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Accelerating the cleantech revolution: Exploring the financial mobilisation functions of institutional innovation intermediaries

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Abstract: This research article explores the role of innovation intermediaries to accelerate the commercialisation of (clean) technologies. Drawing from the finance and innovation intermediaries literatures we show that financial barriers to eco-innovation can be partly overcome by particular functions of innovation intermediaries which in turn mobilises private finance along the innovation process. Therefore, we empirically evaluate roles and instruments of institutional innovation intermediaries (innovation intermediation, policy support, public-private cooperation, financial instruments). We contribute an intersection of the finance and innovation systems literature, by exploring the 'financial mobilisation functions' of innovation intermediaries to address barriers for eco-innovation along the innovation process.

Keywords: Intermediaries, management of technological innovation and R&D, barriers, thin markets, financial instruments, government policy, information asymmetries

JEL codes: G23, G24, O32, O38, Q55, Q58

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1 Introduction

The on-going debate about how to mitigate climate change has encouraged policy-makers to conduct R&D for eco-innovations. The aim of these initiatives is twofold: firstly to reduce carbon emissions and secondly to foster long-term economic 'green' growth (Strand & Toman 2010; OECD 2009). However, complex system failures occur surrounding the commercialisation of eco-innovations[1] due to high uncertainty, missing carbon markets and technological lock-in (e.g. subsidies for fossil fuel-based technologies) (Leitner et al. 2010). Many (small and medium-sized) firms and research institutes invent technologies that are eventually not introduced to the market because of underinvestment in R&D or other (finance-related) barriers such as imperfect capital markets, scalability, asset intensity, missing complementary assets such as infrastructure and an inadequate regulatory environment (Marcus et al. 2013; Kenney & Hargadon 2012; Olmos et al. 2012; Mathews et al. 2010; Haley & Schuler 2011). The incorporation of the "finance perspective" at an early stage in the innovation process (including a cooperation of innovative firms and research institutes with financiers) could leverage public and private funds more effectively, enhance innovative activity and finally accelerate the commercialisation and diffusion process. Consequently especially for climate change-related eco-innovation, there is huge potential in 'connecting' public support with private finance, as information asymmetries between innovators and financiers persist (Mowery et al. 2010).

Key actors in the innovation process include institutional (i.e. government affiliated) intermediaries that play a crucial role in establishing and governing a closer collaboration and in fostering knowledge flows between innovators and financiers to reduce information asymmetries and uncertainty (Kivimaa 2014; Howells 2006; Hoppe & Ozdenoren 2005). In recent years a lot of work has been done on innovation intermediaries (Howells 2006; Katzy et al. 2013; Klerkx et al. 2014; Klerkx & Leeuwis 2009; van Lente et al. 2003; Yusuf 2008) resulting in conceptual and qualitative evidence that institutional intermediaries at the intersection of public and private R&D and commercialisation have beneficial effects (Kivimaa 2014; Klerkx & Leeuwis 2009; Yusuf 2008; van Lente et al. 2003). More specifically previous research has looked at their functions (Hoppe & Ozdenoren 2005; Howells 2006), at user-producer interactions and demand articulation (Boon et al. 2008; Boon et al. 2011), their role in commercialising research (Yusuf 2008), their interaction with the policy environment (Klerkx & Leeuwis 2009) and at their role with regard to transition towards sustainability in a broader frame (Kivimaa 2014; van Lente et al. 2003).

[1] Based on previous literature (Horbach et al. 2012; Foxon & Pearson 2008; Rennings 2000) this article adopts the following definition: Low-carbon innovation can be defined as the 'invention, commercialisation and diffusion of technologies that reduce carbon emissions and/ or other environmentally negative impacts and thus contributes to sustainability'.

By drawing together previously separated literature streams of financing innovation and innovation intermediaries it becomes apparent that these agents could play an important role in addressing (financial) barriers to (low-carbon) innovation along the innovation cycle as they hold a critical position between market actors and government. However there has been no systematic evaluation of (institutional) intermediary roles and functions to address barriers to (low-carbon) innovation (Howells, 2006; Kivimaa, 2014; Yusuf, 2008) and correspondingly mobilise private finance. This is what our paper seeks to address by analysing the following research question: *How do institutional innovation intermediaries address the complex set of barriers surrounding (eco-) innovation especially from R&D to commercialisation?*

While we address this question in the context of eco-innovation, as innovation system problems such as thin markets for finance, information asymmetries, failing markets for technologies are more pronounced there, we also belief it to be of relevance for innovation in general. We present qualitative in-depth evidence, exploring the financial mobilisation functions and the role of institutional intermediaries. The article is structured as follows: Section 2 outlines the theoretical underpinnings and integrates the streams of literature on innovation finance and innovation intermediaries. Section 3 sketches the methodological approach taken to assess the role of intermediaries and to evaluate their financial mobilisation functions. Section 4 presents the results, while section 5 mirrors these results to theory to draw conclusions.

