition when I asked how they defined smart grids. Also, an interviewee from an electricity supplier defined smart grid in the following way:

“I’m looking at smart grids from a holistic point of view; not just the smart meters, but as a set of technologies that will enable the electricity network to be more observable, and more controllable through sensor technology and information technology. Also, a network that enables different types of generations to be connected at different levels of the grid, and that enables consumers to take a more active role in the electricity system.” Electricity supplier.

The main role of the ENSG was to develop a vision for the new industry that could be accepted by all stakeholders. This vision was built from the ENSG’s early work which identified new concepts and novel network technologies that were being developed in R&D projects in the UK and abroad. Furthermore, the ENSG identified specific technology areas that needed to be developed providing clear direction for subsequent innovation activity.

As a result of the work of these three early collective actors, in 2008, Ofgem launched a review of the regulatory framework for the electricity network companies that resulted in a new regulatory model (RIIO) which aimed to encourage network companies to “play a full role in delivering a low carbon economy and wider environmental objectives” (Ofgem, 2013). Since the new regulatory framework would not apply until 2015, in the preceding regulatory period (DPRC5, 2010-2015), Ofgem established the Low Carbon Networks Fund (LCNF), an innovation incentive that made £500 million
available to distribution network companies (DNOs) to trial technological and commercial innovations towards the development of low carbon networks during the 2010-2015 period.

“Our objective is to encourage the DNOs to use the DPCR5 period to begin the transition and prepare for the potentially greater role they will have to play as GB moves to a low carbon economy. We will therefore establish a Low Carbon Networks fund (LCN fund) to enable DNOs to run trials so that they can gain experience of the new technology, commercial and network operating arrangements that they should put in place to a) respond to the new network requirements that arise from a low carbon economy and b) encourage low carbon solutions such as demand side management. We also expect these trials will help us to understand what changes may need to be made to the regulatory framework to enable DNOs to respond to these challenges in subsequent price control reviews.” (Ofgem, 2009)

During this initial stage of industry emergence, the main role of the collective actors was to trigger the change process by establishing and legitimising the case for change, and to develop a collective technological frame of the new industry that could be accepted by all the relevant stakeholders. To achieve this, collective actors engaged the industry elite in determining the need for change, they connected the need for change to broader environmental goals and engaged relevant stakeholders, including all the network companies, Intellect, the trade body for ICT firms, the Renewable Energy Association, The Centre for Sustainable Electricity and Distributed Generation, The Carbon Trust and innovating firms, in developing a collective understanding of the emerging industry which would direct subsequent innovation activity. At the field level, this work resulted in regulatory change and in the creation of collective resources for innovation.

4.1.3. Innovating firms: educating and promoting their vision of the new industry
In 2005, the UK distribution network operators (DNOs) started to benefit from the Innovation Funding Incentive (IFI), a regulatory mechanism established by the regulator to incentivise innovation in the electricity networks. The IFI allowed DNOs to dedicate 0.5% of their revenues to innovation projects (R&D and small trials) focused on the technical development of the networks.

As a result, all DNOs established research partnerships with universities and R&D collaborations with large established technology firms such as ABB, Areva T&D and GE. In addition, some DNOs also
started R&D collaborations with smaller firms, both established and new entrants. These smaller innovating firms either already had or were developing unique technologies that could solve the technological challenges created by incorporating increased amounts of distributed generation into the electricity networks. For example, Fundamentals, a small UK incumbent technology firm founded in 1994, developed voltage control technologies that could be used to address the voltage fluctuations caused by connecting renewable technologies to distribution networks. This motivated five UK DNOs to establish a collaboration project with Fundamentals to explore whether their active voltage control technology could facilitate the connection of distributed generation. The quotes below from interviews with innovating technology firms reinforce that having a unique technological capability aligned with the needs of the emerging industry facilitated access to the collaborative innovation projects:

“We were able to access the projects because of our contacts and because we have a unique technology. For many of our products we still don’t have real competition.”

“Having a niche technology enables firms to become part of the innovation projects.”

“Having a unique approach that adds value allows firms to access the innovation projects.”

The vision and route map for the development of smart grids published by the ENSG towards the end of 2009, drew and built on from the smart grid capability being developed through these early collaborative innovation projects. Concepts such as active network management, demand response, dynamic line ratings, network monitoring control and optimisation, superconducting fault current limiters and smart asset management, included in the vision and route map for smart grids, started to be developed during this phase. Thus, being part of the early innovation collaboration projects gave technology firms the opportunity to be part of the vision of smart grids.

Furthermore, innovating firms that engaged with the various groups during this initial phase, either directly or through trade associations, could participate more actively in developing the meaning of smart grids. As the quotes from the interviews below show, these collective actors provide a forum where innovating firms engaged in research, development or trial of new network technologies, could
“make space for something new,” by educating the industry on their novel technology and how it could solve the technological challenges faced by the industry.

“Participating in working groups shape what people think is possible technically, it helps build confidence around a technology and shape thinking.” New smart grid technology vendor.

“Firms try to influence the development of smart grids by communicating their own vision of the industry and communicating to other stakeholders what their technology is about and how it will benefit them.” New smart grid technology vendor.

“Firms that participate in institutional groups can influence policy by helping other industry participants understand their technology and its impact on the industry.” Network operator.

Furthermore, these firms had an early awareness of the technological needs of the emerging industry which they used to shape their own R&D activity and to receive R&D and demonstration funding. The thorough understanding of the industry’s challenges and technology needs was an advantage when it came to formulating projects that could win funding competitions because they addressed key technical challenges, or developed technologies, for which a technology gap had been identified. The statement from the industry regulator below shows how influential the working groups were in directing the innovation funding towards specific technology areas:

“We think the ideas and momentum created by the Working Group provides a valuable basis for identifying projects that should seek funding from the LCNF and the Innovation Funding Incentive. Ofgem Statement published in the Electricity Networks Strategy Group: A Smart Grid Routemap - February 2010.

The quotes from interviewees below also reflect the influence of the work of the groups on their own innovation activity:

“Participating in the working groups helps firms scope innovation projects that solve the industry’s needs.” New smart grid technology vendor.

“Participating in working groups allows firms to shape and direct their technology investments.” Established SME technology vendor.
“Institutional activity is a two-way conversation, firms try to influence the thinking of the networks, and the knowledge that firms gather there informs their innovation strategy. Firms use the knowledge and information from their institutional activity at a strategic level, to shape their innovation portfolio towards that future.” Global technology firm.

During this early phase, innovating firms focus on applying their technological capabilities to solving the challenges that the industry is facing. Innovating firms that participate in the stakeholder groups during this initial phase had an early awareness of the technological needs of the emerging industry and aligned their innovation activity to those needs. Furthermore, because during this early phase the meaning of the industry is still fluid, innovating firms can use collective actors as a forum to educate others on their technology and to put forward their own vision of the new industry.

4.2. 2010-2014: co-evolutionary industry emergence stage

In 2010, following the development of a collective understanding of smart grids and the availability of collective resources for smart grid demonstration projects, the innovation activity is catapulted and the need for field coordination and integration increases. The Smart Grids Forum, a highly influential collective actor, is created to address the coordination of the emerging field and facilitate its progression. During this second stage, the innovation activity progresses from developing component technologies to the demonstration of integrated smart grid solutions. Large, flagship technology demonstration projects are set up by all DNOs encouraging the entry of innovating firms from the ICT sector and from other parts of the energy value chain, such as demand side management and low carbon transport. The key challenges during this phase were; engage stakeholders outside the traditional energy industry in the development of smart grids, understand how smart grids could deliver value to consumers, coordinate technological progression across the value chain to avoid bottlenecks, and develop the institutional infrastructure to support consumer adoption of smart grid technologies.

4.2.1. Theorise value ecosystems

Once the need for the electricity networks to change had been legitimised and the vision of smart grids had been developed by key stakeholder groups, in April 2011, the UK government (DECC) and
regulator, Ofgem, set up the Smart Grids Forum (SGF), a collective body created to coordinate and facilitate the development of smart grids in the UK. The Smart Grids Forum was formed by 24 individuals selected by Ofgem and DECC on the basis of their own personal experience, following an open invitation for applications and a careful selection process. Its members were key opinion formers, experts and stakeholders involved in the development of smart grids in the UK. Furthermore, it included senior representatives from the government and regulator. As stated in its first annual report, the overarching goal of the SGF was to drive forward the smart grid agenda:

“In April last year, Ofgem and DECC established the Smart Grids Forum (SGF) to provide further leadership to the industry on smart grid issues. The SGF brings together key opinion formers, experts and stakeholders in the development of GB smart grids to provide strategic input to help shape Ofgem's and DECC's policy making and leadership in this area. The Forum should also help provide the network companies with a common focus in addressing future networks challenges, ensure that whole system benefits are considered in this work and provide drive and direction for the development of smart grids.” Smart Grids Forum Annual Report 2012.

The vision of smart grids developed in the previous phase by the ENSG required the engagement of actors traditionally outside the electricity supply chain, such as providers of information and communications technologies (ICT). The LCNF provided a financial incentive for ICT and innovating firms to engage in the development of smart grid technologies, and the SGF, through its membership, ensured these new actors were represented in the development of policy recommendations.

The membership of the SGF, shown in the table below, was much broader than that of the previous groups and included representatives from the government, regulator, network companies, traditional providers of network technologies (BEAMA), ICT firms (Tech UK), demand-side response providers (UKDRA), the environment and consumers (Sustainability First), the UK’s communications regulator (Ofcom) and electric vehicles (OLEV). In sum, the SGF included members of the different stakeholder groups that needed to engage in the development of smart grids and whose participation in the new industry had been legitimised by the acceptance of the collective vision.
Table 5: Members of the Smart Grids Forum -April 2011

<table>
<thead>
<tr>
<th>Name</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hannah Nixon (Joint Chair)</td>
<td>Ofgem</td>
</tr>
<tr>
<td>Sandy Sheard (Joint Chair)</td>
<td>DECC</td>
</tr>
<tr>
<td>Mike Calviou</td>
<td>National Grid (TSO)</td>
</tr>
<tr>
<td>Dave Openshaw</td>
<td>UKPN (DNO)</td>
</tr>
<tr>
<td>Steve Johnson</td>
<td>ENW (DNO)</td>
</tr>
<tr>
<td>Phil Jones</td>
<td>CE Electric (DNO)</td>
</tr>
<tr>
<td>Mark Mathieson</td>
<td>SSE (DNO)</td>
</tr>
<tr>
<td>Robert Symons</td>
<td>WPD (DNO)</td>
</tr>
<tr>
<td>Jim Sutherland</td>
<td>Scottish Power (DNO)</td>
</tr>
<tr>
<td>Chris Harris</td>
<td>RWE nPower</td>
</tr>
<tr>
<td>Ashley Pocock</td>
<td>EDF (Supplier)</td>
</tr>
<tr>
<td>Graham Meeks</td>
<td>CHP Association</td>
</tr>
<tr>
<td>Roger Critchley</td>
<td>BEAMA</td>
</tr>
<tr>
<td>Chris Welby</td>
<td>Good Energy</td>
</tr>
<tr>
<td>Petter Allison</td>
<td>British Gas</td>
</tr>
<tr>
<td>Marina Hod</td>
<td>UKDRA (kiwi Power)</td>
</tr>
<tr>
<td>Gavin Jones</td>
<td>Tech UK (Electralink)</td>
</tr>
<tr>
<td>Judith Ward</td>
<td>Sustainability First</td>
</tr>
<tr>
<td>John Scott</td>
<td>Chiltern Power</td>
</tr>
<tr>
<td>Duncan Botting</td>
<td>PB Power</td>
</tr>
<tr>
<td>Steve Unger</td>
<td>Ofcom</td>
</tr>
<tr>
<td>Nick Jenkins</td>
<td>Cardiff University</td>
</tr>
<tr>
<td>Ben Davison</td>
<td>Office for Low Emission Veh.</td>
</tr>
</tbody>
</table>

Furthermore, as well as being represented in the main strategic group, these other stakeholders participated in some of the work streams responsible for specific deliverables:

“The SGF will continue to work in co-operation with other industry groups such as ENSG, SGGB\(^6\), and the Institution of Engineering and Technology” Smart Grids Forum Annual Report 2013.

“During year four, the number of parties engaged in the Work Stream 5 ‘project’ has increased. The ENA, Smart Grids GB, HubNet and BEAMA have been joined by the Technology Strategy Board, the Energy Technologies Institute and the Institution of Engineering and Technology.” Smart Grids Forum Annual Report 2014.

During its first years, the SGF produced three highly influential pieces of work. Work stream one, in collaboration with the government, developed projections up to 2030 on the adoption of low carbon

\(^6\) Smart Grids GB (SGGB) was associated with Intellect, later rebranded Tech UK, which was the trade association representing the ICT firms.
demand-side technologies, such as electric vehicles and heat pumps, and on the penetration of low carbon generation technologies such as wind farms and solar panels. These projections were the basis for the main analysis carried out by work stream two, an evaluation framework for smart grids which allowed to understand whether there was a business case for supporting the development of smart grids. The evaluation framework did not consider the value of smart grid technologies in isolation, it considered the value of what they initially termed smart grid investment packages.

“Given interdependencies between the functionality of different smart grid technologies, the costs and benefits of each individual technology are likely to be dependent on whether other technologies have been rolled out. Because of these interdependences, rather than assessing the incremental costs and benefits of each individual smart grid technology in isolation, it makes sense to assess the costs and benefits of representative smart grid investment packages or strategies.” A framework for the evaluation of smart grids, March 2012.

This complex evaluation task concluded that smart grids were worth pursuing:

“The overall conclusion that can therefore be drawn is that smart grid solutions are expected to deliver benefits in the coming decades but more analysis is required to decide at what point their deployment should commence in a significant way.” A framework for the evaluation of smart grids, March 2012.

Finally, work stream three built on the work of work stream two to develop smart grid solution sets, that is, combinations of different component technologies which together provide a smart grid service or application. For example, active network management is a smart grid solution made up of different component smart grid technologies: intelligent voltage control, fault limiting devices, sensors and data communications close to real time. Work stream three identifies 12 smart solutions sets and their component technologies and develops future scenarios as to how these smart solution sets may be deployed towards 2020-2030. These smart grid solution sets were then employed in combination with the scenarios developed by work stream one and the cost benefit analysis developed by work stream two, to build a ground-breaking model, the Transform model, which allowed to quantitatively assess the value of smart grids under different scenarios of penetration of low carbon technologies. The Transform model was then used by all UK distribution network companies for the development
of their business plans for the 2015-2023 regulatory period, thus having an enormous impact on their future investment in smart grid solutions.

The smart grid solution sets were also the basis for the analysis of work stream six which led to identifying new roles and relationships that needed to be established among different industry actors for smart grids to develop. Work stream six also anticipated possible conflicts among industry participants, proposed how those conflicts could be managed and recommended actions needed from each stakeholder to overcome the challenges to the implementation of smart grids in the UK.

The early work of the Smart Grids Forum sought to understand the different value propositions of smart grids, which new and existing technologies were required for the various smart grid solutions to be developed, and which new roles and relationships among the different actors needed to emerge for those new smart grid solutions to be delivered. Defining smart grid solution sets allowed distribution network companies and all the other actors engaged in the development of smart grids to understand the different technologies that comprised a specific smart grid solution and plan their investment and innovation activity around that. Furthermore, by building on those solutions to identify new roles and relationships between the different actors in the smart grid, the SGF were effectively working towards developing value ecosystems around new smart grid technologies. That is, the group of technologies that needed to interact as well as the structure of that interaction, defined by the roles and relationships between the different actors. The smart grid solution sets encouraged the development of value ecosystems around new smart grid technologies and the coordination of the development of the different component technologies needed for smart grids to emerge.

The interviews also point to the importance of stakeholder groups, such as the Smart Grids Forum, in the coordination of a new industry:

“In a liberalised market, industry groups become central for the coordination of the emergence of the new field.” Energy consultant.
“Industry groups are crucial for moving the industry forward through bringing together industry and government, addressing key challenges, sharing best practices, identifying technology gaps, making sure policy is moving in the right direction, and defining technical specifications and standards.”

Electricity supplier.

4.2.2. Provide institutional support

The Smart Grids Forum (SGF) did not have executive power, however, it provided advice to the UK government (DECC) and regulator (Ofgem) on issues related to the development of smart grids.

“In April last year, Ofgem and DECC established the Smart Grids Forum (SGF) to provide further leadership to the industry on smart grid issues. The SGF brings together key opinion formers, experts and stakeholders in the development of GB smart grids to provide strategic input to help shape Ofgem’s and DECC's policy making and leadership in this area.” Smart Grids Forum Annual Report 2012.

One of the central objectives of the SGF was to “ensure regulatory and commercial frameworks enable and support the deployment of smart technologies and new commercial practices” Smart Grid Forum, Updated Smart Grid Vision and Routemap, February 2014.

Work stream six of the SGF was established precisely with the aim of identifying the regulatory and commercial challenges to implementing smart grids in the UK and making recommendations on how those challenges should be addressed. To gain an understanding of how those challenges could be overcome, work stream six organised a learning event where participants in the LCNF demonstration projects could present and raise issues regarding existing barriers to deployment of smart grid technologies based on their experience and learning through the demonstration projects. In addition, work stream six compiled a list of smart community energy trials, identified the barriers and enablers arising from the projects and converted those into specific actions. The evidence from these smart grid demonstration projects was the basis for the policy recommendations made by work stream six. These policy recommendations were then used by Ofgem, the regulator, to inform its strategy for the 2015-2023 regulatory period (RIIO-ED1) and its position paper on distribution network flexibility:

“Ofgem have indicated that they plan to reference the work of this work stream in their September strategy consultation for RIIO-ED1.” WS6 Interim Report, August 2012.
“We will build on the work to date (including the learnings from the Low Carbon Network-Fund) and the thinking undertaken through Workstream six of the Smart Grid Forum and will engage with stakeholders in carrying out our work.” Ofgem flexibility position paper.

The learning from the technology demonstration projects funded by the Low Carbon Networks Fund (LCNF) also influenced the analysis of work stream three which developed the “building blocks” or smart solution sets that would form the base of smart grids in the UK.

"The WS3 project will use the overall evaluation framework set out in this report but will also:

- increase the granularity of the network modelling;
- disaggregate network conditions by region and sub-region;
- increase the number of smart grid technologies considered; and
- incorporate new learning from the LCN Fund projects." An evaluation framework for smart grids, March 2012.

The analysis delivered by work stream three was then used by the distribution network companies, the government, and the regulator to plan for the regulatory period 2015-2023.

“The report is structured to deliver key messages that will support Ofgem, DECC and the network companies in the first stage of the ED1 regulatory business plan preparation for the period 2015-2023.” Developing Networks for Low Carbon, The Building Blocks for Britain’s Smart Grids, DECC / Ofgem Smart Grid Forum Work stream 3, October 2011.

The learning from the smart grid demonstration projects, therefore, became an important input into the work of the Smart Grids Forum which resulted in specific policy recommendations. By engaging with the technology demonstration projects in the development of the “building blocks” of smart grids and by drawing from the experience of network companies in deploying smart grid solutions in demonstration projects, the SGF contributed to aligning the development of the institutional context with the ongoing technology development and demonstration activity. The policy recommendations made by the SGF contributed to creating a supportive institutional infrastructure for smart grids and aimed to drive consumer adoption of smart grid solutions.
During this second stage of industry emergence, the Smart Grids Forum and its work streams played a crucial role in advancing the emergence of smart grids in the UK through developing an understanding of the value of smart grid solutions and how that value could be created and by encouraging the development of a supportive institutional infrastructure. As a result, the SGF encouraged investment in all the technology components required for the new industry to create value and drove the development of a market for the products and services of the new industry.

4.2.3. Innovating firms: increase value of their technology and remove barriers to innovation

During this second stage of industry emergence, the innovation activity for the development of smart grids progresses from the R&D phase into the demonstration phase where different technology components are integrated to provide value-added smart grid solutions. This innovation activity was incentivised by the Low Carbon Networks Fund (LCNF) established as a result of the work of collective groups in the previous phase. The LCNF made available £500 million over five years (2010-2015) to trial technological and commercial innovation that would facilitate the transition towards low carbon networks. This innovation incentive was crucial to facilitate the engagement in the collaborative innovation projects of ICT companies that had not engaged in the earlier R&D projects and had technologies that could increase the level of intelligence, connectivity and communication of the electricity networks. These companies included large ICT firms, such as IBM, Wipro, Cisco, Silver Spring Networks and Logica CGI and, smaller ICT firms, such as Capula, AMT-Sybex, Current, Sentec, Power Plus Communications and PowerSense. Furthermore, it allowed the engagement of other players in the electricity value chain such as generation companies, metering firms, providers of smart home systems and, most notably, demand management firms such as Enernoc, Flexitricity and Kiwi Power. The LCNF enabled the funding of medium and large-scale demonstration projects that increasingly reflected the progression of the smart grids vision with projects around ICT, data management and systems integration gaining importance.
However, to engage with the demonstration projects, firms needed to have a technology that had been through the development phase and was ready to be trialled. In this sense, innovating firms that had established R&D collaboration projects with DNOs in the earlier periods had the advantage of having been involved in the innovation activity for approximately five years and had technologies that were now ready to be demonstrated at a larger scale. This was the case, for example, of Smarter Grid Solutions that had been developing a new active network management technology in collaboration with one of the UK DNOs since 2005. The LCNF funding enabled demonstrating Smarter Grid Solutions’ new technology at a larger scale.

Participating in demonstration projects gave small innovating firms visibility and prompted other distribution network operators experiencing similar technological challenges to establish further collaboration projects with these small firms and continue developing their technologies. In the case of Smarter Grid Solutions (SGS), between 2010 and 2013, all the other UK network companies established collaboration projects with them, which led to the first commercial roll-out of a smart grid technology in the UK.

As some of the earlier demonstration projects came to conclusion, the value of some smart grid technologies became established and their business case proven. Some firms started to emerge as technology leaders with their efforts often rewarded with innovation awards, as in the case of Sentec, Kelvatek, Smarter Grid Solutions and Nortech.

During this period, the Smart Grids Forum (SGF) provided a number of channels through which innovating firms could participate in the development of the institutional context for the advancement of smart grids. Innovating firms could, directly or through trade associations, engage with the technical analysis of the work streams, responding to consultations or carrying out contracted work. For example, innovating firms including Smarter Grid Solutions, Nortech, EA Technology, IBM and GE, engaged directly with the SGF while others, including Sentec or Fundamentals, engaged through their trade associations.
Firms or individuals were invited to be part of the working groups of the Smart Grids Forum based on their position as technology experts and thought leaders and needed to prove that they could make a contribution towards the work stream deliverables. Interviews with small innovating firms suggest that they were invited to be part of the work streams of the SGF as a result of been perceived as leaders in their field:

“Firms interested in participating in working groups can reach out to the conveners of the groups and prove they have something to contribute.” New smart grid technology firm.

“Firms access the working groups through contacts and by been seen as a player in the smart grid delivery.” Established SME smart grid technology firm.

“A firm’s reputation will enable it to access the working groups.” Global IT firm.

In addition, innovating firms could engage with the SGF directly by responding to its consultations. For instance, before the final smart grids evaluation framework was published, the smart grids forum consulted stakeholders on the methodology used for establishing the value of smart grids. This gave stakeholders the opportunity to respond to the consultation and influence the final evaluation framework.

“We set out our proposed methodology for developing this framework for consultation in November 2011. This report now sets out a revised modelling methodology, based on the comments received to the consultation, and presents an initial analysis of the costs and benefits of smart grids.” A framework for the evaluation of smart grids, March 2012.

17 organisations responded to the Smart Grid Forum’s consultation on the evaluation framework for smart grids, including all the network companies, electricity suppliers, the trade association for manufacturers of traditional electricity network equipment such as ABB and GE, the trade association for ICT firms, and two innovating firms, IBM and Smarter Grid Solutions.

In its response to the Evaluation Framework Consultation, Smarter Grid Solutions, a university spin-off developing a novel active network management technology (ANM) included the following statement:
“The model fails to recognise the importance of various key technologies. One such technology is ANM. ANM is being widely deployed across a number of existing Smart Grid projects as the central coordinating technology for the management of network constraints. [...] The omission of ANM and interaction with commercial innovation as smart solutions appears to be a significant oversight.”

*Smarter Grid Solutions Response to Evaluation Framework, December 2011*.

An interviewee from Smarter Grid Solutions explained the considerable effort he invested in crafting the response to that consultation; however, he felt it was important for the company.

“I’ve spent two of the five days this week drafting a six page letter response to a consultation document which was 140 pages long and had two separate documents 30 pages long as appendices. That is quite significant for a small company.”

As can be seen below from an extract from the final smart grids evaluation framework, active network management (ANM) was included as a key representative smart grid solution:

“Solutions covered in this document are:

- *Battery Electrical Energy Storage*;
- *Dynamic Thermal Ratings*;
- *Enhanced Automatic Voltage Control*;
- *Technologies to facilitate DSR to reduce local network costs*; and

Thus, by engaging with the consultation of the Smart Grids Forum, Smarter Grid Solutions was able to shape a crucial piece of work and ensure that its novel technology was considered valuable within the context of smart grids.

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The ability of the activity of the SGF to build a business case for smart grid technologies and identify and remove barriers to the deployment of technological innovation was an important factor that drove smaller firms to engage with its work because it facilitated the adoption of their novel technologies.

During this phase, innovating firms focus on demonstrating the value of their technology to remove barriers to its adoption. The demonstration projects provided firms with evidence that they could use to shape the development of the institutional framework to favour their new technologies. The learning and experience gained from the technology demonstration projects become important inputs into the work of collective actors that could determine the value of a new technology and drive its adoption by consumers.

Furthermore, success in the innovation projects conferred innovating firms legitimacy to participate in the development of the institutional context. Perception as a technology leader gave innovating firms access the working groups of the Smart Grids Forums and the ability to respond authoritatively to a consultation on specific technical issues. Participation in the demonstration projects becomes of double importance, as it provides innovating firms with evidence on the value of their technology and allows them to shape the development of the institutional context.

4.3. Integrated framework of industry emergence

The emergence of a new industry involves the co-evolution of complex social, institutional and technological processes. I develop a framework to understand the role of collective actors during the early stages of industry emergence, pre-dominant design, and the interactions between the different co-evolutionary processes. The observation period corresponds approximately with the era of ferment before a dominant design is established. During that period, two phases unfold; an initial phase which culminates with the development of a collective technological frame, and a second, or co-evolutionary phase, at the end of which technology leaders start to emerge, although the process of convergence on a dominant design is still ongoing at the end of my observation period.
During the initial stage of industry emergence, societal demands put pressure on the incumbent electricity system. A collective body is formed to understand the nature of the challenges and to develop an understanding on how those challenges can be addressed. The early collective actors had a central role in legitimising the need for change by engaging elite players in understanding the problem, connecting the need for change to broader environmental issues and engaging stakeholders along the value chain in proposing solutions for the challenges identified. Once the case for change had been legitimised, another collective body was responsible for setting the direction of the new industry. This group brought together incumbent and new actors in the electricity system to develop a vision of the new industry that could be accepted by all relevant stakeholders, including the government, regulator, network companies, electricity suppliers, consumers, ICT firms, innovating firms and environmental groups. This vision built from existing innovation activity and directed subsequent technology development and demonstration projects. The work of this early group resulted in the development of a collective technological frame and led to regulatory change and the creation of collective resources for innovation.

During the initial stage of industry emergence, where the meaning of the new industry is still unclear, innovating firms with the technological capabilities to provide a solution to the challenges that the industry was facing, establish R&D partnerships with DNOs, responsible for implementing smart grids in the UK. These firms were able to influence the direction of the emerging industry via two mechanisms. First, by participating in early R&D partnerships developing novel network technologies, their innovation activity was considered by collective actors working towards the development of a vision of the new industry. Second, by engaging directly with collective actors to educate them on the ability of their innovation to solve the technological problems of the industry, and to promote their view of smart grids, thus contributing to the development of a collective technological frame. Firms that engaged with the activity of collective actors could then use their increased awareness of the industry’s technological needs to direct their R&D activity and increase the possibility of obtaining funding to continue developing their novel technologies.
The emergence of a collective technological frame marks the end of the initial stage of industry emergence and the start of the second, or co-evolutionary stage. Following the development of a collective technological frame for smart grids, a new, broader collective body is formed which includes new actors and is representative of the emerging industry. This collective group facilitates the progression of the new industry by developing an understanding of the value of the new technologies and how that value is created, what other interdependent technologies are required, what other actors need to get involved and what relationships between those actors need to be developed for the new technologies to create value. Once the value of those technologies is understood, as well as the ecosystem of technologies and actors that need to emerge around them, collective actors encourage the investment in the entire ecosystem and make recommendations for the removal of institutional barriers so that the entire ecosystem can emerge thus reducing the possibility of the creation of technology bottlenecks. Finally, collective actors support the adoption of smart grid technologies by making policy recommendations based on evidence from technology demonstration projects. The work of collective actors during this second stage facilitates the coordinated emergence of the different technology components required for the new industry to create value and drives the development of a market for the new technology by removing institutional barriers to its adoption identified by technology demonstration projects.

Innovating firms that seek to influence the emergence of the new industry during this second stage, need to engage in both technological and institutional activity. Participating in technology demonstration projects is crucial for innovating firms as it provides them with evidence that they can use to prove the value of their technology and remove institutional barriers to the adoption of their innovations. Furthermore, success in the technology development and demonstration activity gives innovating firms legitimacy to engage with collective actors who influence policy and regulatory decisions. By engaging with influential collective actors innovating firms ensure that their technology is considered as part of the theorised value ecosystems and supported by the emerging institutional framework. Figure 5 below illustrates this framework:
Figure 5: An integrated framework of industry emergence
5. Discussion

This study aimed to increase our understanding of the complex technological, institutional and social processes that take place during the early stages of industry emergence through the analysis of the emergence of smart grids in the UK. This study suggests that in the emergence of new industries characterised by complex network technologies, the role of collective actors, in the form of stakeholder groups, was crucial for overcoming the challenges to the progression of the new industry since its inception. In the initial stage, it legitimises the case for change in the incumbent industrial order and provides a collective technological frame that guides subsequent innovation activity and encourages the entry of actors with crucial new capabilities into the innovation network. In the second phase, these groups coordinate technology development by promoting investment in integrated value-centered services that require several component technologies, and by focusing on the different technologies, roles and relationships that need to develop for the entire value ecosystem to emerge. Finally, collective actors facilitate the development of a supportive institutional infrastructure that facilitates the adoption of new technologies by taking evidence from technology demonstration projects and feeding it into the policy-development process.

This study also suggests that in industries characterised by complex open technologies, the government, regulator and other stakeholders genuinely welcome the views of technical experts, and in the case of smart grids in the UK, small firms perceived that institutional players appreciated their sharing of their unique technological knowledge and expertise. Small innovating firms were able to participate in institutional activities, mainly during the second phase of industry emergence, as a result of being perceived as a technology expert or leader, often following a successful innovation project. This was the case, for example, of Nortech and Smarter Grid Solutions, small technology firms very central in the innovation network, invited to participate in a work stream of the Smart Grid Forum.

This interesting finding suggests that, in the context of industries with a complex technological base characterised by interdependencies, the power of innovating firms is in their unique technological capabilities which they can leverage to compensate for their lack of market power and influence the
institutional context. In the case of the emergence of smart grids in the UK, unique technological capabilities and expertise legitimised the access of small innovating firms to institutional activity and enabled them to shape the development of the institutional environment. Therefore, collaborative innovation projects enabled the progression of the industry by legitimising firms and technologies that participated in those projects, and by providing evidence that shaped the institutional context in support of novel technologies.

This study makes two contributions to the literature on the emergence of new industries. First, it extends previous co-evolutionary models of industry emergence by identifying new mechanisms of interaction between institutional and technological processes (Pacheco et al., 2014; Van de Ven & Garud, 1989, 1993). It identifies the strategic action of technology firms that participate in both collaborative innovation projects and institutional activity, often via collective actors, as a mechanism of interaction between the development of the technological base of an industry and its institutional framework. Innovating firms that participate in collaborative demonstration projects, leverage the evidence from their projects to remove institutional barriers to the adoption of their new technologies, and build on the information gathered by engaging with influential collective actors to strategically align their innovation activity with the expected direction of the emerging industry.

Second, it contributes to previous studies that examine the role of collective actors in industry emergence (Dowell et al., 2002; Garud & Karnøe, 2003; York et al., 2016) by highlighting the changing role of collective actors as the industry progresses. During the initial stage of industry emergence, collective actors focus on identifying issues and proposing solutions, aligning the interests of different stakeholders and developing a collective understanding of the new industry. During the co-evolutionary stage, the role of collective actors centres on coordinating technology development across the value chain, ensuring alignment between technology and policy developments and driving consumer adoption and market creation. This changing role of collective actors dictates the opportunities for innovating firms to engage with their work. During the initial stage, innovating firms focus on educating and framing to make space for their technology in the collective vision of the
new industry, while in the co-evolutionary stage, innovating firms focus on increasing the value of their technology and removing barriers to its adoption.

Finally, at the firm level, this study suggests that in the emergence of complex technological fields, small innovating firms that don’t have the market power to use traditional nonmarket strategies such as lobbying (Oliver & Holzinger, 2008), may use their status as technology experts conferred by unique technological capabilities and innovation success, to try and influence the development of the institutional context. In the emergence of smart grids in the UK, small technology firms that had become technology leaders as a result of their innovation activity were able to access the working groups or carry-out contracted work for the SGF which had a policy impact. This was the case, for example, of Smarter Grid Solutions, the leading firm in providing active network management technologies, Nortech, a leader in systems integration, and EA Technology, a leader in asset management.

6. Boundary conditions and limitations

The findings from this study draw from a single case study which limits its generalizability. First, the regulated aspect of the electricity industry leads firms to be more active in developing relations with institutional players and trying to influence regulation. Second, the sector is highly political and is dominated by a small number of powerful firms. Finally, smart grid technologies are complex and interdependent and require knowledge from different fields, including engineering and ICT. In this case, institutional players genuinely required input from technology experts to develop some of the policies and regulations. Examining the role of collective actors in additional settings with different characteristics, for example, less complex technologies or less political sectors, would allow for the development of more robust findings.

Nonetheless, I expect that the insights from this study will be applicable to industries characterised by complex technological systems strongly influenced by the government or regulator. In industries with complex technologies, collective actors have a greater role because coordination becomes crucial to
the progression of the industry to avoid technology bottlenecks, to encourage system-wide investment and to support market creation. Dependence on the government or regulator will motivate innovating firms to engage to a greater extent in the development of the institutional context to ensure support for their technologies. In addition, in industries characterised by complex technologies and high dependence on the government and regulator, policy making and regulation will have a greater reliance on technology experts for advice on aspects related to the development of the institutional context to facilitate the emergence of the new industry.

In relation to the limitations of the data, it would have been useful to carry out further interviews with members of the collective actors to better understand the tensions, feedback loops, and need for reassessment that take place during the emergence of a new industry. Interviewees for this study include members of the collective actors whose activities I analyse and these interviews were crucial for understanding the role and importance of these groups during the early stages of the emergence of smart grids in the UK. Nonetheless, given the extensive archival data available on the activities of these groups in the form of annual reports, output reports and summaries of the meetings, these documents were the main source of data for developing the integrated framework for industry emergence presented in this chapter. These data sources do not fully capture the tensions and feedback loops that most likely took place during the emergence of smart grids in the UK and, therefore, the framework presented lacks part of the dynamism present in the process of industry emergence.