2 Theoretical background

2.1. Financing of R&D and innovation

As regards financing innovation, scholars consider financiers as crucial to support the commercialisation and diffusion of new (clean) technologies (Hekkert & Negro 2009; Hekkert et al. 2007; Perez 2002; Schumpeter 1939), and several researchers have pointed towards an underinvestment in R&D as a market failure for innovative activity in the early stages (Hall & Lerner 2010; Hall 2002; Myers & Majluf 1984): Firstly, the market logic does not permit financiers to evaluate the quality of the research due to its highly uncertain nature (Jaffe et al. 2005; Akerlof 1970; Arrow 1962). Possible gains from R&D cannot be fully appropriated by the firm due to knowledge spillovers, i.e. the social returns are higher than the private return appropriated (Jaffe et al. 2005; Griliches 1992). Secondly, imperfections in capital markets concern the fundraising capability of firms (Hall 2002). While financing innovation and its related market failure are clearly an issue within the framework of innovation systems, the broad question of financing innovative activity has not been treated holistically, though several authors have indicated that the 'financial innovation system' underlying the national and technological innovation systems is a significant driver of innovative activity and should therefore include well-coordinated policies (Dahlstrand & Cetindamar 2000; O'Sullivan 2006; Perez 2013; Wonglimpiyarat 2011). Especially in the light of a transition towards

clean innovation, private finance is highlighted as a critical factor (Leete et al. 2013; Mathews et al. 2010; Perez 2013).

Within the innovation policy mix to enable this transition, different policy instruments are implemented (see Borras & Equist (2013) for an overview), of which economic transfers comprising different forms of finance is one of the categories. Different phases of the innovation process i.e. basic and applied R&D, demonstration and commercialisation, pre-commercial phases, niche-market and supported commercial as well as the fully commercial phase call for different forms of finance, the so-called finance chain of innovation (Auerswald & Branscomb 2003).

In the basic and applied R&D phases, governments address underinvestment in risky R&D due to intangibility and limited appropriability with subsidies and grants (Link & Scott 2010; Dahlstrand & Cetindamar 2000). Moving to the commercialisation phases (Demonstration, pre-commercial, niche-market and supported commercial), as 'investment readiness' is proven by signalling quality of the business proposition linked to the emerging technology, external financiers such as business angels and venture capitalists (VCs) start financing (Mason & Harrison, 2001). Informed financiers (i.e. so-called 'competent' VCs – Dahlstrand & Cetindamar, 2000) try to overcome underlying information asymmetries and other barriers, such as missing managerial talent, marketing capabilities or networks thereby reducing the monitoring and moral hazard problems (Da Rin et al. 2006; Repullo & Suarez 2000; Holmstrom & Tirole 1997). However, VCs have several shortcomings such as the necessity of a well-functioning equity market and a focus upon only certain industries at a time, which makes them unsuitable for investing in infrastructure, larger R&D projects or asset-heavy firms and projects (Hall & Lerner 2010; Oakey 2003; Hall 2002). In addition, private equity, mezzanine and bank finance are often not available due to missing collateral or the overall level of risk related to the technologies and institutional environment (Ughetto 2010; Ughetto 2007). More mature firms often rely on internal funds however as commercial viability is often uncertain, the companies refrain from commercialisation activities. In many cases, this leaves structural holes (e.g. known as 'valley of death') in the commercialisation phase, since private equity, many VCs and credit financiers are often unable to seamlessly invest in companies that reach the end of the public R&D support phase or in complementary assets such as infrastructure required for commercialisation (Auerswald & Branscomb 2003). In consequence this might lead to thin financial markets as difficulties arise in the supply and demand of finance. Simply increasing demand or supply is not sufficient as coordination problems often arise between innovators (e.g. entrepreneurs), financiers and government (Nightingale et al. 2009; Dahlstrand & Cetindamar 2000). Policy makers could therefore systematically strengthen the market demand side by establishing public procurement programs or public private-research partnerships in order strengthen technological capability to support the supply side (Audretsch & Lehmann 2004; Auerswald & Branscomb 2003; Edquist & Zabala-Iturriagagoitia 2012; Hargadon 2010; Link & Scott 2010).

In later stages of the innovation cycle (supported commercial and fully commercial), (clean) technologies face regulatory risks, flawed market pricing mechanisms or policy coordination failures (Weber & Rohracher 2012; Haley & Schuler 2011; Foxon et al. 2005). Hence governments could provide incentives to the financial sector and play a catalytic role in providing risk capital. This could be done by regulating certain industries, setting up institutions to make investments more profitable (Borrás & Edquist 2013; Wonglimpiyarat 2011) or by using direct instruments such as public procurement for innovation (Edler & Georghiou 2007; Edquist & Zabala-Iturriagagoitia 2012; Guerzoni & Raiteri 2014). An overview of instruments used to finance innovation can be derived from table 1.

Table 1: Overview of barriers to innovation and financing instruments

Phase in the innovation cycle	Barriers	Instrument	References
Basic and applied R&D	Intangibility and limited appropriability (Knowledge spillovers)	Subsidies, grants	(Meuleman & De Maeseneire 2012; Kleer 2010)
	Underinvestment in R&D	Tax credits	(Czarnitzki et al. 2011; Hall & Lerner 2010)
Demonstration and pre-commercial phase	Capital intensity Scalability	Mobilise private finance (Business angels, VC)	(Kenney & Hargadon 2012; Hendry et al. 2010)
	Economic/ Technological/ Institutional lock-in	STI policy Regulation	(Foxon & Pearson 2008; Klein Woolthuis et al. 2005; Rennings 2000)
	Infrastructure	Public procurement Public-private-partnerships (PPP)	(Foxon & Pearson 2008; Köhler et al. 2010)
	Market/ demand articulation	Public procurement Effective coordination of demand-side policies	(Edquist & Zabala-Iturriagagoitia 2012; Hargadon 2010; Edler & Georghiou 2007)
Niche-market and supported commercial	Missing VC Flawed pricing mechanisms	Strategic research partnerships (e.g. SBIR, ATP, ARPA-E)	(Audretsch & Lehmann 2004; Link & Scott 2010; Auerswald & Branscomb 2003)
Fully commercial	Regulatory risks Policy coordination and reflexivity failures	Mobilise private finance (Private equity, banks, mezzanine, project finance)	(Weber & Rohracher 2012; Haley & Schuler 2011; Foxon et al. 2005)

2.2. The role of intermediaries in addressing (financial) barriers

One way to address the barriers and structural financial gaps in the innovation cycle (see Table 1) is having intermediaries between different actors (Howells 2006). These actors intermediate knowledge, technologies and finance which is crucial for advancing markets (Stewart & Hyysalo 2008; Boon et al. 2008; Howells 2006; Hoppe & Ozdenoren 2005). Howells (2006, p.720) defines an innovation intermediary as *'an organisation or body that acts an agent or broker in any aspect of the innovation process between two or more parties. Such intermediary activities include: helping to provide information about potential collaborators; brokering a transaction between two or more parties; acting as a mediator, or go-between, bodies or organisations that are already collaborating; and helping find advice, funding and support for the innovation outcomes of such collaborations'*. Throughout this paper we focus on the functions of innovation intermediaries that relate to finance, since the mobilisation of financial resources is considered a key function of innovation systems which often hinders technologies from being developed and deployed (Jacobsson & Karltorp 2013; Jacobsson & Bergek 2011; Bergek et al. 2008). This function is further differentiated along the innovation cycle (see Table 2) as innovation intermediaries may adopt different roles along the phases for market creation (Howells 2006; van Lente et al. 2003).

Table 2: Overview of financing instruments (available to intermediaries)

Category	Instrument	Corresponding phase in the innovation cycle	References
Direct	Subsidies, grants	Basic and applied R&D Demonstration and pre-commercial phase Niche-market and supported commercial	(Kivimaa 2014; Howells 2006)
	Tax credits	Basic and applied R&D	(Howells 2006)
	Public procurement or Production support measures	Demonstration and pre-commercial phase Niche-market and supported commercial	(Kivimaa 2014)
	Mobilise private Finance (Business angels, VC) / Improving positive expectations of future market opportunities	Demonstration and pre-commercial phase Niche-market and supported commercial	Mentioned by several authors (Kivimaa 2014; Yusuf 2008; e.g. Howells 2006) *under-researched*
Indirect	Support for regulation	Niche-market and supported commercial Fully commercial	(Kivimaa 2014; van Lente et al. 2003)
	Support for science, technology and innovation (STI) policy	Niche-market and supported commercial Fully commercial	(Klerkx & Leeuwis 2009; van Lente et al. 2003)

Strategic research partnerships (e.g. SBIR, ATP, ARPA-E)	Basic and applied R&D Demonstration and pre-commercial phase	(Kivimaa 2014; Klerkx & Leeuwis 2009; Yusuf 2008)
Mobilise private Finance (Private equity, banks, mezzanine) / Improving positive expectations of future market opportunities	Niche-market and supported commercial Fully commercial	Mentioned by several authors (Kivimaa 2014; Yusuf 2008; e.g. Howells 2006) *under-researched*

During the basic and applied R&D phases which face high technological and market uncertainty and a general underinvestment in R&D, innovation intermediaries help in finding new sources of capital for researchers, such as R&D programs, research grants and subsidies. Especially in public-private-partnership constellations that deal with the development of complex innovations with a highly uncertain outcome such as pharmaceutical or medical products which have parallels to clean technologies, a more active management approach is needed i.e. enhanced research governance in the form of bringing the necessary resources and stakeholders together and reducing development time and costs (Yaqub & Nightingale 2012). Prior research also points out the selection of the most suitable finance mechanisms for each type of project (e.g. subsidy, revolving fund, loan, etc.) as equally relevant (Eickelpasch & Fritsch 2005). The goals of the research efforts need to be aligned with the selection process of supported firms and corresponding financial support mechanisms (Santamaría et al. 2010). In this regard intermediaries might also be capable of sending signals to certify the quality of research (Yusuf 2008; Howells 2006).

During demonstration and pre-commercial phases where clean technologies exhibit high capital intensity and challenging scalability as well as missing complementary assets such as infrastructure and demand articulation problems, the distribution of R&D grants and demonstration support characterises resource allocation of innovation intermediaries (Samila & Sorenson 2010; Brown & Hendry 2009). Additionally they might coordinate public-procurement programs in order to increase demand. Beyond, innovation intermediaries may also engage into public-private-partnerships (PPP) between private financiers, government agencies and inventors or start-ups as seen in the SBIR and ATP programs [2]. The evaluation of these PPPs revealed mixed evidence with regard to commercialisation success of the participating firms (Link & Scott 2010; Audretsch et al. 2002; Chang et al. 2002; Lerner 1999). Clearly, these PPP programs address the underinvestment in R&D and commercialisation showing firms need financial support to scale up their operations when they have passed the seed and invention stage (Cooper 2003). Put alternatively, government or government-

[2] ARPA-E - Advanced Research Projects Agency – Energy, SBIR - Small Business Innovation Research, ATP - Advanced Technology Program refer to cooperative innovation programs in the US:

affiliated entities such as intermediaries thicken up 'thin' financial markets for early stage innovations (Mazzucato 2013; Link & Scott 2010).