Furthermore, although the main focus of this study is the activity of the collective actors, I also pay attention to the activities of innovating firms and, in particular, I examine how they engage with collective actors. Although I study a range of firms that participate in the development of smart grid technologies funded by the Low Carbon Networks Fund mechanism and my data collection efforts include interviews with global firms such as Siemens and GE, in the context of smart grids in the UK, during the observation period, most of the new technologies were introduced by small innovating firms. While larger firms such as GE and Siemens were mostly developing incremental innovations
on existing technologies through the innovation projects, smaller innovating firms, such as Smarter Grid Solutions or Kelvatek, were developing radical innovations such as active network management technologies. As a result, the activities of innovating firms described in this chapter, primarily capture the activities of small and medium innovating firms.

7. Conclusion
Understanding the different processes that interact during the emergence of a new industry is of strategic importance for technology firms that wish to participate in its development. During this complex period, individual firms must make strategic decisions regarding what type of technical and institutional activities they will engage in (Van de Ven & Garud, 1993).

Firms that wish to take advantage of the opportunities offered by entering an industry during this risky stage, need to be aware of the changing role of collective actors as the industry progresses because it determines their ability to shape the institutional environment via participation in collective actors. During the initial stages, firms may attempt to influence the development of a collective technological frame that will guide subsequent technological innovation, by engaging with collective actors to educate the industry on their technology and to advance their view of the new industry. During the co-evolutionary stage, once there is a collective understanding of the meaning of the new industry, innovating firms focus on the development of a market for their new technologies and may engage with collective actors to provide evidence from technology demonstration projects that proves the value of their innovation and removes barriers to its adoption.
<table>
<thead>
<tr>
<th>Company</th>
<th>Country</th>
<th>Technology</th>
<th>Year-Start</th>
<th>Year-End</th>
<th>Size (GBP ‘000)</th>
<th>Partner</th>
<th>Lead DNO</th>
<th>Institution</th>
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<td>Note</td>
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<td>France</td>
<td>Overhead Line Incipient Fault Detection</td>
<td>2014</td>
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<td>£2,200,000</td>
<td>Firma</td>
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<td>2014</td>
<td>2014</td>
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<td>Firma</td>
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Note: AEA (2010 onwards)
# Appendix 2: Group membership


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<td>Ofgem</td>
<td>Dr Brian Wharmby</td>
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<tr>
<td></td>
<td>Schroder Salomon Smith Barney</td>
<td>Dr Tony White</td>
</tr>
<tr>
<td></td>
<td>DTI (Gov)</td>
<td>Dr Graham Bryce</td>
</tr>
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<td>DTI (Gov)</td>
<td>Steve Jacobs</td>
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<td>Utilities Buyers Forum</td>
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<tr>
<td></td>
<td>British Energy (Suppliers)</td>
<td>Terry Brookshaw</td>
</tr>
<tr>
<td></td>
<td>NECC/Energy Watch Domestic and other small consumers</td>
<td>Andrew Horsker</td>
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<td></td>
<td>National Grid</td>
<td>Dr Lewis Dale</td>
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<tr>
<td></td>
<td>Yorkshire Electricity</td>
<td>Dr Phil Jones</td>
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<td></td>
<td>Scottish Power</td>
<td>Alan Laird</td>
</tr>
<tr>
<td></td>
<td>Confederation Renewable Energy Association/ Warwick univ</td>
<td>Dr Catherine Mitchell</td>
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<td>Association of Electricity Producers</td>
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</tr>
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<td></td>
<td>Ofgem</td>
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</tr>
<tr>
<td></td>
<td>DETR</td>
<td>Leslie Packer</td>
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<tr>
<td></td>
<td>Energy Division Scottish Executive</td>
<td>Ben Maguire</td>
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<td>Energy Saving Trust</td>
<td>Nick Eyre</td>
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Members of the Electricity Networks Strategy Group (2005)

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<td>Claire Durkin</td>
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<td>Ofgem</td>
<td>David Gray</td>
<td>MD, Networks</td>
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<td>John Scott</td>
<td>Ofgem Technical Director</td>
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<td>NG</td>
<td>Simon Cocks</td>
<td>Commercial Director, Transmission.</td>
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<td>Jim Sutherland</td>
<td>Regulation and Asset Director</td>
</tr>
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<td></td>
<td>Scottish and Southern</td>
<td>Colin Hood</td>
<td>Chief Operating Officer</td>
</tr>
<tr>
<td></td>
<td>CE Electric UK</td>
<td>Phil Jones</td>
<td>Strategy and Investment Director</td>
</tr>
<tr>
<td></td>
<td>EdF</td>
<td>Paul Cuttill</td>
<td>Chief Operating Officer, Networks</td>
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<tr>
<td></td>
<td>RWE Npower</td>
<td>Nic Rigby</td>
<td>Head of Strategy and regulation</td>
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<td></td>
<td>Climate Change Capital</td>
<td>Tony White</td>
<td>Director of Research</td>
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<td>Formerly PB Power</td>
<td>Malcolm Kennedy</td>
<td>Former Chairman of PB Power</td>
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<td></td>
<td>Defra</td>
<td>Jackie Jones</td>
<td>Head of Sustainable Energy Policy</td>
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<td></td>
<td>Scottish Executive</td>
<td>Wilson Malone</td>
<td>Head of Energy and Telecommunications</td>
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<td>Welsh Assembly</td>
<td>Ron Loveland</td>
<td>Director, Energy Wales</td>
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<td>Ofgem</td>
<td>Arthur Cooke</td>
<td>ENSG Secretary</td>
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Source ENSG Annual Report 2005
Members of the Distributed Generation Working Group (2005)

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<td><strong>Vice President, Utility Automation</strong></td>
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<tr>
<td>Ofgem</td>
<td>Gareth Evans</td>
<td>Technical Adviser</td>
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<tr>
<td>REA</td>
<td>Gaynor Hartnell</td>
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<tr>
<td>Manchester University</td>
<td>Nick Jenkins</td>
<td>Professor (Power Systems)</td>
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<tr>
<td>United Utilities</td>
<td>Mike Kay</td>
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<td>Frodsham Consultancy</td>
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<td>Managing Director</td>
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<td><strong>Eden Electric</strong></td>
<td><strong>Guy Nicholson</strong></td>
<td><strong>Managing Director</strong></td>
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<td>Dave Openshaw</td>
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<td>ENA</td>
<td>Dragana Popovich</td>
<td>Distributed Generation Engineer</td>
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<td><strong>John Scott</strong></td>
<td>Technical Director</td>
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<td>Micropower Council</td>
<td>Dave Sowden</td>
<td>Chief Executive</td>
</tr>
<tr>
<td>Ofgem</td>
<td>Ronke Adenuga</td>
<td>Electrical Engineer</td>
</tr>
<tr>
<td>U. of Strathclyde</td>
<td>Graham Ault</td>
<td>(founder of smarter grid solutions)</td>
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<td><strong>EA Technology</strong></td>
<td>Mike Lees</td>
<td></td>
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<tr>
<td>LIFE-IC</td>
<td>Philip Johnson</td>
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<td><strong>GE Energy</strong></td>
<td>David Hawkins</td>
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Source: ENSG Annual Report 2005

Members of the Reconstituted Electricity Networks Strategy Group (2008)

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<td>DECC</td>
<td>Jonathan Brearley</td>
<td>Director, Energy Strategy &amp; Futures</td>
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<tr>
<td>Ofgem</td>
<td>Stuart Cook</td>
<td>Senior Partner, Transmission</td>
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<td>National Grid Electricity Transmission</td>
<td>Alison Kay</td>
<td>Commercial Director, Transmission</td>
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<tr>
<td>Scottish Hydro Transmission Ltd</td>
<td>Mark Mathieson</td>
<td>Board Member - SSE</td>
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<td>Scottish Power Transmission</td>
<td>Colin Taylor</td>
<td>Renewables Development Manager</td>
</tr>
<tr>
<td>EDF Energy</td>
<td>Barry Hatton</td>
<td>Director – Capital Programme</td>
</tr>
<tr>
<td>CE Electric UK</td>
<td>Phil Jones</td>
<td>President and Chief Operating Officer</td>
</tr>
<tr>
<td>E.ON</td>
<td>John Crackett</td>
<td>Managing Director</td>
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<tr>
<td>British Energy</td>
<td>David Love</td>
<td>Head of Regulation</td>
</tr>
<tr>
<td>RWE Npower</td>
<td>David Mannering</td>
<td>Corporate Economic Regulation Director</td>
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<tr>
<td>Renewable Energy Systems</td>
<td>Douglas Wright</td>
<td>Managing Director – Wind Energy</td>
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<tr>
<td>Centrica Energy</td>
<td>Sarwjit Sambhi</td>
<td>Director, Power Business</td>
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<td>Vattenfall</td>
<td>David Hodgkinson</td>
<td>Managing Director</td>
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<td>REA/ BWEA/ Scottish Renewables Forum</td>
<td>Robert Longden</td>
<td>Trade Association nominated representative to ENSG</td>
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<td>Colin Imrie</td>
<td>Deputy Director Energy Markets</td>
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<td>Welsh Assembly</td>
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<td>Head of Sustainable Energy &amp; Industry</td>
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<tr>
<td>DECC</td>
<td>John Overton</td>
<td>Deputy Director, Grid Renewables Deployment Team</td>
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Source: ENSG Membership List 2008
Members of the Smart Grids Working Group 2009-2010

EA TECHNOLOGY
Association of Electricity Producers
CE Electric UK
Centrica Energy
DECC
EDF Energy Networks
Electricity North West Limited
Energy Networks Association
Energy Research Partnership
Energy Retail Association
E.On Central Networks
Energy Technologies Institute
Intelect
National Grid
Ofgem
Renewable Energy Association
RLTech
RWE Npower
Scottish & Southern Energy
Scottish Executive
Scottish Power
The Centre for Sustainable Electricity and Distributed Gen.
Smarter Grid Solutions
The Carbon Trust
Western Power Distribution

Source: ENSG A Smart Grid Vision 2009
SmartGrids GB

Founding members

Accenture
British Gas
British Telecom
DECC
Consumer Focus
EDF Energy
Elexon
Engage Consulting
GE Energy
Hitachi
HP
IBM
Intellect
Ofgem
Oracle
PPC
Airwave
Sensus
Siemens
SP Energy Networks
Toshiba
UK Power Networks
Navigant
Vodafone
Wipro
AMT-Sybex
Arqiva
KEMA

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### Appendix 3: Firm entry into innovation network

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<th>PHASE 1 2005-2008 ESTABLISHED FIRMS</th>
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<th>Exit date</th>
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<th>LCNF</th>
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<td>Dec-17</td>
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<td>2004/05</td>
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<td>Dec-15</td>
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</tr>
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<tr>
<td>BAE Systems</td>
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<td>2014/13</td>
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</tr>
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<td>Industrial gases (hydrogen)</td>
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<td>Mar-15</td>
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<tr>
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<tr>
<td>Cumberland (CFL)</td>
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<td>2012/13</td>
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<tr>
<td>Mitach</td>
<td>Voltage control</td>
<td>Mar-14</td>
<td>Mar-15</td>
<td>0</td>
<td>1</td>
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References


ENSG. (2010). Electricity Networks Strategy Group, a Smart Grid Routemap. Retrieved from


Chapter Three. Collaboration Strategies of New Technology Firms in Emerging Industries

Abstract
This study examines the determinants of the collaboration strategies of new technology firms innovating in ecosystem environments, where value creation requires interaction with other technologies. Through an inductive, longitudinal study of the collaborative innovation activities of 16 new firms developing smart grid technologies in the UK, I identify four distinct collaboration strategies that vary in timing and scope. I propose that these four collaboration strategies are driven by a new firm’s resource munificence and its dependence on ecosystem innovation for its new technology to create value. I extend theories of cooperative innovation behaviour by identifying factors, both internal and external to a firm, that make depth and breadth of collaboration beneficial to its innovation activity. Furthermore, I contribute to the literature on ecosystems by highlighting the role of collaborations in the later stages of the innovation process as an important means of identifying ecosystem components and directing R&D resources to solving ecosystem emergence challenges.

1. Introduction
New technology firms are central actors in the early stages of industry emergence because they are often responsible for exploiting novel knowledge and developing innovative products or services that can lead to the creation of new industries (Powell, Koput, & Smith-Doerr, 1996; Schumpeter, 1934; Tushman & Anderson, 1986). However, while new firms often have the knowledge and capabilities required to develop new technologies, they typically lack the necessary resources to successfully develop their new technologies into commercial products (Baum, Calabrese, & Silverman, 2000; Diestre & Rajagopalan, 2012; Lee, Park, Yoon, & Park, 2010; Rothaermel & Deeds, 2004). Collaboration with external partners is therefore a significant aspect of a new technology firm’s innovation and survival strategy (Baum et al., 2000).
While new technology firms have traditionally been considered the weaker part in a collaborative relationship (Katila, Rosenberger, & Eisenhardt, 2008; Roijakkers, Hagedoorn, & van Kranenburg, 2005), recent studies suggest that new technology firms are not passive takers of collaboration agreements and that they make strategic decisions regarding who to collaborate with and when (Diestre & Rajagopalan, 2012; Katila & Mang, 2003; Katila et al., 2008; Ozcan & Eisenhardt, 2009). Furthermore, new technology firms need to carefully consider the collaborations they engage in to ensure they remain valuable (Baum et al., 2000).

Given the importance of new technology firms for the creation of new industries and their reliance on collaboration in their efforts to innovate, we need a broader understanding of what factors drive their collaboration patterns. Previous research on the collaborative behaviour of innovating firms has addressed three aspects of a firm’s collaboration strategy: type of partner, scope and timing. This body of work has identified the nature of the innovation pursued as the main determinant of a firm’s collaboration strategy (Belderbos, Carree, & Lokshin, 2004; Fritsch & Lukas, 2001; Laursen & Salter, 2006; Tether & Tajar, 2008). However, a limitation of this work is that is does not consider firms developing innovations that are embedded in broader systems characterised by technological interdependencies. Furthermore, given our interest in new technology firms, we know that access to funds is an important factor that drives new firms to collaborate; however, we do not know how resource-scarcity impacts their collaboration strategy (Katila & Mang, 2003).

In this study I will address some of the limitations identified in the literature by asking, **which are the determinants of the collaboration strategies of new technology firms innovating in ecosystem environments and the strategic trade-offs attached to each collaboration strategy?** Each collaboration strategy carries different strategic trade-offs and it is important for innovating firms to understand those if they are to efficiently allocate their valuable R&D resources. Finally, I adopt an ecosystem approach because it captures the interdependent nature of value creation in complex technological environments (Adner, 2017; Kapoor & Furr, 2015).
In order to address the research question, I carried out an inductive longitudinal study of the collaboration activities of 16 new technology firms developing smart grid technologies in the UK between 2005 and 2014. This is an interesting context in which to address the research question first, because smart grid technologies depend on other technologies to deliver value, such as communication technologies, and second, the innovation incentives for the development of smart grids in the UK established by the regulator for electricity networks in 2005, resulted in a large number of collaborative innovation projects on which there is publicly available data.

Findings from this study suggest two main determinants of a new technology firm’s collaboration strategy in its efforts to innovate: its resource munificence and the level of dependence on ecosystem innovation for the focal firm’s new technology to deliver value. These two factors taken together give rise to four distinct collaboration strategies that vary in timing and scope.

This study makes three contributions. First, it identifies a firm’s level of resources and its dependence on ecosystem innovation as determinants of its collaboration strategy. Second, it deepens our understanding of the circumstances, both internal and external to a firm, that make depth and breadth of collaboration beneficial to a firm’s innovation activity. Finally, it points to technology collaborations in the later stages of the innovation process as an important means of identifying ecosystem components and directing R&D resources to avoid technology bottlenecks that may hinder the competitiveness of the focal innovation.

2. Theoretical framework

2.1. Determinants of collaboration strategies of innovating firms

Technological progress is predominantly the result of the collaborative efforts of diverse organisations (Freeman, 1991; Hagedoorn, 2002; Kapoor & McGrath, 2013; Powell & Grodal, 2005; Rosenkopf & Schilling, 2007). The reasons for firms to collaborate in their efforts to innovate are varied and include technological uncertainty and complexity, pooling of skills, access to new markets, increasing the speed of technological development, technological complementarities and developing capabilities
Previous research on cooperative innovation has predominantly focused on three specific features of an innovating firm’s collaboration strategy: first, the type of partner an innovating firm collaborates with, whether it is suppliers, customers, competitors or universities and research institutes; second, the scope of a firm’s external collaborations, that is, to what extent an innovating firm engages deeply or broadly with external collaborators; and third, the timing of collaboration, which considers at which point in the innovation process an innovating firm engages in collaboration.

A large body of work has focused on understanding the first aspect of a firm’s collaboration strategy in its efforts to innovate, that is, which type of partners it collaborates with. This work suggests that the main determinant of an innovating firm’s collaboration strategy is the nature of the innovation it pursues which will determine the type of resources it needs to access (Belderbos et al., 2004; Fritsch & Lukas, 2001; Miotti & Sachwald, 2003; Tether, 2002; Tether & Tajar, 2008). As a result, this body of work proposes that firms aiming to develop radical innovations are most likely to engage in collaboration with universities, customers and competitors while firms pursuing incremental innovations aimed at improving firm productivity are more likely to collaborate with suppliers and competitors (Belderbos et al., 2004). Furthermore, previous research suggests that firms pursuing process innovations are more likely to collaborate with suppliers, firms pursuing product innovations are more likely to collaborate with customers or universities while firms pursuing organisational innovation are more likely to collaborate with suppliers or customers (Fritsch & Lukas, 2001; Tether & Tajar, 2008).