In the niche-market, supported commercial and the fully commercial phases the role of innovation intermediaries is less visible as the technology matures. However regulatory risks and the provision of complementary assets need to be handled to fully deploy technologies (Yusuf 2008; Howells 2006). Thus a relevant function during commercialisation and diffusion is the mitigation of uncertainty and risk between firms or research institutes and potential financiers as the latter are neither able to access the potential markets for the application of the novel technologies nor their surrounding institutional environment (regulation and STI policy). Intermediaries evaluate commercial value and reduce uncertainty by bringing potential innovators and market participants together (i.e. these benefits that lead to a market equilibrium outweigh the costs incurred by the intermediating organisation) (Hoppe & Ozdenoren 2005).

Kivimaa (2014) thereby highlights the role of government-affiliated or institutional intermediaries to address (systemic) failures along the innovation cycle. These would be ideally positioned for this, because they intermediate knowledge and finance between public (research organisations, government) and private actors such as firms in the innovation system, translating policy objectives on the one hand and requests or demands from the private side (Klerkx & Leeuwis 2009). Institutional intermediaries are affiliated with policy bodies (i.e. ministries) whose aim is to advance technologies but also to foster markets and generate subsequent private investments after the R&D support phase (Yusuf 2008). Their relation with policy actors depend on the degree of contractual or financial, hence influencing the degree of independence (Klerkx & Leeuwis 2009; Kivimaa 2014)Because of their affiliation with policy bodies, institutional intermediaries might be subject to limitations regarding neutrality and impartiality as conflicts of interests between the public bodies to which they are affiliated and private entities could arise (Klerkx & Leeuwis 2009).

3 Methods and data

To develop an empirically-based perspective in the context of the above reviewed literature, an exploratory, inductive methodology is applied since there is limited empirical understanding of the phenomenon and a small number of cases available build and refine theory (Eisenhardt 1989; Yin 2009). Our approach consists of a multiple case study design (six cases of project managing organisations fulfilling the intermediary role) that generates in-depth knowledge about a complex phenomenon (Patton 2002). Within this frame, we chose analytic induction since we base our empirical work on an initial theoretical perspective also referred to as 'abduction' (Patton 2002; Mantere 2008). Our iterative process of literature review and empirical data analysis leads to new insights that were not expected previously (Patton 2002).

The initial analytical framework (see sections 2.1 and 2.2) revolved around barriers to low-carbon innovation along the innovation cycle and possible policy responses. During the research process we

investigated the role, functions and instruments of innovation intermediaries to address these barriers by conducting interviews and a workshop with central intermediary actors in the German innovation system and hence sharpened the initial theoretical understanding.

3.1. Research context

Germany is a particularly interesting research setting due to its strong focus on innovation-led growth, public-private cooperation, comprehensive environmental regulation and particular financial system. Germany plays a leading role in conducting systematic transition towards sustainable energy systems using eco-innovations. These conditions necessitate stronger attention and have consequences for our research design that focuses on financial mobilisation functions of innovation intermediaries in the policy context: First the industry structure in Cleantech (i.e. large firms, 'Mittelstand', SMEs) is orientated towards leading-edge technologies and therefore established strong ties towards universities and research institutes taking the form of public-private-partnerships which requires intermediation between public and private entities. Second, the conservative bank-based system focuses on investment banking and project finance, thus lacking an institutionalised finance system (i.e. pension funds and other institutional investors that invest into VC and PE) as in the UK or US. This condition calls for other forms of financial intermediation which in the case of US and UK is often done by VCs. Third the strong mission driven government that sets up proactive public policies to overcome existing lock-ins and path dependency creates a need for intermediation between the innovators affected and policy makers.

3.2. Sample

The role of intermediaries in addressing barriers to low-carbon innovation and their functions to mobilise private finance in the German innovation system necessitates explanation. Policy making is carried out by the federal government and the 16 'Länder' governments. On the other hand R&D activities are conducted by a range of SMEs and larger companies as well as a range of higher education institutions, academies and research organisations (MPG, FhG, HGF, and WGL [3]). Intermediaries between these three parties include the German research foundation, project managing organisations as well as associations and chambers among others. Following the recommended approach to select case studies for analytic induction, we applied theoretical sampling (Eisenhardt 1989; Yin 2009). Rather than designing a statistically representative sample, our goal was to select cases that are valuable to investigate (Siggelkow 2007). Hence we focus on project managing organisations as they occupy a critical intermediary position (see Figure 1). These public or private corporations gain their mandates from ministries in a competitive process. With regard to competencies and headcount they surpass their ministerial counterparts and thus play a critical role in

[3] MPG: Max-Planck Society; FhG: Fraunhofer Society; HGF: Helmholtz Association; WGL: Scientific Community Gottfried Wilhelm Leibniz

bringing public and private actors together. With our sample, we cover six project managing organisations that manage most of Germanys' cooperative R&D projects. They exhibit no clean technology related characteristics. However, to study their role in the specific context of clean technologies, we focus on 20 government-supported clean technology R&D partnerships at different stages in the innovation cycle (Table 2). These projects appertain to the German framework 'Research for Sustainable Development' that aims at fostering clean technology innovation with a technical focus on energy production and efficiency, mobility and materials, amongst others. They also provided deep insights into high-tech government-supported cooperative R&D projects in general. Figure 1 depicts an overview of the research setting.