A firm’s collaboration strategy in its efforts to innovate has also been characterised by the scope of its collaborations. Extending the work of Katila and Ahuja (2002) on the search strategies of innovating firms, Laursen and Salter (2006) developed the concepts of external search depth and external search breadth to describe the scope of an innovating firm’s collaboration strategy. External search breadth refers to the different external sources that firms draw from in their innovation, including users,
suppliers, universities, research centres and competitors, and external search depth refers to how deeply firms engage with the different external sources to acquire knowledge for their innovation activity (Laursen & Salter, 2006). While search breadth allows an innovating firm to access diverse sources of knowledge, search depth, that is repeated interactions with the same partner, leads to the development of routines for working together and to increased understanding between the partners (Katila & Ahuja, 2002; Laursen & Salter, 2006).

Laursen and Salter (2006) empirically demonstrate that a firm’s collaboration strategy is determined by the nature of the innovation it pursues and shows that firms aiming to develop radical innovations are likely to engage in deep collaboration with a few actors, while firms pursuing incremental innovations are more likely to collaborate with a more diverse set of actors to access the relevant knowledge needed for their innovation activities (Laursen & Salter, 2006). In addition, this study suggests that both external breadth search and external depth search improve the ability of a firm to produce an innovation; however, there is a tipping point after which a firm’s innovation activity will experience diminishing returns to its external search efforts because the firm’s resources will become too dispersed (Laursen & Salter, 2006).

The work of Leiponen and Helfat (2010) supports that breadth, or diversity in the external sources of knowledge a firm has access to, can improve the chances of successful innovation by increasing the probability of obtaining knowledge that will result in a valuable innovation effort (Leiponen & Helfat, 2010). Nonetheless, diversity in a firm’s collaboration partners also increases the difficulty and costs of accessing and assimilating that knowledge (Cohen & Levinthal, 1990; Phelps, 2010). Developing external collaborations requires resources and time, and firms need to be careful managing their resources so that they are used effectively in a firm’s collaborative innovation efforts (Laursen & Salter, 2006).

Finally, a small number of studies have considered a firm’s collaboration strategy from the perspective of when in the innovation process a firm chooses to engage in collaboration. This is an important aspect of a new technology firm’s collaboration strategy given that timing is key in
exploiting a technological opportunity and early access to resources can be crucial for new technology firms (Katila & Mang, 2003). Furthermore, speed to market is one of the main strategies that small firms engaged in cooperative innovation adopt to protect their innovation returns (Leiponen & Byma, 2009).

In their study of the history of 86 biopharmaceutical product development projects between 1976-1992, Katila and Mang explore which factors facilitate early collaboration of entrepreneurial firms and empirically demonstrate that both firm level factors as well as industry factors impact a firm’s decision to collaborate early in the innovation process to speed the exploitation of technological opportunities (Katila & Mang, 2003). Their study empirically demonstrates that a technology firm’s R&D intensity, its previous collaboration experience with a specific partner, the development of an industry-level support infrastructure and the increase of intellectual property protection, facilitate early engagement in collaboration to develop an innovation (Katila & Mang, 2003). Furthermore, it shows that the need for funds drives new technology firms to collaborate, although their empirical results suggest that there is no effect between the actual timing of the collaboration and an entrepreneurial firm’s cash position (Katila & Mang, 2003). This finding is aligned with a number of studies that suggest that access to financial resources to progress their innovation is a central concern for new technology firms who often lack the capital to finance their innovation projects and have not yet developed sources of operational revenues (Bayona, García-Marco, & Huerta, 2001; Katila et al., 2008; Katila & Shane, 2005; Lee et al., 2010).

Despite the benefits of collaborating early in the innovation process to speed up the exploitation of technological opportunities, early collaboration also carries considerable risks. Early in the innovation process knowledge is mainly tacit which, first, it is difficult to articulate and therefore explain its value to potential collaborators, and, second, it is easier for opportunistic partners to misappropriate that knowledge (Katila & Mang, 2003).

Small firms use a number of strategies to mitigate the risk of their knowledge being misappropriated by their collaboration partners. For instance, by selecting partners that have low incentives to exploit
their know-how outside of their collaboration agreement (Diestre & Rajagopalan, 2012) or by waiting until later in the innovation process (Katila & Mang, 2003). It is interesting to note that while large firms use patents to protect their knowledge, small firms tend to rely on different protection mechanisms which include secrecy, speed to market, timing of collaboration and partner selection (Diestre & Rajagopalan, 2012; Katila & Mang, 2003; Katila et al., 2008; Leiponen & Byma, 2009).

Overall, the existing literature on cooperative innovation identifies the nature of the innovation pursued as the main determinant of an innovating firm’s collaboration strategy. Notwithstanding the significant contribution made by these studies, a limitation is that they distinguish between radical and incremental innovation, and product, process and organisational innovation, but do not address innovation in complex technological environments where a focal innovation often requires significant developments in components or complements to create value. The literature on innovation in ecosystems points to unique challenges facing firms innovating in such environments which are described below. Furthermore, although access to funds is one of the major factors that drive small firms to collaborate, we do not know how resource scarcity impacts their collaboration strategies.

2.2. Innovation challenges in ecosystem environments

The ability of an innovation to create value often depends on technological, commercial and regulatory developments in its external environment (Adner & Kapoor, 2010). Specifically, some innovations require technological changes in the broader system they are embedded in, or the development of complement technologies necessary for the focal innovation to create value (Hughes, 1993; Salmenkaita, 2006; Teece, 1986). Often, the commercial success of an innovation will depend on innovations in complement technologies because in their absence consumers cannot derive full benefits from the focal innovation (Adner & Kapoor, 2010; Hargadon & Douglas, 2001). For example, the benefits from electric vehicles can only be realised in conjunction with an infrastructure of charging points and long-range batteries, in their absence the widespread adoption of electric vehicles is compromised (Kapoor & Furr, 2015).
The concept of “ecosystem” captures the phenomenon of several firms coming together to deliver a specific service (Jacobides, Cennamo, & Gawer, 2017). An ecosystem can emerge around a focal innovation and the set of components (upstream) and complements (downstream) that allow it to deliver value (Jacobides et al., 2017). Adner (2017) defines an ecosystem as “the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize” highlighting the interdependent nature of value creation in an ecosystem environment. The ecosystem refers to the different set components necessary for a value proposition to be realised as well as to the relationship or links between the components, and ecosystem innovation may refer to changes in either the components or the links between the components (Adner, 2017; Henderson & Clark, 1990).

Ecosystem environments present unique challenges for innovating firms. In an ecosystem environment, the customer needs the product of the focal firm as well as the complements to derive value from an integrated solution, for example, a printer requires a computer, which may be provided by the same firm as the printer or a different one (Jacobides et al., 2017). While some of the complement technologies may be readily available in the market or may require little modification, others may require significant development, either by the focal firms themselves or in collaboration with external partners (Adner & Kapoor, 2010; Kapoor & Furr, 2015). When the complements of a new technology developed by a focal firm are not readily available in the market, the focal firm will not be able to capture the full benefits from its innovation (Kapoor & Furr, 2015; Teece, 1986).

Kapoor and Furr’s (2015) empirical study of the solar photovoltaic industry highlights the potential challenges facing firms innovating in ecosystem environments, including, design, integration and consumer adoption risks that could increase the complexity, length and cost of the innovation process (Kapoor & Furr, 2015). Their study shows that firms developing innovations for which interdependent technologies were not readily available in the market had to develop their own which required significant capital and technical investments (Kapoor & Furr, 2015). On the contrary, firms developing innovations for which interdependent technologies were available faced lower
commercialisation challenges and could start delivering value in the new industry straight away (Kapoor & Furr, 2015).

Furthermore, if some of the ecosystem elements struggle to emerge creating technology “bottlenecks” the competitiveness of the focal innovation will be compromised (Adner & Kapoor, 2016; Hughes, 1993). For example, in their study of the semiconductor lithography equipment industry, Adner and Kapoor (2016) empirically demonstrate that bottlenecks created by technology development challenges in complement technologies contributed to the delay of technology transitions from one generation of lithography equipment to the next, because the new generation could not realise its performance advantage (Adner & Kapoor, 2016).

Our current understanding of a firm’s collaborative behaviour in its efforts to innovate does not clearly address how firms innovating in ecosystem environments may address these challenges. While greater technological complexity may suggest a broader collaboration strategy to access diverse knowledge bases, deep collaboration with a few key sources facilitates the development of routines for working together that may mitigate some of the innovation risks (Katila & Ahuja, 2002; Laursen & Salter, 2006). Furthermore, young innovating firms may exhibit different collaboration strategies than established firms given the differences in resource availability.

In this study I will address some of the limitations identified in the literature by asking, **which are the determinants of the collaboration strategies of new technology firms innovating in ecosystem environments and the strategic trade-offs attached to each collaboration strategy?** Each collaboration strategy carries different strategic trade-offs and it is important for innovating firms to understand those if they are to efficiently allocate their R&D resources.

3. Methodology

3.1. Research design and setting

I conducted an inductive, multiple-case, qualitative study to identify patterns in the collaborative strategies of new technology firms participating in the development of smart grids in the UK between
2005 and 2014. The aim of this research design is to extend theory on the collaboration strategies of innovating firms by simultaneously considering factors internal and external to a firm (Eisenhardt, 1989; Yin, 2009). The explanatory nature of this study, which seeks to understand the collaborative behaviour of new technology firms innovating in complex fields, justifies a case study approach (Yin, 2009). Furthermore, a multiple-case research design with similar and contrasting cases allows a replication strategy which strengthens the validity of the findings (Eisenhardt & Graebner, 2007; Miles, Huberman, & Saldana, 2013; Santos & Eisenhardt, 2009; Yin, 2009).

The collaborative innovation activity for the development of smart grids in the UK between 2005 and 2014 centred around the collaborative R&D and demonstration projects funded through the IFI and LCNF incentives described in section 3.2. The study’s population sample is therefore formed by the 132 technology firms that participated in those innovation projects between 2005 and 2014. Nonetheless, given this study’s theoretical aim to develop an understanding of the collaborative behaviour of new technology firms, the sample was reduced to 16 new technology firms that participated in more than one collaborative innovation project, so that trends in collaboration strategies could be observed. New technology firms refers to firms established to develop and exploit new smart grid technologies.

The development of smart grids in the UK is an interesting context in which to address the research objectives because the complexity of smart grid technologies and the dependence on other technologies to deliver value, such as communication technologies, make collaboration an imperative. Furthermore, innovation incentives for the development of smart grids in the UK established by Ofgem, the UK regulator for the electricity networks, which started in 2005 with the Innovation Funding Incentive (IFI) and were considerably increased in 2010 with the Low Carbon Networks Fund (LCNF) created a large number of collaborative innovation projects for the development of smart grids in the UK. Given that the money invested in those projects comes from electricity consumers, Ofgem requires UK distribution network operators (DNOs), which lead all the
collaborative innovation projects funded by the IFI and LCNF, to publish information on the projects regularly and make that information publicly available.

A smart grid is an advanced electricity network which incorporates information and communication technologies (ICT) to the traditional electricity network infrastructure allowing it to understand the state of the network at any given moment and automatically respond to changes in electricity generation and demand in close to real time (Teh, Goujon, Bortuzzo, & Rhodes, 2011). It does so by integrating three different layers; a hardware layer, which consists of the traditional network infrastructure and intelligent sensors that collect data on the state of the network, a communications layer, that sends the data from the sensors to an end-device or server, and an ICT layer, which integrates and analyses the data from the sensors (Erlinghagen & Markard, 2012).

A smart grid is a complex system made of different technological components that need to interact to provide an integrated solution (Teh et al., 2011). For example, a smart meter system, which is a component of the smart grid, requires smart meters that collect data on electricity consumption, a communication technology, for example power line communication, that can transfer the data from the smart meter to a central server, and a meter data management system that can analyse the data and provide value-added services (Erlinghagen & Markard, 2012). Furthermore, the same infrastructure can be used by third parties to communicate with electricity consumers and enable other smart grid interventions such as demand side management, where consumers adjust their electricity consumptions in response to changes in electricity demand or generation (Erlinghagen & Markard, 2012).
3.2. **Innovation incentives in the UK electricity sector**

Following the liberalisation of the UK electricity sector in the 1990s, annual expenditure by distribution network operators (DNOs) on research and development (R&D) plummeted from approximately £12 million in 1989/90 to £1 million by 2003/4 (Jamasp & Pollitt, 2015). To encourage DNOs to increase their innovation activity, in 2005 Ofgem introduced two incentives, the Innovation Funding Incentive (IFI) and the Registered Power Zones (RPZ).

The IFI provided funding for innovation projects aimed at the technical development of any aspect of the distribution networks to deliver value to end consumers (EDF-Energy, 2006). The IFI mechanism enabled DNOs to spend 0.5% of its revenue on eligible IFI projects and recover between 70-90% of the projects expenditures from its customers (EDF-Energy, 2006). IFI projects did not need to be approved by Ofgem but each DNO needed to report its IFI projects annually (EDF-Energy, 2006). RPZs, on the other hand, were specifically focused on developing and demonstrating new ways of connecting generation to distribution systems. DNOs could apply for up to two RPZ per year and the additional revenue from RPZ schemes could not be greater than £0.5 million (EDF-Energy, 2006).

In 2010 IFI was extended for 5 additional years and the RPZ was superseded by the Low Carbon Networks Fund (LCNF). The LCN Fund made £500 million available to DNOs over five years (2010-2015) to trial novel technologies and new operating and commercial arrangements to facilitate a transition to a low carbon economy (Ofgem, 2010). The LCNF mechanism also encouraged DNOs
to collaborate in their demonstration projects with partners from both the electricity supply chain and from outside the electricity industry (Ofgem, 2010).

The LCN Fund was divided into two tiers. The First Tier consisted of £80 million available to DNOs over 5 years for small scale demonstration projects that trialled new technologies and commercial arrangements to prepare the networks for a low carbon energy sector (Ofgem, 2010). There was no minimum or maximum size for first tier projects, however, each DNO had a maximum annual first tier allowance (Ofgem, 2010). The Second Tier consisted of a central fund of £320 million to be allocated equally over 5 years for which DNOs compete to fund a small number of large “flagship” demonstration projects (Ofgem, 2010). From April 2010 to March 2015, the LCNF supported forty Tier 1 projects and twenty-three Tier 2 projects with project budgets totalling £29.5 million and £220.3 million respectively (Frame, Bell, & McArthur, 2016).

The IFI and the LCNF innovation incentives resulted in over 500 collaborative innovation projects which aimed to develop and demonstrate new technologies and commercial arrangements for the development of low carbon networks, or smart grids.

3.3. Data collection
The starting point for the selection of the 16 cases used for this study was a database of all the applied R&D, trial and demonstration projects funded by Ofgem through the Innovation Funding Incentive (IFI) and the Low Carbon Networks Fund (LCNF) from 2005 to 2014. I created this database from the information on the projects disclosed in the annual IFI report published by each of the six UK distribution network operators (DNOs), the submission reports of each LCNF project, the six-monthly progress reports of the LCNF Tier II projects, and the closedown report of the LCNF projects. This database of over 500 collaborative innovation projects includes information on the name of the project, its size, start date, end date, project description, project aim, technology area, type of innovation, number of participants, names of other participants and project outcome. Of all the innovation projects collected, 352 included collaboration with firms. These projects were then reorganised around each firm, resulting in a database of all the collaborative R&D and demonstration
projects for 132 firms. Given my research aim of understanding the collaboration patterns of new technology firms in their efforts to innovate, I used this database to identify the new technology firms that participated in more than one collaborative innovation project.

Once I identified the 16 new technology firms that would be used as cases for this study, the data collection focused on developing a longitudinal understanding of the collaborative behaviour of those firms over the observation period, 2005 to 2014. For this purpose, I went back to the IFI annual reports, LCNF project submission reports, LCNF six-month project progress reports and LCNF project closedown reports and collected rich descriptive information on the innovation projects in which the 16 selected technology firms participated in. I collected information on the aims of the project, type of project (feasibility study, technology development, small-scale technology trial, medium scale technology demonstration or large-scale technology demonstration), project partners and their roles, activities carried out throughout the project, technological challenges being addressed, specific technologies being developed or trialled through the projects, whether the project built-on from a previous project, the outcome of the project and whether it resulted in the progression or deployment of the technology.

I also used the Amadeus and Fame databases\(^8\) to collect data on each of the technology firms, where available, including age of the firm, country of origin, and historical financial data, such as total assets, total employees and revenues at different points in time to understand their financial situation at the moment they start to participate in the collaborative innovation projects and at the end of their projects. Finally, I used company reports, where available, and company websites to collect descriptive information on each new technology firm, its origins, history and on the new technologies they had developed or were developing.

\(^8\) Amadeus and Fame databases contain historical financial data on private European and UK firms respectively.
Surenet was a start-up set up by EA Technology to develop a network automation system.