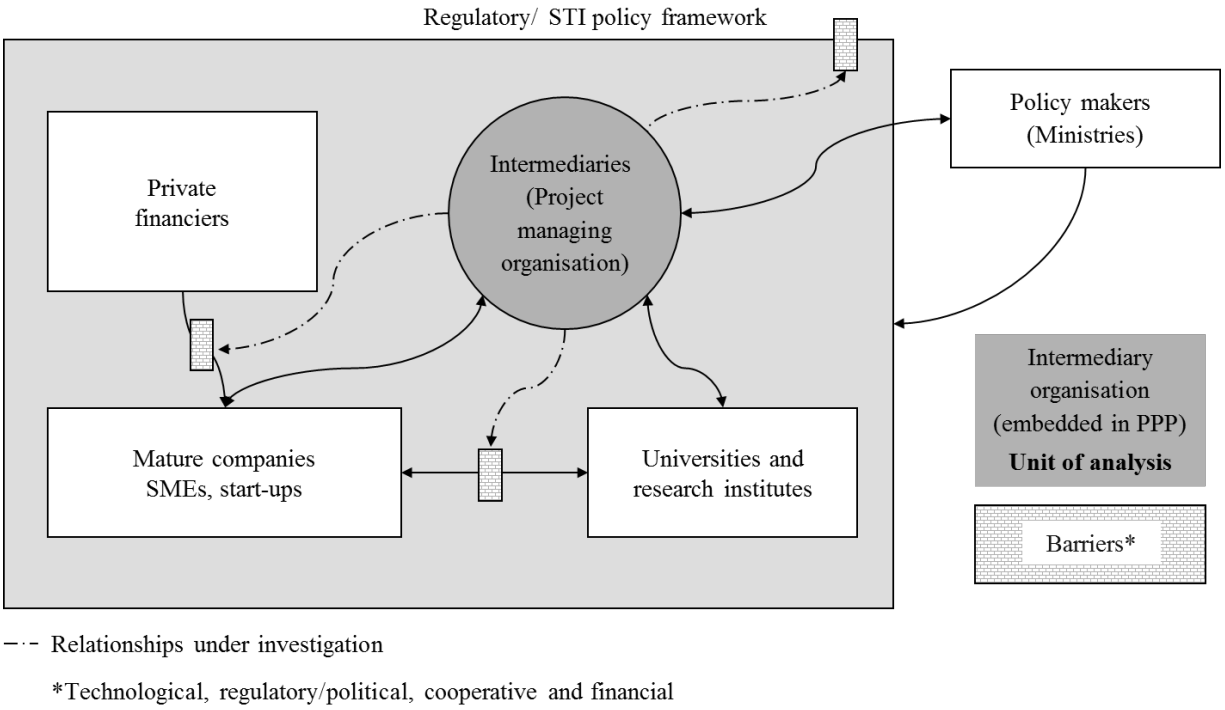

Figure 1: Position of the intermediaries and unit of analysis (research setting)

For our exploratory study, we contacted leading scientists (individuals) from all project-managing organisations executing the above mentioned 20 R&D partnerships. The surveyed project managers possess broad knowledge about ongoing research process and are aware of the regulatory environment. They are also able to establish links between financiers and supported organisations, as they manage relationships consisting of flows of information and finance within R&D projects. Thus these individuals occupy a critical intermediary position between public and private actors (Howells 2006; Klerkx & Leeuwis 2009). Furthermore, as Figure 1 shows, they are not only directly in contact with actors in the innovation system, they are also able to indirectly address barriers to (low-carbon) innovation by capitalising on their position. An overview about the organisations and individual interview participants can be found in Table 3.

Table 3: R&D partnerships and interviewees

R&D Partnership	Project managing organisation(s)	Ministries (Leading)	Interviewees (individuals)
'E-Mobility'	VDI/VDE Innovation + Technik GmbH	BMBF, BMWi, BMVBS	2 Research project managers
Bioeconomy	Forschungszentrum Jülich GmbH (PTJ)	BMELV, BMU, BMBF	Head of research
Biofuels	Forschungszentrum Jülich GmbH (PTJ)	BMBF, BMELV	1 Research project manager
Fuel cells	Forschungszentrum Jülich GmbH (PTJ) NOW GmbH	BMBF, BMWi, BMVBS, BMU	2 Research project managers
Carbon capture and storage	Forschungszentrum Jülich GmbH (PTJ)	BMBF, BMWi	2 Research project managers
Carbon nano tubes	Forschungszentrum Jülich GmbH (PTJ)	BMBF	1 Research project manager
CO_2 sequestration	Forschungszentrum Jülich GmbH (PTJ)	BMWi, BMBF, BMVBS,	1 Research project manager
Chemical usage of CO_2	Deutsches Zentrum für Luft- und Raumfahrt (DLR)	BMBF, BMU	2 Research project managers
'E-Energy'	Deutsches Zentrum für Luft- und Raumfahrt (DLR) Forschungszentrum Jülich GmbH (PTJ)	BMWi, BMU, BMVBS	2 Research project managers
Geoinformation	Deutsches Zentrum für Luft- und Raumfahrt (DLR)	BMBF	2 Research project managers
Geothermal energy	Forschungszentrum Jülich GmbH (PTJ)	BMU, BMBF	1 Research project manager
'Green Carbody Technologies'	Projektträger Forschungszentrum Karlsruhe (PTKA)	BMBF	1 Research project manager
Advanced materials	Forschungszentrum Jülich GmbH (PTJ)	BMBF	1 Research project manager

Table 3 (continued): R&D partnerships and interviewees

R&D Partnership	Project managing organisation(s)	Ministries	Interviewees (individuals)
Light emitting diodes (LED)	VDI Technologiezentrum GmbH Forschungszentrum Jülich GmbH (PTJ)	BMBF, BMWi, BMU	2 Research project managers
Lithium ion battery	Forschungszentrum Jülich GmbH (PTJ)	BMBF, BMWi, BMVBS, BMU	1 Research project manager
Organic light emitting-diodes (OLED)	Forschungszentrum Jülich GmbH (PTJ) VDI Technologiezentrum GmbH	BMBF	2 Research project managers
Organic photovotaics	VDI Technologiezentrum GmbH Forschungszentrum Jülich GmbH (PTJ)	BMBF	2 Research project managers
Photovoltaics	Forschungszentrum Jülich GmbH (PTJ) VDI Technologiezentrum GmbH	BMBF, BMU	2 Research project managers
'Next Generation Solar Energy'	Forschungszentrum Jülich GmbH (PTJ)	BMBF	1 Research project manager
Intelligent mobility	TUV Rheinland	BMWi, BMVBS, BMBF	1 Research project manager

3.3. Data collection

In case study methodology, data collection means reconstructing a phenomenon or a case by means of archival data, interviews or other artefacts and gaining understanding based on an analytical lens at the same time (Flyvbjerg 2006; Yin 2009). We adopted a procedure whereby we embedded our interviews and a workshop to shed light on the role of the intermediaries in extensive desktop research on archival documents from multiple sources to understand the context in which the intermediation takes place. These three elements form our cases. The overall investigation lasted from mid-July to mid-October 2012.

First we reviewed industry reports and reports on climate and innovation policy and we specifically analysed the framework of 'Research for Sustainable Development' for recent and on-going R&D partnerships. These documents (e.g. roadmaps technology documentation, ministerial, participant descriptions) provided basic information about actors, technologies and the innovation process and helped us develop an understanding of how R&D partnerships are structured and what kind of barriers are being faced. For each R&D partnership, a detailed context study with indicative financing needs was developed to reveal potential barriers relating to finance. The material gathered was also grouped under separate topical headings to enable comparison and cross-linkages. The key characteristics of the R&D partnerships have been very heterogeneous. We distinguished these partnerships in a continuum from early stage (commercialisation) to later stage (diffusion) as they typically require different financial instruments and face different barriers (see Table 1). In addition, the volume (2.5

Mio. € - 600 Mio. €) and the ministries responsible for the partnerships as well as the participating actors (SMEs, MNEs, start-ups, universities, research organisations) differed widely.

Second, the descriptions were used in interviews with the experts that took place after a preliminary synthesis and analysis of the written material. The actual interview was important to acquire an in-depth understanding of the peculiarities of specific cases. The number of interviewees per unit varied between 1 and 2 depending on the organisational setup of the R&D partnership, totalling 25 interviews. We conducted the interviews in sequential order to enable the transfer of insights from each case to an improved interview guide for subsequent cases. Each interview took between one and two hours and was conducted face-to-face or via telephone, with one or two researchers present. The interviews were tape recorded with the interviewees' approval and transcribed verbatim. All interviews followed a semi-structured outline, with a set of guiding questions repeated at each interview (see appendix for interview guide). The idea was to follow a 'story-telling' approach, to let the interviewees describe their views on the phenomenon and their role as freely as possible, allowing them to interpret the questions and pursue any themes they regarded as central.

Third, the aggregated results were discussed, validated and extended during a workshop which consisted of 15 study participants and 5 R&D project managers in similar positions. The workshop has equally been recorded and transcribed.

3.4. Data analysis

To analyse the gathered empirical material we followed the abductive circle of inference. Thus, we deepen our understanding of the meaning of the material in circular movement where the details of a certain text are contrasted with emerging, more generalised theoretical thoughts which involves 'a constant movement back and forth between theory and empirical data' (Gadamer 1993; Mantere 2008; Wodak 2004, p.200). Starting with our initial theoretical understanding of the barriers to low-carbon innovation along the innovation cycle we have gone through three empirical steps. Data analysis then follows an iterative, abductive process

First, the extensive desktop research revealed a systemic contextual perspective on the R&D partnerships including the main actors and peculiarities of each field, depending on their stage in the innovation cycle and corresponding technology.