Source: company websites

The table below lists the small technology firms included in this study and offers a brief description of their novel technologies developed, trialled or demonstrated though the IFI or LCNF funded collaborative innovation projects:

<table>
<thead>
<tr>
<th>Firm name</th>
<th>Core Technology</th>
<th>Technology overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>4Energy</td>
<td>Data centre monitoring and control/Intelligent asset management</td>
<td>4Energy develops energy cooling systems and monitoring and control systems for telecommunications and equipment rooms.</td>
</tr>
<tr>
<td>ASL</td>
<td>Superconducting fault current limiters / Fault management</td>
<td>Applied Superconductor (ASL) employs superconducting technologies to develop fault current limiters. These are fitted to electric power distribution networks to provide protection against damage resulting from current surges caused by short circuits. Fault Current Limiters support the connection of renewable energy generators to distribution networks.</td>
</tr>
<tr>
<td>Cresatech</td>
<td>Asset monitoring</td>
<td>Cresatech's technology monitors and alerts in real-time when components of the electricity distribution infrastructure have been disconnected, removed or damaged.</td>
</tr>
<tr>
<td>Current Group</td>
<td>Communication/Monitoring/Data management</td>
<td>Current develops power line carrier (PLC) communication technology as well as sensors and analytics tools to provide real-time distribution grid visibility. In March 2013, Current was acquired by Spanish medium-voltage grid gear vendor Ormazaibal.</td>
</tr>
<tr>
<td>Elimpus</td>
<td>PD Location/Asset monitoring/Intelligent asset management</td>
<td>Elimpus is a spin-off from the University of Strachclyde that develops partial discharge (PD) location technology with communications and data transfer capability. PD is a phenomenon that results in short impulses of current flowing through a site of stressed insulation which can be a precursor to more serious insulation failure.</td>
</tr>
<tr>
<td>EMS</td>
<td>Substation monitoring</td>
<td>Embedded Monitoring Solutions (EMS) developed a web-based substation monitoring technology which continuously monitors and reports on protection operations, quality of supply, stability and substation asset conditions. The new technology provides automatic analysis of the data from system events and sends prioritised reports via email. Remote communications are via LAN, PSTN, GPRS &amp; 3G connections and all reports can be accessed using a web browser.</td>
</tr>
<tr>
<td>Flextricity</td>
<td>Demand response</td>
<td>Flextricity created and operates the largest demand-response portfolio in the UK. Demand response financially incentivizes electricity users to reduce their energy use at time of peak demand to allow for the overall demand to be met without additional generation. Flextricity aggregates demand side resources from industrial and commercial customers to offer system balancing services to National Grid, the UK electricity transmission operator.</td>
</tr>
<tr>
<td>FMC Tech</td>
<td>Real time thermal ratings/monitoring</td>
<td>FMC-Tech was an Irish smart grid Start up that developed a novel technology to allow utilities to monitor their power lines in real time. FMC-Tech was acquired by GE in 2011.</td>
</tr>
<tr>
<td>HVPD</td>
<td>PD monitoring/intelligent asset management</td>
<td>High Voltage Partial Discharge (HVPD), develops on-line PD monitoring technology for condition monitoring of high voltage electrical assets.</td>
</tr>
<tr>
<td>Kehui (UK)</td>
<td>Fault location</td>
<td>Kehui (UK) develops equipment for detecting and locating intermittent faults on low voltage underground cables. Kehui (UK)'s novel equipment facilitates near real-time remote data access.</td>
</tr>
<tr>
<td>Kelvatek</td>
<td>Fault management</td>
<td>Kelvatek develops fault management, LV switching and automation technology which allows for the location and rapid restoration of intermittent faults in the low voltage electricity networks.</td>
</tr>
<tr>
<td>Open Grid Systems</td>
<td>Data management/network analysis software</td>
<td>Open Grid Systems is a software firm that develops data management, visualisation and power system network analysis software.</td>
</tr>
<tr>
<td>PowerSense</td>
<td>Sensors/monitoring</td>
<td>Powersense is a spin-off of the Danish utility DONG Energy. The firm developed an optical sensor technology as well as monitoring and control systems.</td>
</tr>
<tr>
<td>Smart Grid Networks</td>
<td>Communication</td>
<td>Smart Grid Networks is a Swedish technology company that develops digital communication technologies as well as control and automation technologies.</td>
</tr>
<tr>
<td>Smarter Grid Solutions</td>
<td>Active network management</td>
<td>Smarter Grid Solutions is a spin-off from the University of Strachclyde that develops active network management solutions that facilitates integration and control of distributed energy resources.</td>
</tr>
<tr>
<td>Surenet Technologies</td>
<td>LV automation</td>
<td>Surenet was a start-up set up by EA Technology to develop a network automation system.</td>
</tr>
</tbody>
</table>

Source: company websites

Table 6: New technology firms included in this study

3.4. Data analysis

I began the data analysis by carrying out a with-in case analysis of each firm (Eisenhardt, 1989). For that purpose, I developed individual cases of the collaborative innovation activities of each of the 16 firms between 2005 and 2014 ordered chronologically. Each case included descriptive and financial information on the firm before it starts participating in the collaborative innovation projects, and a
chronological account of the collaborative innovation activity of the firm describing for each project the aim of the project, how developed the firm’s technology was at the start of the project, what specific features of the technology were developed during the project, which aspects of the technology needed further work after the project, in which context did the technology deliver value, other project partners, what type of technologies they brought to the project, in what way the technologies of the different partners interacted to deliver value and the outcome of the project. Finally, I included descriptive and financial information of each firm at the end of the projects to understand how the firms and their technologies had evolved during the observation period. This allowed me to familiarise myself with each of the firms and their technologies.

Before moving on to the cross analysis of the cases, I developed a table for each firm which condensed and allowed visualisation of the data (Miles et al., 2013). Each table included total assets of the firm at the beginning of each project, where available, and information on each project as well as on the technology being developed. Next, I aggregated the data at the firm level and created a table that included aggregated project data for all the 16 new technology firms selected for this study (this table can be found in appendix 1). Finally, for each of the firms, I created basic diagrams that showed which technologies their own technological innovation needed to interact with to create value.

The tables and diagrams described above were the basis for the cross-case analysis which aimed to identify patterns in the collaboration strategies of the selected firms (Yin, 2009). I focused on identifying similarities and differences between the collaborative behaviour of the 16 new technology firms and found that firms followed four different collaboration patterns. I then grouped the firms according to the four distinct patterns of collaborative behaviour identified and tried to find similarities among the characteristics of the firms of each group.

3.5. Definitions and measures

In this study, a new technology firm refers to a firm that has been established to exploit technology opportunities related to the development of smart grids.
Timing of collaboration refers to the moment in the innovation process when a new firm engages in collaboration for the development of its innovation. Following Lee, Park et al. (2010) early-stage collaboration refers to collaborative innovation projects that aim to develop a new technology (R&D phase) and late-stage collaboration refers to collaborative innovation projects that aim to trial or demonstrate a new technology that has already been developed outside the collaboration (trial or demonstration phase). In the energy sector, advancing a technology from R&D to commercialisation often involves a previous demonstration or trial phase to “test” the technology, products, processes and systems, and to promote market diffusion and commercialisation (Hendry, Harborne, & Brown, 2010; Lefevre, 1984). Once a technology goes from R&D to trial or demonstration, it is assumed that the principal technological problems have already been resolved (Brown & Hendry, 2009). As a result of a late-stage collaboration project, the new technology may be enhanced or validated but the core technology should remain unchanged.

The information of whether a collaborative innovation project takes place early or late in the innovation process comes from the project description that is provided for each project and reported either in the IFI annual reports or in the LCNF project submission reports. Some DNOs use the technology readiness levels (TLR) developed by NASA to describe how far in the innovation process a technology is at the beginning of a project. In this case, before TLR 7, which refers to a network trial, the collaboration will be classified as an early-stage collaboration, and from TLR 7 and onwards it will be classified as a late-stage collaboration. A table describing the definitions of the technology readiness levels (TLR) is included in appendix 2.

Scope of collaboration refers to whether the new technology firm engages in collaboration mainly with one or two key partners, or whether it chooses to collaborate with a larger number of partners. I follow Laursen and Salter (2006) and consider repeated projects with one partner as a focused collaboration strategy which is reflected in a firm carrying out over 50% of its innovation projects with the same distribution network operator (DNO). On the contrary, the collaboration strategy of a
A new technology firm will be classified *broad* when the firm distributes its collaborative innovation projects among several DNOs.

**Resource munificence** is the amount of resources available to a firm at one point in time and can be measured by a firm’s total assets. The total assets of the new technology firms used in this study at the point in time in which they engage in their first project ranges from £5k to £4 million. I classify the firms in two groups according to their total assets. Low munificence for the firms with less than £500k in total assets and high resource munificence for firms with total assets over £500k.

![Table 7: Resource munificence of new technology firms.](image)

Financial data from Amadeus and Fame databases

1: As of 2009 first available data
2: As of 2013 last available data
3: As of 2012, last available data
4: As of 2011, first available data

Finally, **dependence on ecosystem innovation** captures the extent to which significant innovation is needed in interdependent technologies for the focal innovation to create value. This variable will be low when there is no significant innovation needed in interdependent technologies because these are
commercially available, and high when interdependent technologies are not commercially available and need to be developed.

4. Findings
This study considers the collaboration behaviour of the new technology firms that participated in the collaborative innovation projects for the development of smart grid technologies in the UK between 2005 and 2014. The observation of the patterns of collaboration of these firms led to the identification of four distinct collaboration strategies that varied in their timing and scope.

The table below shows the determinants of the collaboration strategies of new technology firms found inductively (resource munificence and dependence on ecosystem innovation) and the four possible outcomes identified by this study, which are shown in the inner part of the matrix.

<table>
<thead>
<tr>
<th>Low firm dependence on ecosystem innovation</th>
<th>Low firm resource munificence</th>
<th>High firm resource munificence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early-stage, broad collaboration:</td>
<td>Late-stage, focused collaboration:</td>
<td></td>
</tr>
<tr>
<td>risk-hedging strategy</td>
<td>market access strategy</td>
<td></td>
</tr>
<tr>
<td>High firm dependence on ecosystem innovation</td>
<td>Early-stage, focused</td>
<td>Late-stage, broad</td>
</tr>
<tr>
<td>selective strategy</td>
<td>collaboration: market development strategy</td>
<td></td>
</tr>
</tbody>
</table>

Table 8: Collaboration strategy matrix

In the following sections I describe each of the four collaboration strategies observed.

4.1. Strategy 1. Risk-hedging strategy
The firms in this group engage in collaboration early in the innovation process and partner with a number of different distribution network operators (DNOs). The new technology firms in this group have low levels of resources and their total assets range between £6k and £261k at the time of their first engagement with a collaborative innovation project for the development of smart grids in the UK.
The table below shows the resource munificence and repeated partnerships of the new technology firms in this study.

<table>
<thead>
<tr>
<th></th>
<th>Resource Munificence</th>
<th>% projects same partner</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strategy 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kehui UK</td>
<td>Low</td>
<td>50%</td>
</tr>
<tr>
<td>Surenet</td>
<td>Low</td>
<td>40%</td>
</tr>
<tr>
<td>HVPD</td>
<td>Low</td>
<td>50%</td>
</tr>
<tr>
<td>4Energy</td>
<td>Low</td>
<td>50%</td>
</tr>
<tr>
<td>Elimpus</td>
<td>Low</td>
<td>50%</td>
</tr>
<tr>
<td>Cresatech</td>
<td>Low</td>
<td>33%</td>
</tr>
<tr>
<td>Applied Superconductor</td>
<td>Low</td>
<td>29%</td>
</tr>
<tr>
<td><strong>Strategy 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kelvatek</td>
<td>High</td>
<td>61%</td>
</tr>
<tr>
<td>FMC Tech</td>
<td>Low</td>
<td>60%</td>
</tr>
<tr>
<td>Smarter Grid Solutions</td>
<td>Low</td>
<td>60%</td>
</tr>
<tr>
<td>EMS</td>
<td>Low</td>
<td>67%</td>
</tr>
<tr>
<td>Smart Grid Networks</td>
<td>High</td>
<td>100%</td>
</tr>
<tr>
<td>Open Grid Systems</td>
<td>Low</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Strategy 3</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PowerSense</td>
<td>High</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Strategy 4</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexitricity</td>
<td>High</td>
<td>40%</td>
</tr>
<tr>
<td>Current Group</td>
<td>N.A.</td>
<td>25%</td>
</tr>
</tbody>
</table>

Table 9: Resource munificence and repeated partnerships of new technology firms in this study

Some of the new technology firms that collaborate early in the innovation process have formed partnerships with large electricity distribution network companies through the Energy Innovation Centre. The Energy Innovation Centre was set up in 2008 by three large electricity distribution network operators (DNOs) and three gas distribution network companies to facilitate collaboration in the development of new technologies between small innovating firms that needed resources to deliver their novel technologies and large firms that needed the new technology solutions. This is the case of FMC Tech, Surenet, Open Grid Systems, and Cresatech all of which collaborate early in the innovation process. For many of these small new firms, the income from the projects are a major
source of revenue while their technologies are being developed and are not yet ready for commercialisation.

The case of Surenet illustrates how the low level of resources of some of these young firms often makes them rely on the revenues from the collaborative innovation projects for their survival while their technology is ready for commercialisation. In 2005-06 Surenet engaged in a cooperative innovation project with UK Power Networks (UKPN), one of the UK distribution network operators (DNOs), to jointly develop a novel network automation system. At the end of that project, UKPN did not continue to support Surenet in the development of the new technology through successive innovation projects. In 2006-07, Surenet engaged in a new collaboration project with two other DNOs, Scottish Power Electricity Networks (SPEN) and Scottish and Southern Electricity Networks (SSE), to jointly develop the novel automation system. This project was successful and delivered a prototype of the new technology. SPEN and SSE continued supporting the development of Surenet’s new technology through a second collaboration project that allowed the development of the new technology to progress. Nonetheless, as can be seen from the extract of the project report below, the project was stopped before a full commercial product was developed.

“Although the initial prototype unit was developed it was concluded its size and functionality would have to be modified to develop the solution into a viable product. Further work looking at using different types of materials failed to advance the project sufficiently to allow it to continue” SPEN IFI annual report 2013-14.

Following this project, Surenet was closed as a result of not finding a partner to support the final stages of the development of its new technology into a commercial product.

The need for resources to take a novel technology concept through the innovation process until a commercial product is developed drives new firms to collaborate in their efforts to innovate. The resources and capabilities a new firm is endowed with, or can obtain from investors or customers, may influence how far in the innovation process the new technology firm can progress before approaching potential collaboration partners. Collaboration early in the innovation process carries a
higher level of risk but may be necessary to exploit a technological opportunity before others. In the
context of the development of smart grids, the cases of new technology firms that engage in
collaboration early in the innovation process suggest that resource-scarcity may drive new firms to
collaborate early in the innovation process.

Apart from being resource-scarce, the firms in this group were developing new technologies that
required limited innovation in ecosystem complements to create value for their customers and could
therefore readily participate in the emerging industry. This is the case of Kehui UK, a firm set up in
2004 to develop a novel technology to locate faults in the low voltage underground electricity cables
which provides remote, near real-time access to the data. The new technology was developed and
trialled in collaboration with 3 distribution network companies (DNOs) between 2005 and 2011. At
the beginning of the collaboration projects Kehui UK had low level of resources, total assets of £8k.
Once the innovation project concluded, the three collaborating DNOs, SP Energy Networks,
Electricity North West and UK Power Networks, adopted the new technology because they could
derive value from it straight away. By collaborating with three different DNOs, Kehui (UK) was able
to access a diverse set of resources and develop a more robust technology that incorporated a broader
set of demands.

The ecosystem complements needed for Kehui’s innovation to deliver benefits to its customers are a
GPRS network and a data host. This only required some minor development work. The figure below
shows the ecosystem complements needed for the new fault location technology to create value for
Kehui’s customers, the electricity distribution network operators (DNOs). Both complements are
mature technologies.

![Figure 7: Kehui’s fault location technology downstream interdependencies](image)

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Elimpus offers a similar example. A spin-off from the University of Strathclyde, the firm was established in 2007 to develop a partial discharge (PD) location technology with communications and data transfer capability. PD is a phenomenon that results in short impulses of current flowing through a site where the insulation is beginning to wear off, and can be a precursor to more serious insulation failure. The technology developed by Elimpus in collaboration with SP Energy Networks (SPEN) enables long-range assessment of network assets in a non-invasive way and can communicate any events of partial discharge in real time. The figure below shows the technology complements that allow Elimpus’ novel PD location technology to create value, that is a GPRS communications network, a data server, and a vehicle to install the device on.

![Diagram of PD location technology](image)

**Figure 8: Elimpus’ PD location technology downstream interdependencies**

As the extract from SP Energy Networks’s IFI Annual Report 2007-08 below illustrates, after a year of collaboration, Elimpus and SP Energy Networks were able to take the technology from an early stage to being ready for commercialisation. At the beginning of the project Elimpus had low resources, total assets of £261k.

“During the past year SP Energy Networks and Elimpus have been working together to produce a portable device capable of picking up and pin pointing the location of partial discharge. Through the IFI programme the Sentinel v1.0 was developed. The monitoring system hardware comprises of a trailer, fitted with radiometric PD\(^9\) locating equipment, together with GPRS communications for recorded data transfer.” SPEN IFI Annual Report 2007-08.

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\(^9\) PD, or partial discharge detection.
Once the innovation project concluded the technology was adopted by SP Energy Networks showing that it could start delivering value straight away. Following the completion of this project with SPEN, in 2007-08, Elimpus was able to attract three other partners, Western Power Distribution (WPD), Scottish and Southern Electricity Networks (SSE) and UK Power Networks (UKPN) to participate in a second collaborative innovation project which aimed to develop a radiometric partial discharge locator for use on the helicopters routinely used by distribution network operators (DNOs) to inspect the electricity network. Although this project introduced new actors into the ecosystem it did not require major development work in component technologies to deliver value, only the adjustment of the technology to the helicopter frame and redesigning the PD locator technology’s antenna.

Both Elimpus and Kehui (UK) are new firms with scarce resources developing novel technologies for which little innovation in ecosystem complements is required. They both engage in collaboration early in the innovation process, during the technology development phase, and partner with a number of different DNO partners. Other small technology firms in this study, such as HVPD and Cresatech, have followed a similar strategy. Both firms partner early in the innovation process and with a different number of DNOs. HVPD participates in three innovation projects with three different electricity distribution network companies and Cresatech participates in two innovation projects with three different electricity network operators. Like other firms in this group, HVPD and Cresatech have limited assets when they start engaging in the collaborative innovation projects (£94k and £33k respectively) and both develop intelligent asset monitoring technologies that identify a specific event in the network and then communicate it via a modem, so they only require a GSM/GPRS communication network and data host to deliver value, both commercially available technologies.

This collaboration strategy allows resource-scarce firms to access diverse resources from different partners early in the innovation process which can reduce the innovation risks in two ways: first the new technology is exposed to a broader set of demands which align with the interests of the different partners which may benefit its later diffusion, and second, collaboration with different partners
increases the chances that one of the partners will continue supporting the development of the new technology throughout the innovation process until it is ready for commercialisation.