Second, the interview texts were analysed through a hermeneutical research approach (Gadamer 1993). We applied a combination of narrative and content analysis since we covered most of the aspects asking broad questions, leaving as much room as possible for the interviewee to recount the characteristics of the partnerships, their role in addressing potential barriers (Polkinghorne 1988) and embedding their views in the context analysis based on the documents (Boje 2001; Mantere 2008). Two researchers systematically analyse the data for corresponding patterns and independently mark quotes in the interview protocols, which is referred to as actual process of analytic induction (Eisenhardt 1989; Yin 2009).

To infer from the data, we employed axial open coding with emerging categories (Dougherty 2002) which is guided by an overarching (theoretical) understanding (Patton 2002). The coding scheme was developed top-down and bottom-up to remain amenable to the emergence of new categories which could still use the axial coding procedure to identify relationships between the main constructs. Following this procedure the first order constructs emerged. The corresponding coding procedure resulted in 1375 quotes from 322 pages (see Table 4). We used the software MaxQDA 11 for the text analysis to manage the data.

The relational analysis revealed patterns of codes that occurred repeatedly with each other, and the results were structured around second order constructs (dimensions) to reduce complexity. The dimensions represent factors that influence the perception of barriers by intermediaries and their role in addressing these. The dimension comprise political/ regulatory environment, constellation of actors, underlying technology, financing innovation, forms of interaction, intermediaries roles and intermediaries instruments (see Table 4). Based on these dimension we carried out a cross-case-analysis on the individual level. The project managing organisation as the unit of analysis did not turn out to be a critical influencing factor (dimension).

Third, the final categories of our analysis have been validated throughout the workshop held (see Table 4). The workshop participants focused on the definition of the financing problem for (eco-) innovations as well as the contextual dependency of the resulting financing problems which left the question of adequate tangible instruments to address the abstract gap. This workshop setup permitted us to reflect on the role of the intermediaries, to discuss the barriers to low-carbon and to validate the results across industries, which is unique to an intermediary study.

Finally, based on the dimensions above, we wrote micro-narratives integrating document analysis and interview texts, resulting in a holistic perspective on the 20 R&D partnerships which simplified interpretation of the interviewees' opinions against the contextual background made up by the bulk of documentation.

Table 4: Qualitative interview coding scheme and category emergence

Freq.	First-order codes	Second order codes (dimensions)	Final categories
44	Regulatory /political barriers	*Political/ regulatory environment*	***Sources for barriers to (low-carbon) innovation on the public and private side*** (Foxon & Pearson 2008; Klein Woolthuis et al. 2005)
40	Policy instruments		
49	Policy environment (STI and regulation)		
47	Interfaces (between major actors and phases in the innovation cycle)		
113	Characteristics of the R&D partnership (i.e. Strategy, roadmaps, goals)	*Constellation of actors*	
37	Technological barriers	*Underlying technology*	

32	Commercialisation (of the respective technology)		
25	Properties of the technology		
77	Subsidies (given to research institutes and firms)	*Financing innovation*	
50	Financial barriers		
32	Entrepreneurship (activities of universities and research institutes)		
25	Own involvement (how intermediaries execute related finance tasks)		
50	Public-private cooperation	*Forms of interaction*	
19	Private-private cooperation		
32	Intermediaries competencies and mandates (general)	*Intermediaries roles*	***Role of intermediaries in addressing barriers*** (Howells 2006; Kivimaa 2014; Klerkx & Leeuwis 2009)
11	Administration		
38	Manager		
32	Consultant		
29	Bridge builder		
41	Limitations		
13	Demonstration	*Intermediaries instruments*	
21	Socio-economic tools		
22	Advisory opinion		
29	Other tools		

To ensure the robustness of our analysis a number of measures have been taken (Creswell & Miller 2000; Moran-Ellis et al. 2006; Patton 2002): First, to ensure construct validity (establishing correct measures) several data sources have been used (archival documents, notes, interview transcripts and workshop transcripts) (Patton 2002). After analysing all the cases, we asked the project managers to review the key results from their individual technology fields at the workshop held to detect and avoid potential misunderstandings ('member checking') (Creswell & Miller 2000). Second, to ensure internal validity (avoiding alternative explanations) we compiled a representative sample (including all major project managing organisations in Germany) which includes typical cases across of a large set of technologies covered by the R&D partnerships This approach allows us to add to existing theory (Moran-Ellis et al. 2006). Third reliability was ensured by conducting the research with two scholars, by developing and refining the semi-structured interview guide for both interviews and workshop, by recording and transcribing the evidence, by developing a case database and by finally writing micro-narratives.

4 Results

Based on the hermeneutical and relational analysis and the emergent categories we identified financial barriers to (eco-) innovation that are linked to other forms of barriers which are typically addressed by innovation intermediaries such as regulatory, cooperative and knowledge or information barriers. We then explore the role of institutional intermediaries in addressing these barriers, focusing on their financial mobilisation functions. Finally we argue that based on their role and the use of these functions intermediaries exercise an influence on the innovation process of selected technologies. Representative, numbered quotes for the following argumentation can be found in Table A.1 (Appendix). The two examples highlighted in the boxes provide an in-depth understanding of the most advanced intermediary role and their possibilities to address (financial) barriers for their respective innovations.