The case of Applied Superconductor (ASL) illustrates these benefits. ASL was a new technology firm established in 2004 to develop fault current limiters from superconducting materials, a superior technology to manage current faults in the electricity networks. ASL engages in collaboration early in the innovation process and participates in four collaborative innovation projects with six different DNOs. In 2005-2006 the firm established a collaborative R&D project with three distribution network companies, Scottish Power Electricity Networks (SPEN), Electricity Northwest (ENW) and Northern Power Grid (NPG) to design, develop and trial three superconducting fault current limiting devices. At the beginning of the projects ASL had total assets of £6k. Partnering with three different network companies facilitated raising the £3 million needed for the development of the devices as well as trialling them in electricity networks with different physical conditions and facing distinct challenges making the devices more resilient. The collaborative R&D project was successful, and a prototype fault current limiting device was developed and trialled; however, following the initial R&D project the technology still needed to be demonstrated in an operational environment before it could be adopted. Both SPEN and ENW decided to stop supporting the development of the new technology at this stage; however, the third DNO partner, NPG took the new technology into demonstration phase establishing a £2.8 million demonstration project in collaboration with Applied Superconductor to take the technology to the next stage of development.

Nonetheless, despite the support of NPG, during the demonstration project the new device did not meet the technical requirements, so the technology was not developed into a full commercial product and the company went into administration in 2014 as it could not continue to financially support the development of its new technology. However, as the extract from the project closedown report shows, following the collaborative R&D and demonstration projects, although that specific solution was not adopted, all the other interdependent technologies were available so that fault current limiters could be adopted and deliver benefits to distribution network companies (DNOs) straight away:
“Together with the experience that we have gained through the implementation of the 11kV SFCL device we now have sufficient confidence to recommend 11kV fault current limiters in general for use as a business-as-usual option for those areas on the network where fault level capacity is constrained and a good economic case can be made against alternative mitigation. The learning gained is being used to create the appropriate standards and design policies” 33kV Superconducting Fault Current Limiter Project Closedown Report, January 2015.

The new technology firms in this group have limited resources to fully develop their innovations into a commercial product and are developing technologies that don’t require innovation in interdependent technologies at the ecosystem level to deliver value. As a result of collaborating early in the innovation process with a variety of partners, all the firms in this group except for the two that go into administration and are dissolved (Surenet and ASL), are able to develop a novel technology which is immediately adopted by the industry after the collaboration projects.

The firms in this group benefit from this collaboration strategy because it gives them access to diverse resources from different partners at an early stage of technology development. This strategy allows new firms to be among the first to access an emerging market with a technology aligned with the needs of the industry, therefore increasing the possibility of developing a successful innovation. By collaborating with a variety of partners, new firms can potentially reduce the commercialisation risks as their product will have been exposed to diverse partners within the industry and is therefore likely to meet a broader set of demands which may facilitate its diffusion. Moreover, this strategy increases the possibility of one of the partners taking their innovation forward into the next stage of development, therefore reducing part of the innovation risk.

Firms in this group were able to attract a variety of partners because it is easier for potential partners to understand the value of an innovation if all the complement technologies are available and that innovation can start to deliver benefits relatively soon. Furthermore, although potential partners need to assess the innovation risk before deciding to allocate R&D resources to a particular project, they will not be exposed to additional risks associated with the requirement for significant innovation at the ecosystem level for the focal innovation to create value.
The analysis of the cases leads to the following proposition:

**P1. New technology firms with scarce resources and low dependence on ecosystem innovation are likely to pursue an early-stage, broad collaboration strategy, which facilitates access to diverse resources.**

4.2. **Strategy 2. Selective strategy**

The second group of firms that follow a distinct collaboration strategy are also resource constrained; however, as opposed to collaborating with a variety of partners to reduce some of the innovation risk and access diverse resources, these firms tend to have one or two main partners with whom they engage with in most the collaborative innovation projects they participate in. The small technology firms that follow this strategy engage with the same partner in over 50% of their innovation projects.

One of the new firms in this group is Embedded Monitoring Systems (EMS) which engaged in collaboration with Scottish Power Energy Networks (SPEN) early in the innovation process\(^\text{10}\) to develop a novel substation monitoring solution, Sub.net. Substation monitoring is a smart grid technology that provides real-time visibility of the electricity grid and facilitates an improved performance of the overall system. In 2007, at the time of its first collaboration, EMS had low resources, total assets of £5k, and, and as of May 2017 Sub.net was still the company’s main technology\(^\text{11}\), which implies that in 2007 EMS most likely had no other major sources of revenue besides those from the collaboration projects.

EMS collaborates with only two distribution network operators (DNOS), Scottish Power Energy Networks (SPEN) and Western Power Distribution (WPD) in nine innovation projects. EMS’ core technology is developed in the first collaboration project with SPEN. The other eight collaboration

\(^{10}\) At the start of the collaboration project the TLR of the substation monitoring solution was at an early stage 5 which means that the technology components had been tested in a lab (see appendix 2 for TLR definitions).

projects are aimed at understanding in which contexts the new technology delivers value and what
other new or existing technologies need to interact with the focal technology to create value, which
sometimes leads to the establishment of further collaborations to develop those new interdependent
technologies. For example, during the first collaboration project between EMS and SPEN, the
partners realised that using mapping software in combination with the data from EMS’ monitoring
technology, an algorithm could be developed that allowed to identify the location of a fault in the
network. Following this finding, SPEN invested in developing that algorithm in-house and
established a follow-up collaborative innovation project with an IT company to develop a software to
feed the data from EMS’s substation monitoring technology into a mapping software so that, in
combination, EMS’ technology and the mapping software, could create value by identifying the
precise location of network faults in real time. The follow-up collaboration explored the ability of the
new technology to provide a specific function and carried out the required development work in
interdependent technologies to enable that.

Following this development project, in 2012, EMS engaged in a second collaboration with SPEN, the
Ashton Hayes Smart Village, a two-year, medium-scale demonstration project in which EA
Technology, a medium-sized established consulting and technology firm, also participated. During
this collaboration another value of the technology was explored, the ability to help a community,
through innovative technology and the provision of near real-time information, to reduce its carbon
emissions. As can be seen from the Ashton Hayes Smart Village project closedown report below,
SPEN selected EMS, with whom it had collaborated in the development of its technology, among a
number of competing technology providers.

“Upon the creation of the specification SPEN circulated it to several manufacturers known to provide
power quality instruments. The resulting bids/proposals received were then assessed on technical and
commercial grounds and the preferred vendor was awarded the contract. […] The company winning
the tender for monitoring equipment was EMS.” Ashton Hayes Smart Village, Closedown Report.
SPEN also selected EMS to supply its substation monitoring technology for one of its flagship large-scale demonstration projects, Flexible Networks for a Low Carbon Future which started in January 2012 and lasted three years.

EMS also participated in six collaborative innovation projects with Western Power Distribution (WPD) which investigated the use of EMS’ new technology for different applications that were of interest to WPD. As a result of one of those collaborative projects, a large-scale demonstration project, WPD identified that one of the factors delaying the widespread deployment of substation monitoring was the lack of analysis tools able to make sense of the large amounts of data produced by the new technology. This can be seen in the project closedown report below.

“If the installation of long term, large scale LV substation monitoring is required, then further development work will be required to find a software system that can handle large amounts of complex data with less manual intervention. A future “Big Data” project is being developed.” Photovoltaic Impact on Suburban Networks, project closedown report, December 2016.

EMS’ case shows that its technology could not realise its full potential without further external innovation. It also shows that focusing its collaboration projects with two main partners was beneficial to EMS. As well as dedicating resources for the development of EMS’ core technology, both partners established additional innovation projects to develop necessary interdependent technologies, explored the ability of the new monitoring system to deliver value in different contexts, and selected EMS to participate in a large flagship demonstration project, which gave the new firm and its technology greater visibility and provided additional revenues for EMS. As an illustration of the long innovation process faced by EMS, the firm started collaborating with SPEN in the development of a substation monitoring solution in 2007 and its technology was not adopted by SPEN until 201612, almost 10 years later.

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Smarter Grid Solutions (SGS) is another example of a new technology firm that collaborates early in the innovation process and develops a long-term partnership through multiple collaboration projects with Scottish and Southern Electricity Networks (SSE), a UK electricity distribution network operator (DNO). SGS was established in 2008 as a spin-off from the University of Strathclyde to develop and exploit a novel active network management technology. The development of the active network management technology started in 2005 through a collaboration between the University of Strathclyde and SSE, and the technology was commercially deployed in 2016. In 2008, when SGS was established it had low resources, total assets of £265k, and during approximately a decade, the main source of revenues for SGS were its collaborative innovation projects. SGS has been one of the most successful firms in capturing funds though collaboration projects and during the observation period participated in 30 collaborative innovation projects 18 of which (60%) were with the same partner, SSE.

Following this strategy of collaborating early in the innovation process and with mainly one partner, was beneficial to SGS because it contributed to sustaining the firm financially, especially during the early stages, and it allowed the firm to develop and improve its novel technology. Once the core active network management technology was developed, subsequent projects with SSE explored its application to a number of challenges faced by SSE and developed interdependent technologies, such as communication platforms and IT hubs, necessary for customers to benefit from the new technology.

However, one drawback of this strategy, is that the development of the new technology is dependent on the technical needs and challenges confronted by a narrow set of partners. The development of SGS’ active network management technology in partnership with SSE focused mainly on solving one of SSE’s major technical challenges which was to increase the amount of renewable generation it could connect to its network in a particular physical environment, the Orkney Isles, where most of the demonstration projects with SSE take place. The novel technology was developed to address this particular challenge and other potential applications of the new technology that were aligned with SSE’s interests. For example, SSE set up a collaboration project with SGS to understand whether the
novel active network management technology could be used to reduce distribution network losses, which would give the technology an additional functionality; nonetheless, the project was stopped early on as this particular application was not a priority for SSE.

The figure below shows the complement technology needed for the active network management platform developed by SGS to deliver benefits. The collaboration projects identified that innovation was required in the complement technologies in red boxes.

![Diagram of active network management platform](image)

**Figure 9: Smarter Grid Solutions downstream technological interdependencies**

Another firm in this group is FMC Tech, a small technology firm established in 2001 to develop novel conductor temperature sensors. FMC Tech engages in collaboration early in the innovation process and participates in 4 collaboration projects all with Scottish Power Energy Networks (SPEN) before being acquired by GE Energy in 2011. In 2005, at the time when FMC Tech engages in the innovation projects for the development of smart grids in the UK, the firm had low resources, with assets of just over £100k, and no commercial products.

In 2005 FMC Tech and SPEN started collaborating on the development of a line temperature monitor that provided data on the thermal conditions of electricity lines in real time, also known as real time thermal ratings (RTTR). RTTR of electricity lines can facilitate the connection of wind generation because when the wind is blowing, normally the temperature of the electricity lines decreases allowing for greater amounts of electricity to go through the cable without reaching its thermal limits. Once the RTTR system was developed using FMC Tech’s technology it was validated in a medium
scale demonstration project that took place between July 2010 and June 2013. However, as can be seen from the extract from the Real Time Thermal Ratings project closedown report below, SPEN considered that the RTTR technology could only create value used in conjunction with an active network management scheme. Active network management is also smart grid technology being developed through the LCNF innovation projects.

“The development of an operationally compliant and business adopted ANM scheme is a **prerequisite** for the role out of RTTR based connection offers to wind farms. As such the acceptance and roll out of RTTRs will be tied to the success of SP Energy Networks’ adoption of ANM schemes currently on trial / in development.” Real Time Thermal Ratings, project closedown report, October 2013.

As a result, SPEN decided to set up a follow-on innovation project to continue developing the ANM system.

“SP Energy Networks are planning a follow-on project, focused on ANM in readiness for the accommodation of prospective generation connection applications.” Real Time Thermal Ratings, project closedown report, October 2013.

The new technology developed by FMC Tech in collaboration with SPEN was not deployed following the technology development and demonstration projects because additional technology innovation was required for the line temperature monitor to deliver benefits.

The figure below shows the downstream technology complements in the real time thermal ratings ecosystem and which technology areas (in red boxes), identified through the collaborations, require innovation.
The second group of firms that follow a distinct collaboration strategy are also resource-scarce at the time when they engage in collaboration with the smart grid projects in the UK, their assets ranged from £6k to £261k. In addition, these firms had not yet fully developed a product so they had no revenues from commercial sales. Furthermore, as the examples above illustrate, the smart grid technologies developed by the new firms in this group required innovation in complements to deliver value which involved additional development and integration work. As the table below shows, the development of the technologies of the three firms in this group, Embedded Monitoring Systems (EMS), Smarter Grid Solutions (SGS) and FMC Tech all require a technology demonstration phase following the R&D project before they are taken up or deployed by distribution network companies. In the case of FMC Tech, the firm was acquired by General Electric (GE) in 2011 and the technology does go into demonstration but at that point it is controlled by GE. The technologies of the other two firms from this group don’t go into the demonstration phase because the innovation process is still ongoing at the end of the observation period.

On the other hand, as an illustration of the lower innovation challenges faced by the technology firms that follow the first collaboration strategy described earlier, Kehui, 4Energy, Cresatech, HVPD and Elimpus develops new technologies through the innovation projects that are adopted by the electricity
distribution network operators (DNOs) after the R&D and small trial phase without the need for larger
demonstration projects.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Total proj.</th>
<th>% R&amp;D</th>
<th>% demo medium</th>
<th>% demo large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy 1</td>
<td>Kehui UK</td>
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Table 10: Distribution of innovation projects in R&D and small trials (IFI) and demonstration (LCNF)

Firms in this group are resource-scarce and may face innovation processes that are relatively more
complex, uncertain and potentially costlier because of the lack of complement technologies at the
ecosystem level that enable their innovation to deliver value. Given that collaboration with external
partners requires time and resources and it is unlikely that small young firms have the resources to
sustain a large number of collaborations; new technology firms in this group may favour finding one
or two partners with whom to develop long-term relationships as opposed to spreading their
innovation efforts among a larger number of partners. It therefore makes sense for firms in this group
to follow a collaboration strategy that allows them to access resources early to develop their
innovations into commercial products before potential competitors, and invest in developing one or
two long-term partners that can support them in future collaborations aimed at developing the broader
system of interdependent technologies that enable their innovation to fully realise its potential
benefits.
As the cases show, often through the collaboration projects the need for innovation in specific technology areas for a focal innovation to create value is identified which can lead to the establishment of another collaboration project to develop the required new technology. Furthermore, the cases also show that these partnerships can facilitate the access of new firms to other collaboration projects led by their established partner, pre-empting competition with other technology providers. Finally, a long-term collaborative relationship can make the established partner more receptive to the innovation proposals of the new firm, building innovation projects around their ideas.

Nonetheless, firms in this group trade-off long-term support for diversity. Repeated innovation projects with one partner may limit the diversity of resources and knowledge a new technology firm can access. The new technologies are developed to address a narrower set of demands as collaboration partners aim to address specific technical challenges and strategic objectives though their collaborative innovation projects.

The analysis of the cases leads to the following proposition:

**P2. New technology firms with scarce resources and high dependences on ecosystem innovation are likely to pursue an early-stage, focused collaboration strategy, which facilitates the development of a small number of long-term partnerships that support them through longer and more challenging innovation processes.**

### 4.3. Strategy 3. Market access strategy

Some of the new technology firms that participate in the collaborative innovation projects for the development of smart grids in the UK engage in the collaboration projects later in the innovation process, once their core technology has been developed and is ready to go into the trial or demonstration phase. Within the firms that collaborate later in the innovation process, one new small technology firm, PowerSense, follows a focused collaboration approach, that is, it participates in four collaboration projects with the same partner.
PowerSense has a higher resource availability than the firms that collaborate earlier in the innovation process. PowerSense was established in 2006 and engages in its first collaboration project in 2008; however, the first available financial data is as of 2011 when PowerSense had total assets of almost £5 million\textsuperscript{13}. Furthermore, PowerSense had financially strong investors as it was owned by DONG Energy, one of Northern Europe's leading energy groups, and NES partners, a Danish private equity firm. In 2008, when PowerSense started participating in the collaboration projects for the development of smart grids in the UK, it had already developed a unique monitoring technology based on optical current sensors and through the collaboration projects the new technology was validated.

Between 2008 and 2015 PowerSense participated in four collaborative innovation projects in the UK, all with the same distribution network operator, UK Power Networks (UKPN). The first collaboration project, the Intelligent Distribution Network Monitoring study, which was carried out between 2008 and 2009, evaluated the benefits to network planning and operation of deploying PowerSense’s unique sensing technology alongside existing monitoring and control devices. As part of the project, PowerSense’s optical sensors were installed in two secondary stations to provide data on the distribution network. As a result, UKPN had a better understanding of the benefits of increased monitoring in the electricity networks.

Following this project, in 2011, PowerSense participated in a second collaboration project with UKPN as the main partner and which also included; Capula, a software firm; GE Energy, which provided an existing network visualisation tool; Remsdaq, a provider of the existing monitoring technology, remote terminal units (RTUs); and PPA Energy, a small specialised energy consulting firm. This collaborative innovation project developed a software tool that used data provided by PowerSense’s technology as well as data from existing monitoring equipment (RTUs) to visually display the

\textsuperscript{13} Source: Amadeus data base, financial information from earlier years not available.
electricity network, and integrated the data from PowerSense’s technology into GE’s existing electricity network visualisation tool, GE Distribution Power Flow (DPf).

Through this collaborative innovation project, a new software tool was developed to visualise the distribution network using data from new and existing monitoring technologies. The data provided by PowerSense’s new monitoring technology gave additional information, in more points of the network and in real time, on the state of the network, therefore enhancing the granularity and scope of the previous monitoring technology. The interdependent technologies that allowed PowerSense’s innovative sensors to create value already existed. The figure below shows the downstream interdependent technologies needed for PowerSense’s sensors to deliver value:

![Figure 11: PowerSense's optical sensors downstream technology interdependencies](image)

This collaboration project was followed by another collaboration project with UKPN, Distribution Network Visibility, a medium-scale demonstration project led by UKPN in which Capula and PPA Energy were also partners. The aim of the project was to demonstrate the benefits of the smart collection, utilisation and visualisation of electricity distribution network data. An extract from the project closedown report shows that network power flows visualisation tools were already commercially available at the time of the innovation project, which took place between September 2010 and November 2013.

“Two commercially available load flow tools (GE DPF and CGI DPlan) were trialled, and recommendations made on what further work is required between DNOs and suppliers of these tools to ensure they deliver maximum benefits.” Distribution Network Visibility, project closedown report.
This project established the benefits of enhanced network monitoring and validated PowerSense’s novel advanced monitoring technology as can be seen from the project closedown report:

“It was established that the optical sensors were a suitable solution to monitor sites with no RTUs, although there are limitations in their application with HV steel wire armoured cables.” Distribution Network Visibility, project closedown report.

This project demonstrated the value of enhanced network monitoring and following this demonstration project, the network visualisation tool developed was adopted by UKPN.

“The visualisation and analysis application developed as part of the project and described in this report is in the process of being adopted by UK Power Networks as a “business as usual” application supported by Capula through UK Power Networks’ IT department.” Distribution Network Visibility, project closedown report.

Finally, PowerSense also participated in UKPN’s large flagship demonstration project Flexible Plug and Play, from January 2012 to December 2014, providing its novel optical current sensors.

At the start of the four collaboration projects with UK Power Networks, PowerSense already had a fully developed technology and no technology development takes place as a result of the collaborations. Through the projects, PowerSense in able to access an existing market with a more advanced technology for which interdependent technologies needed to deliver value already exist. The collaborations take consecutive steps towards validating a novel advanced monitoring technology and integrating it with existing and new network power flows visualisation software. Once the technology has been validated and integrated by one UK distribution network operator (UKPN) into existing network power flows visualisation tools, it is ready to be adopted by others in the industry.

PowerSense had higher resource munificence than the new firms that follow the two previous strategies and a novel technology that could start to deliver benefits straight away without the need for ecosystem innovation. Firms with these characteristics may benefit from following a late-stage focused collaboration strategy as collaboration later in the innovation process carries less risks and, since their new technologies can start to deliver value as soon as they have been demonstrated in an
operational environment by one partner, the new technology firm does not need to invest further resources in carrying out additional collaboration projects with different partners once the technology is ready to be adopted. Furthermore, given that these new technology firms have already developed their novel technology and that no ecosystem innovation is required, the value of accessing diverse resources is limited.

The analysis of the case above leads to the following proposition:

**P3.** New technology firms with high resource munificence and low dependence on ecosystem innovation are likely to pursue a late-stage, focused collaboration strategy, which facilitates access to a new market.

### 4.4. Strategy 4. Market development strategy

The firms in this group also collaborate later in the innovation process; however, as opposed to the firms in the previous group, they distribute their projects among different DNO partners and therefore have a broader approach to collaboration.

One of the firms in this group is Flexitricity, founded in 2004 to develop a technology platform to support aggregated electricity load management and flexible generation. Its business model consists of aggregating and controlling the electricity demand and generation from large industrial and commercial consumers and using that capability to offer a variety of services to National Grid, the UK electricity transmission network operator. Between 2011 and 2015, Flexitricity participated in five large-scale collaboration projects with four different distribution network operators (DNOs). In 2011, at the time when Flexitricity engages in its first collaborative innovation project for the development of smart grids in the UK, the firm already had a fully developed technology platform and sustained revenues from services offered to National Grid. Nonetheless, participating in the demonstration projects allows Flexitricity to explore the value of its new technology in a related emerging market.

As stated in the closedown report of one of the first collaboration projects in which Flexitricity participated, demand response technologies are new in the UK electricity distribution industry, which provides the opportunity to develop a new market:
“While network management and demand response technologies already exist and are well documented, they had not previously been deployed at distribution level in a market with the degree of vertical separation of Great Britain (GB)”.


In January 2011, Flexitricity joined UK Power Networks (UKPN) as one of the partners in Low Carbon London, a £34.5 million large-scale and complex collaboration project measuring and evaluating the impact of a variety of low carbon technologies on London’s electricity distribution network. One of the aims of the project was to understand whether demand aggregators such as Flexitricity could provide valuable demand side response (DSR)\textsuperscript{14} services in the context of smart grids. The project trialled the use of demand response in three different applications and, as can be seen from the project extract report below, concluded that the use of DSR in the context of smart grids required changes in the distribution network operator’s control systems:

“Control systems and processes need to be updated to incorporate the operational use of DSR. For DSR to be embedded in Business as Usual (BaU) by the control room, control room systems will need to be updated so that opportunities to deploy DSR can be identified in real time, and to allow control engineers to send out instructions for the deployment of DSR to respond to real time requirements.”


Through this demonstration project, UKPN identified a number of technological challenges that could be successfully addressed by using DSR technologies and the necessary additional technologies for the benefits of DSR to be realised. As can be seen from the Low Carbon London (LCL) project closedown report below, following the demonstration project, UKPN is confident that DSR can be adopted in the medium term\textsuperscript{15}.

“LCL has identified the value of DSR to operational and planning functions of the business. LCL has contributed significantly to the understanding and application of DSR enough to be rolled out as part of UK Power Networks’ RIIO-ED1 strategy. [...] Implementing DSR will be beneficial in managing

\textsuperscript{14} Demand side response relates to any programme that motivates customers to alter their electricity consumption.

\textsuperscript{15} UKPN states that DSR will be rolled out during the RIIO-ED1 period which is the eight-year regulatory period from 1 April 2015 to 31 March 2023.
planned and unplanned faults as well as enabling the deferral of network reinforcement investments.” Low Carbon London, Closedown Report.

Furthermore, the demonstration project also included the trial of DSR used in combination with active network management (ANM), a smart grid technology being developed by a new technology firm, Smarter Grid Solutions, in collaboration with Scottish and Southern Electricity Networks (SSE), through the collaborative innovation projects funded by Ofgem. By combining the two technologies demand response could be automated, therefore enhancing the value of the technology. As can be seen from the LCL project closedown report, UKPN was considering this enhanced version of DSR opening up further applications of the technology:

“The projects trial of automated despatch of distributed generation, via the ANM system both direct to sites and aggregators, has given confidence to UK Power Networks to consider this approach for the I&C DSR which is being implemented.” Low Carbon London, Closedown Report.

Also in 2011, Flexitricity participated in a second large-scale demonstration project led by Northern Power Grid, another UK distribution network operator. This four-year project, Customer Led Network Revolution (CLNR), had the objective of understanding to what extent customers could be flexible in the ways they use and generate electricity, and to reducing the electricity costs and carbon footprint of their customers. One of the technologies trialled as part of this demonstration project was demand side response. The project deployed demand side response (DSR) in combination with a bespoke active network management system developed for the project and demonstrated the value of using DSR together with ANM for specific applications. As can be seen from the extract below from the project closedown report, following the project, Northern Power Grid planned to implement demand side response in the future; however, previous innovation was required beforehand.

“Although we plan to introduce I&C DSR into business as usual, further innovation will continue to be needed to develop suitable solutions.” Customer Led Network Revolution, Closedown Report.

Flexitricity participated in two other large-scale demonstration projects with two other different UK distribution network companies, Electricity North West (ENW) and Western Power Distribution.
Through Capacity to Consumers, the project carried out with ENW, the use of DSR and control and automation to manage faults on the network was trialled. As the quotes from the project closedown report show, the need for control solutions limits the use of DSR for distribution networks, and network management systems need to be upgraded with increased automation:

“Electricity North West now recognises that the requirement to develop technical solutions to control the customer’s demand in all possible connection situations is not feasible. Therefore C2C solutions involving additional loads or the purchase of network capacity should be restricted to those customers for which a technical solution to control demand is available. Any customer supplied at LV requires a bespoke solution on their switchgear.” Capacity to Consumers, Closedown Report.

“Implementation of the Solution is dependent on development work currently being undertaken in Electricity North West’s new NMS. This will replicate the functionality provided during the Trial across the entire network.” Capacity to Consumers, Closedown Report.

Finally, the project with WPD, FALCON, explored the ability of demand side response to alleviate network constraints. During this demonstration no automation was used and the demand side response interventions were initiated using email or telephone. Nonetheless, as the extract from the project closedown report shows, more advanced automation and control technologies are necessary to broaden the services that DSR could offer in the context of smart grids:

“For the purposes of a trial the DSR services were dispatched manually by agreed communications method in order to avoid unnecessary cost and complexity. In (S1) this was by means of a phone call from the CTL 30 minutes in advance of the DSR event start time. Due to the change in approach for (S2), and increased notice of the event dispatch it was possible to provide an email giving a schedule of operation that preceded dispatch by 7 to 12 days. This was more than adequate to support the service scope within the trials but should a more complex commercial offerings be developed where a DNO were to require real time visibility then significant technical enhancements would be necessary. If any automation or M2M integration is proposed, additional capability in this discipline will need to be developed or third party relationships established to meet the requisite.” Project FALCON, Closedown Report.

Each of the four distribution network operators (DNOs) that Flexitricity collaborates with explores the use of Flexitricity’s demand response technology for different applications which match the distinct
technological challenges that each partner faces. This allows Flexitricity to have a better understanding of the industry’s needs and to deliver a more robust solution closely aligned with the industry’s demands. At the beginning of the demonstration projects, the market for DSR in the context of smart grids did not exist, and through the projects, the value of DSR for distribution network operators in the UK becomes understood, as well as the interdependent technologies that allow Flexitricity’s technology to deliver value. All the projects agree that new control and automation technologies are required for DSR to deliver value in the context of smart grids. To deliver benefits, Flexitricity’s demand response platforms need to interact with distributed energy resources (DER), which are small energy generators connected to the distribution network and include most of the renewable technologies, the existing control systems of distribution network operators (DNOs), and new technologies that automatically control DER, such as active network management technologies being developed through the collaboration projects. These downstream technology interdependencies are shown in the figure below.

Figure 12: Flexitricity downstream technological interdependencies

Another firm in this group is Current Group a US firm founded in 2000 with the initial aim of delivering data over utility power lines which later expanded its offering to intelligent sensing and analytics. Current engages in the collaboration projects later in the innovation process, in the trial or demonstration phase, and between 2008 and 2014 participates in four collaboration projects with four
different DNOs. Current was a private US company at the time of engaging in the collaboration projects and therefore its financial data is not available; however, it had powerful investors which included leading technology firm Google and leading US investment bank Goldman Sachs. In the UK, Current engages in collaborative innovation projects related to two of its novel technologies, power line carrier communication technology and substation monitoring.

Between 2005 and 2014 Current participated in four innovation projects with four different distribution network operators. Current first started collaborating in the innovation projects in 2008-09 with Central Networks, a UK electricity distribution network company which was merged with Western Power Distribution in March 2011. The aim of this project was to assess Power Line Carrier (PLC) technology on an urban low voltage distribution network. The project was not about developing the new technology but about understanding PLC technology and its suitability to provide the communications layer of the smart grid.

Next, Current participated in a project with Scottish and Southern Electricity Networks that deployed and compared three different substation monitoring technologies. Through participating in this project Current gained important market information about its technology, how it could be adapted to the needs of the market, and how its technology performed compared to that of its competitors. Furthermore, it identified the most appropriate component selection and integration to deliver a full substation monitoring solution. As the extract from the project closedown report states, this demonstration project was therefore an important source of market intelligence in an emerging field:

“This project was an important learning experience for the manufacturers.” SSE, Benefits of Monitoring LV Networks, Closedown Report.

Following this project, substation monitoring technology was not adopted because, “it was recognised that any scaled-up substation monitoring deployment would fundamentally depend on the efficient

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16 Current was acquired by Spanish Group Ormazabal in 2013 for undisclosed terms.
and economic transmission of data from substations to the DNO’s systems.” SSE, Benefits of Monitoring LV Networks, Closedown Report. This project evidenced the need for innovation in the communication technology between the substation monitoring system and the DNO’s control system.

The collaboration projects Current participated in do not involve technology development. The collaboration projects aimed to understand the value of the novel technology in the context of smart grids, identify technology components and complements necessary at the ecosystem level for Current’s novel technology to deliver value, and point to technology areas that require further innovation. By engaging in collaborative innovation projects with different partners, Current could gain a broader understanding of the different applications of its technology in the context of smart grids in the UK and identify other necessary innovations for the successful commercialisation of its new technology.

Both Flexitricity and Current have higher resource munificence that the firms that follow strategies one and two, and are developing technologies that require ecosystem innovation for the full potential benefits to be realised. Before engaging in the collaborative innovation projects for the development of smart grids in the UK, both firms have already developed their core technology; however, it makes sense for them to collaborate later in the innovation process to validate their technologies in a new context. Collaboration in the later stages of the innovation process involves integrating the new technology into the broader technological system and demonstrating its value as part of that broader system. When innovation at the ecosystem level is required for a new technology to deliver benefits, its value proposition is not as straightforward and the later stages of the innovation process can become more complex. This was the case for both Flexitricity and Current, and therefore, it made sense for these new firms to collaborate with a variety of distribution network operators (DNOs) which allowed them to trial the ability of their technology to create value by solving different technological challenges, often in combination with different component technologies. This collaboration strategy facilitates identifying the innovations required at the ecosystem level for a
technology to create value within the smart grid context, therefore increasing the chances of successful commercialisation of an innovation.

The analysis of the cases leads to the following proposition:

**P4. New technology firms with high resource munificence and high dependence on ecosystem innovation are likely to pursue a late-stage, broad collaboration strategy, which increases the possibility of successfully commercialising their innovation.**

My research therefore suggests two main determinants of a new technology firm’s collaboration strategy in its efforts to innovate: its level of resources and the level of dependence on ecosystem innovation for its new technology to deliver value. These two factors taken together give rise to four distinct collaboration strategy that vary in timing and scope.

### 5. Discussion

This study aimed to explore the determinants of the collaboration strategies of new technology firms innovating in ecosystems environments, where a focal innovation needs to be integrated with other technologies to create value. To this aim, I observed the collaboration patterns of new technology firms participating in the collaborative innovation projects for the development of smart grid technologies in the UK. I found that new smart grid technology firms in the UK followed four distinct collaboration strategies which differed in their timing and scope. These four strategies can be explained by jointly considering a new firm’s level of resources and its dependence on ecosystem innovation for its customers to fully benefit from its novel technology.

With regards to the timing of collaboration, this study suggests that the resource munificence of a new technology firm influences its decision to engage in collaboration early or late in the innovation process. Within the new technology firms that participate in the innovation projects for the development of smart grids in the UK, there is a group which is resource-scarce for which the revenues from the projects are an important source of finance for their innovation, and often sustain them until they have a commercial product. For the other group, the revenues from the projects to
finance their innovation activity are not as important since they have higher resource munificence, either because they have strong financial investors or because they have revenues from other activities or markets, such as Flexitricity. This second group of firms engages in collaborative innovation projects to validate their technology in a new context and to access market information. This study shows that the first group of firms tend to collaborate earlier in the innovation process while the second group tend to collaborate later in the innovation process. This finding extends Katila and Mang’s proposition (2003) that the need for financial resources drives firms to collaborate, by suggesting that the need for funds drives firms to collaborate earlier in the innovation process.

Nonetheless, this study shows that the collaboration strategies of the new technology firms engaged in the innovation projects for the development of smart grids, can only be understood by simultaneously considering two driving factors, their resource munificence and their dependence on ecosystem innovation. The need for innovation at the ecosystem level for a focal technology to deliver value introduces new challenges and uncertainties into the innovation process that influence a new technology firm’s collaboration strategy.

Resource-constrained firms developing new technologies that don’t require innovation at the ecosystem level are likely to follow an early-stage, broad collaboration approach. That is, they are likely to engage with partners in the development of their technologies early in the innovation process and are likely to spread their innovation projects across different partners. Although by partnering broadly this strategy can potentially increase the knowledge appropriation risks associated with collaborating early in the innovation process, these risks are offset by the increased possibility of innovation success associated with access to different partners and diverse resources. In the case of firms developing new technologies that require little or no ecosystem innovation, this strategy makes sense because, once the technology is developed, it can be adopted almost straight away and start delivering benefits to its customers. This contrasts with the situation facing resource-scarce firms developing new technologies that require ecosystem innovation that often confront relatively more complex, longer and uncertain innovation processes. These firms may therefore benefit from
investing resources in developing long term partnerships with one or two key collaborators. In the cases studied, this is done through repeated innovation projects with the same partner, which limits the diversity of resources an innovating firm can access but gives the innovating firm the backing of a strong partner that can collaborate in the development of the new firm’s focal technology as well as in the exploration and development of new value ecosystems.

The collaboration strategies of new technology firms with higher levels of resource availability are also influenced by their dependence on ecosystem innovation. Firms with higher levels of resources developing new technologies for which little or no ecosystem innovation is required, might use their resources more efficiently if they collaborate with a small number of partners that validate their technology which will then be ready to be adopted by other customers. On the other hand, new technology firms with higher resource availability developing new technologies that require ecosystem innovation to deliver value are likely to pursue a late-stage, broad collaboration strategy that allows them to access a diversity of partners confronting distinct technological challenges so that they can explore the value of their technology in a variety of applications and in combination with different technologies being developed by different players. This facilitates the development of a market for their innovations.

This study makes two contributions to the literature on cooperative innovation. First, previous research suggests that collaboration strategies which facilitate access to a variety of partners and to diverse sources of knowledge can improve a firm’s innovation performance (Baum et al., 2000; Laursen & Salter, 2006; Leiponen & Helfat, 2010; Phelps, Heidl, & Wadhwa, 2012). This study complements this work by identifying circumstances, both internal and external to the firm, that make partnering broadly beneficial to an innovating firm. In the case of new technology firms, this study suggests that partnering broadly will be more beneficial to resource-scarce firms developing technologies that don’t require ecosystem innovation to deliver value, because it increases the chances of accessing adequate reduces to successfully develop its innovation while reducing some of the innovation risks. Furthermore, these firms face a less challenging and often shorter innovation
process. Likewise, firms with higher level of resources developing new technologies that require innovation in their external technological environment, might benefit from a broader access to a variety of resources, which will allow them to explore different value ecosystems for their innovation aligned with the requirements of the industry.

Second, this study complements the work of Laursen and Salter (2006) that identifies the circumstances under which collaborating intensely with a small number of partners might be most beneficial for innovating firms. In the context of the development of smart grids in the UK, resource-scarce firms, developing new technologies that required innovation at the ecosystem level to create value, engaged intensely with a small number of partners. This study highlights the importance of developing strong partnerships for firms developing new technologies that require ecosystem innovation which can increase the costs, risks and challenges of innovation. Despite reducing the diversity of resources accessed, repeated projects with the same partner facilitates continuity, allows for sustained development of the new technology and contributes to identifying, and often developing, the complements needed for the focal technology to deliver value. Moreover, firms with higher resource availability, developing new technologies for which interdependent technologies are readily available may use their innovation resources more efficiently if they collaborate with a small number of partners that validate their technology which will then be ready to be taken up by other customers.

Finally, this study also contributes to the literature on ecosystems by showing how innovating firms can contribute to solving ecosystem emergence challenges through their collaborative innovation activity (Adner & Kapoor, 2016). Collaborative innovation projects in the later stages of the innovation process often focus on understanding the value proposition of a new technology, how a technology delivers value, which other components or complements are needed and how the different components or complements link together to deliver value, all of which are typically not fully understood during the emergence stage of a new industry (Moeen, 2016). Therefore, through these collaborations, different ecosystems for a focal innovation are being explored and developed. This study shows that the collaborations innovating firms engage in to develop their novel technologies,
particularly collaborations in the later stages of the innovation process, can identify other innovation needs in the external environment and encourage the allocation of R&D resources to developing other elements of the ecosystem.

6. Limitations
This study has two major limitations which are related to the data. First, the data only allows me to account for technological interdependencies, but I do not consider other interdependencies, for example institutional interdependencies, that could potentially also influence a new technology firm’s collaboration strategy. Second, given my interest in understanding patterns of collaboration of new technology firms, my sample is formed by new technology firms that participated in two or more innovation projects. However, many of the new technology firms that participate in the collaborative innovation projects for the development of smart grids in the UK, only participate in one project, which reduces the number of firms that could be observed to identify patterns of collaboration and does not explain the collaboration strategy of a significant group of firms. Third, of those new technology firms that participate in more than one project and were therefore included in this study, most participate in a low number of projects, which makes it challenging to identify different collaboration strategies. Furthermore, there is only one firm that follows one of the strategies, making it necessary to delve deeper into the causes of this.

The dataset from which the new technology firms were identified and their collaboration activity was observed includes all the collaborative innovation projects funded by Ofgem, the UK regulator for the electricity networks, through the Innovation Funding Incentive (IFI) and the Low Carbon Networks Fund (LCNF) mechanisms. The IFI mechanism started in 2005 and ended in 2015; however, the data only includes projects that started in 2014. The LCNF projects started in 2010 and ended in 2015 and the dataset includes all projects that started between 2010 and 2014. Both the IFI and the LCNF were replaced in 2015 by two new funding mechanisms, the Networks Innovation Allowance and the Network Innovation Competition, that continue to date. Therefore, it is possible to expand the
database to include innovation projects that started after 2014 which would provide additional observations to strengthen the cases and the propositions made by this study.

7. Conclusion

Given the importance of collaboration for the innovation success of new technology firms, this study seeks to better understand the determinants of their cooperative innovation behaviour and the strategic trade-offs that new technology firms confront when choosing a collaboration strategy over another. Furthermore, it does so by taking into account the broader innovation needs in a firm’s external technological environment that impact the ability of the focal firm to create value for its customers.

Small technology firms have limited R&D resources and it is therefore crucial that they develop a collaboration strategy that optimises their use. Given the resources and attention that collaboration requires and that small firms have a restricted capacity to pursue innovation projects, new technology firms need to decide whether to distribute their innovation projects among several partners or to develop a strong relationship with one or two key partners through repeated innovation projects. The decision on the scope of the collaboration strategy will require balancing the need to establish a strong partnership with a key trusted collaborator, with accessing diverse resources from a variety of partners. This study suggests that this decision will partly be driven by a firm’s dependence on ecosystem innovation and its resource munificence.
### Appendix 1: New technology firms included in this study

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<td>2001</td>
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<td>Communications</td>
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<td>Voltage management</td>
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<td>UK</td>
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<td>Communications</td>
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<td>Surenet</td>
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<td>UK</td>
<td>Automation</td>
<td>3</td>
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Financial data from Amadeus and Fame databases
Appendix 2: Definition of Technology Readiness Levels

Table C1: Technology Readiness Level / Probability of Success Definition

<table>
<thead>
<tr>
<th>TRL</th>
<th>Definition</th>
<th>Networks Interpretation</th>
<th>Company Resource (time / €)</th>
<th>Likelihood of Success (adoption)</th>
</tr>
</thead>
</table>
| 1   | Basic principles observed and reported. | Blue skies research | □□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□<<<<<<<<<<<<<
References


Moenen, M. (2016). Entry into nascent industries: disentangling a firm's capability portfolio at the time of investment versus market entry. Browser Download This Paper.


Thesis conclusion

My research aims to deepen our understanding of the dynamics that take place during the early stages of industry emergence before a dominant design is selected. While previous research has identified complex technological, social and institutional processes co-evolving during this period, I found that we did not have a full understanding of the mechanisms that connect the different co-evolutionary processes and that, although the literature on the management of technological innovation had extensively considered firm strategic action in the period surrounding the selection of a dominant design, there were not many studies that addressed how innovating firms strategically attempt to influence the technological direction of a new industry during its initial stage and, more broadly, how innovating firms navigate this complex and risky period.

The review of the literature on the emergence of new industries suggests that innovating firms engage in two main activities, the development of their proprietary technologies and the development of the institutional structures needed to support their innovation (Van de Ven & Garud, 1993). Furthermore, the literature emphasises that both activities are often pursued in collaboration with other actors, thus highlighting the role of collaboration as a central strategy for innovating firms in emerging industries. Finally, previous research on the emergence of new industries demonstrates the path-dependent nature of both technology and institutional developments, suggesting the importance of understanding what happens early on as it influences later developments of significant material interest, such as technological standards. Therefore, firms must make strategic decisions regarding what type of technical and institutional activities to engage with as the industry evolves (Van de Ven & Garud, 1993).

My two empirical chapters then proceeded to explore, (i) the role of collective actors in industry emergence, paying specific attention to how that role changes over time as the industry evolves, and how innovating firms engage with their activity, and (ii) the collaboration strategies of innovating firms in their efforts to develop their new technologies.
I selected the emerging smart grids industry in the UK as my research site because it allowed me to observe the emergence of a new industry from its inception, when the term smart grid was still elusive. The development of smart grids requires both technological and institutional change and during the observation period (2005-2014) the field was still in an early stage of development with technological standards, business models and consumer services in flux (Erlinghagen & Markard, 2012; Kunneke, 2008). Furthermore, given the technological complexity of smart grids, socio-political forces will be important in their development (Tushman & Rosenkopf, 1992), thus providing a unique case to explore how innovating firms engage with the technological, social and institutional processes that facilitate the emergence of a new industry (Eisenhardt, 1989; Yin, 1994).

My research suggests that innovating firms benefit from engaging with collective actors and dedicate time and resources to contributing to their work. I find that the role of collective actors changes over the industry life cycle, as do the opportunities of innovating firms to shape the institutional environment via collective action. During the initial stages, firms may attempt to influence the development of a collective technological frame that guides subsequent technological innovation by engaging with collective actors to educate the industry on their technology and to promote their view of the new industry. During the co-evolutionary stage, once there is a collective understanding of the meaning of the new industry, innovating firms focus on the development of a market for their new technology, and may engage with collective actors to ensure that the evidence from demonstration projects that proves the value of their innovation is taken into account in their policy recommendations and serves to remove barriers to the adoption of their novel technologies.

My first empirical study also suggests that small innovating firms that do not have the market power to use traditional non-market strategies, such as lobbying, to influence the development of the institutional context, were able to leverage their technological expertise gained through collaborative innovation activity to participate in the development of the institutional context. In industries characterised by a complex technological base, other industry participants, including powerful institutional actors, may welcome the advice of technology experts, and innovating firms can often
achieve this status through their participation in technology development and demonstration projects. This evidenced the importance for small innovating firms of engaging in early R&D collaborations that increased their presence in the innovation network over time and gave them visibility and legitimacy to participate in the development of the institutional context.

This important finding led to the second empirical study, which focuses on the collaboration strategies of new technology firms in their efforts to innovate. In this study, I adopt an ecosystem perspective which allows me to account for the complexities introduced into the innovation process by technological interdependencies in a firm’s external environment. Very rarely can an innovation create value in isolation and often a focal innovation requires other technologies to create value. These interdependent technologies may be readily available or may need to be developed. I find that new technology firms developing smart grid technologies adopt four distinct strategies that vary in their timing and scope.

I find that firms with low resource munificence are more likely to engage in collaboration early in the innovation process, which is in line with previous research that demonstrates that access to financial resources is a main concern of small innovating firms that collaborate in R&D (Bayona, García-Marco, & Huerta, 2001; Lee, Park, Yoon, & Park, 2010). However, although Katila and Mang’s work on the timing of collaboration demonstrates that the need for funds drives new technology firms to collaborate, their empirical results do not support that low resource munificence determines the timing of collaboration (Katila & Mang, 2003).

Building on previous research that suggests that firms must pay attention so that their R&D resources do not become too dispersed (Laursen & Salter, 2006) and recognising that small firms have a restricted capacity to pursue innovation projects, new technology firms need to decide whether to distribute their innovation projects among several partners or to develop a strong relationship with one or two key partners through repeated innovation projects. The decision on the scope of a firm’s collaboration strategy will require balancing the need to establish a strong partnership with a key trusted collaborator with accessing diverse resources from a variety of partners. I propose that this
decision will partly be driven by a firm’s dependence on ecosystem innovation and its resource munificence.

Finally, I find that innovating firms that depend on ecosystem innovation for their focal innovation to deliver value, use their collaboration activity to identify other ecosystem elements and, in some cases, to develop interdependent technologies in collaboration with external partners. The analysis of the collaboration activity of smart grid technology firms shows that often, through the collaboration projects, the need for innovation in specific technology areas for a focal innovation to create value is identified, which could lead to the establishment of another collaboration project to develop the required new technology. Also, if the innovating firm had developed a long-term collaborative relationship with a strong partner, the established partner could become more receptive to the innovation proposals of the new firm, building innovation projects around their ideas. Innovating firms could then use their collaboration activity to drive innovation funds towards developing interdependent technologies without which the adoption of its innovation would be challenged.

One issue that I would have liked to address through my research is whether engaging with collective actors, or participating in institutional activity more broadly, has a direct impact on a firm’s innovation activity; however, my data was not suitable for this analysis. Future research could focus on two aspects related to the relationship between a firm’s institutional and innovation activity. The first is to understand whether participating in institutional activity improves a firm’s chances of obtaining innovation funding. My data does not allow making this connection; however, it does suggest that it is a relationship worth exploring. Second, it would be interesting to analyse whether participating in institutional activity increases the speed to market of a firm’s innovation. This would be of material interest to small innovating firms given their reliance on speed to market as a way to protect the returns on their innovation (Leiponen & Byma, 2009).

Following the brief discussion of the main insights of this dissertation, I now review the specific contributions of this research and draw implications for innovating firms and for policymakers.
1. Contributions to emerging industries research

I extend previous co-evolutionary models of industry emergence by identifying new mechanisms of interaction between institutional and technological processes (Pacheco, York, & Hargrave, 2014; Van de Ven & Garud, 1989, 1993). I identified the strategic action of technology firms that participate in both collaborative innovation projects and institutional activity, often via collective actors, as a mechanism of interaction between the development of the technological base of an industry and its institutional framework. Innovating firms engaged in collaborative demonstration projects leverage the evidence from their projects to remove institutional barriers to the adoption of their new technologies and build on the information gathered by engaging with influential collective actors to strategically align their innovation activity with direction in which the emerging industry is expected to develop.

Second, I contribute to previous studies that examine the role of collective actors in industry emergence (Dowell, Swaminathan, & Wade, 2002; Garud & Karnøe, 2003; York, Hargrave, & Pacheco, 2016) by highlighting the changing role of collective actors as the industry progresses. During the initial stage of industry emergence, collective actors focus on identifying issues and proposing solutions, aligning the interests of different stakeholders, and developing a collective understanding of the new industry. During the co-evolutionary stage, the role of collective actors becomes more focused on coordinating technology development across the value chain and ensuring the development of an institutional structure that drives consumer adoption and market creation. This changing role dictates the opportunities for innovating firms to engage with their work.

2. Contributions to collaborative innovation research

I contribute to the literature on cooperative innovation in two ways. First, previous research suggests that collaboration strategies which facilitate access to a variety of partners and to diverse sources of knowledge can improve a firm’s innovation performance (Baum, Calabrese, & Silverman, 2000; Laursen & Salter, 2006; Leiponen & Helfat, 2010; Phelps, 2010). I complement this work by identifying circumstances, both internal and external to the firm, which makes partnering broadly...
beneficial to an innovating firm. In the case of new technology firms, this study suggests that partnering broadly will be more beneficial to resource-scarce firms developing technologies that don’t require ecosystem innovation to deliver value, because it increases the chances of accessing adequate reduces to successfully develop its innovation while reducing some of the innovation risks.

Furthermore, these firms face a less challenging and often shorter innovation process. Likewise, firms with higher level of resources developing new technologies that require ecosystem innovation might benefit from a broader access to a variety of resources which will allow them to explore different value ecosystems for their innovation aligned with the requirements of the industry.

Second, I extend the work of Laursen and Salter (2006) that identifies the circumstances under which collaborating intensely with a small number of partners might be most beneficial for innovating firms. In the context of the development of smart grids in the UK, resource-scarce firms developing new technologies that required ecosystem innovation to create value, engaged intensely with a small number of partners. I highlight the importance of establishing strong partnerships for firms developing new technologies that require ecosystem innovation, which can increase the costs, risks and challenges of the innovation process. Despite reducing the diversity of resources accessed, repeated projects with the same partner facilitate continuity and allows for sustained development of the new technology. Furthermore, repeated projects with the same partner contribute to identifying, and often developing, the complements needed for the focal technology to deliver value. Moreover, firms with higher resource availability developing new technologies for which interdependent technologies are readily available, may use their innovation resources more efficiently if they collaborate with a small number of partners that validate their technology which will then be ready to be adopted by other customers.

3. Implications for innovating firms

I believe this dissertation offers a number of insights for small innovating firms. First, firms innovating in industries characterised by open complex technologies, such as telecommunications or electricity, need to be aware that long before the institutional activity that results in the selection of
industry standards, collective actors may effectively influence the technology selection process by (i) identifying the technological challenges and needs to be addressed by the new industry, (ii) developing a collective technological frame of the new industry, and (iii) theorising value ecosystems, that is developing an understanding of the combination of new technologies, actors and their relationships that lead to value creation in the emerging industry. This collective activity guides both technology and institutional developments. Innovating firms must therefore make strategic decisions as to whether to engage with the activity of collective actors and at which point in time to do so.

Second, in emerging industries characterised by complex technologies, innovating firms can leverage their technological capabilities to try and influence the development of the institutional context. In this sense, it is important to highlight the central role of technology demonstration projects to give small technology firms visibility. In the case of the development of smart grids in the UK, small technology firms that had been successful in the collaborative innovation projects became considered technology experts which gave them legitimacy to participate in institutional activity.

Finally, where the value of an innovation can only be realised in combination with other technologies, the collaboration strategy of innovating firms needs to take into consideration whether those technologies are readily available or need to be developed. Innovating firms that face the greatest challenges are those with scarce resources, developing technologies that require innovation in interdependent technologies. These firms may benefit from investing in developing collaborations with a small number of key partners as opposed to spreading their innovation efforts among a larger number of partners. Although this collaboration strategy limits the diversity of resources an innovating firms has access to, the cases of small technology firms developing smart grid technologies show that long-term partners can support innovating firms in identifying and often developing the broader system of interdependent technologies that enable their innovation to fully realise its benefits.
4. Implications for policy

My research also offers insights to policy makers. An important implication is that policy makers may need to consider creating channels through which small innovating firms can participate in the development of the institutional context as a new industry emerges. The case of the early stages of development of the smart grid industry in the UK, shows the importance of harnessing the knowledge and experience gained by small technology firms through their innovation activity in developing an institutional context that facilitates the progression of the emerging industry.

Finally, it is important for policy makers to consider supporting the emergence of complete value ecosystems in the design of their innovation support mechanisms. For example, in the case of the development of smart grids in the UK, the funding made available to distribution network companies to carry out technology demonstration projects, that is innovation projects in the later stages of the innovation process, were instrumental for understanding the value proposition of a new technology, how a technology delivers value, what other components are needed and how are the different components link together to deliver value, all of which are typically not fully understood during the emergence stage of a new industry (Moeen, 2016). Demonstration projects, therefore, allowed technology firms to identify other innovation needs in the external environment and encouraged the allocation of R&D resources to developing other elements of the ecosystem.
References


Moeen, M. (2016). Entry into nascent industries: disentangling a firm's capability portfolio at the time of investment versus market entry. Browser Download This Paper.