4.1. An intermediaries' perspective on the relation between financial barriers and other barriers to (low-carbon) innovation

On the one hand, practically every field of innovation sets out goals towards commercialisation and application in Germany, while some build on sophisticated roadmaps as part of their strategy (e.g. electric mobility or organic electronics). However only a few of them specified instruments to tackle the transition from basic research over applied R&D towards commercialisation. On the other hand, the interviewees were returning to the perceived barriers to eco-innovation along the innovation cycle as a major theme. From an intermediary position this perspective provides valuable insights. The analysis of the interview texts however revealed that financial barriers often pertain to other aspects such as the political environment and corresponding barriers, technological barriers, commercialisation, information asymmetries, intermediaries competences and limitations and public-private cooperation depending on the phase in the innovation cycle.

In the phase of basic research the R&D project managers highlighted technological barriers such as complexity and administrative barriers such criteria for the selection of projects (B1, B2). These translated directly into constrains regarding funding (i.e. grants), as well as potential sources of finance for further development (B3, B4). Upon entering the applied R&D phase, the experts stressed the missing orientation towards commercialisation, both on the private side such as slow adoption of technologies, missing cooperation along the value chain, low corporate R&D and on the public side i.e. limited ability to make the technological development process transparent, missing links between STI and industrial policy as well as public-private interaction (commercial viability or business models for technologies) (B6, B8, B9). These barriers directly relate to missing private risk capital (i.e. business angels or VC) and uncertainty about further public funding for the technologies under development (B5, B7).

Throughout the demonstration and pre-commercial phases the R&D project managers referred to severe financial barriers on the private side e.g. capital intensity and missing collateral, bankability,

insurability, competence problems and too short time horizons for financiers (B10, B12). On the public side, administrative barriers such as missing interfaces between phases in the innovation cycle and government bodies and a limited availability to address this gap by the intermediaries themselves were highlighted (B11). Finally institutional barriers such as infrastructure occurred (B13).

Finally, for the niche-market, supported commercial and the fully commercial phase, the interviewees perceived a high path dependency on the private side regarding technologies and business models (B17) but also high regulatory and political uncertainty and inconsistent support for different technologies (i.e. picking the winner problem) on the public side (B14, B15, B16) Public-private barriers arise from too early commercialisation effort as a result of technology push measures and responding private actors as well as infrastructure problems (B18). In addition the compatibility between private finance and public support initiatives is lacking (B19).

Drawing from the perspective of institutional intermediaries that allows to analyse obstacles to eco-innovation as they intermediate knowledge and finance between public (especially policy makers) and private actors, the results indicate that technological, cooperative and political barriers along the innovation cycle (see section 2.1) translate into financial barriers. This translation takes different forms along the innovation cycle. In the early stages of the innovation cycle technological and administrative barriers such as opaque technology development process, commercial viability limit the matching with funding sources and thus result into early stage financial constraints. A missing orientation towards commercialisation including a focus on costs and potential business models and missing interfaces between ministries and stages in the innovation cycle combined with limited capabilities of financiers translates into a severe gap for private risk capital during the demonstration and niche-market phases. During the later stages in the innovation cycle (supported commercial and fully commercial) regulatory and policy uncertainty as well as inconsistent support mechanisms represent the most persistent barriers, which translate into large investments (projects and infrastructure) been delayed or withdrawn.

4.2. Role of institutional intermediaries in addressing these barriers

Having lined out the perceived technological, cooperative, regulatory or political and corresponding financial barriers we analysed the role of institutional intermediaries to address these barriers and correspondingly mobilise private finance which is inhibited by the barriers.

Competencies and mandates regarding commercialisation

Although the intermediaries institutionally fulfil the same position, we found a variety of roles, competencies and mandates that impact their behaviour within their respective contexts. The surveyed project managers see themselves as experts – a prerequisite for fulfilling managerial task of the R&D partnerships (C1). Secondly, they act as bridge-builders between critical actors in the innovation system – within the supported R&D projects and the corresponding participants (C2, C3, C5) that addresses cooperation barriers in the early stages. However, only few explicitly regard themselves as

organisations designed to bridge the gap between R&D and commercialisation respectively address underlying financial, regulatory and technological barriers (C4).

The R&D project managers allocate resources between projects canalising public funds, selecting participants and documenting and controlling the process as well as the usage of the generated knowledge (products, processes or patents). Some of them do not see a relevant role within that process (C6), whereas others have a holistic understanding of their managerial capabilities (C7). Most surveyed project managers have a broader commercial perspective which is supported by the analysis of archival documents for each field. However, only a few directly address barriers such as capital intensity and scalability on the private and the missing provision of infrastructure on the public side as one can see from the LED lighting example.

Example: 'LED Lighting R&D and Lead-market Initiative'

The LED has been government supported since the potential for general lighting was found at the end of the 1990s. The project management organisation and individual project managers financed *basic and applied research* pushing the technology from small scale to large scale application along the technological life cycle with a focus on interfaces between ministries and stages. The aim was to provide the German LED manufacturers with possibility to cope with the transition in the lighting industry (e.g. Solid State Lighting - SSL). Thus mostly *mature companies, research institutes and universities* benefited from this program. At the verge of commercialisation in 2009, the ministry together with the project managing organisation launched the LED lead market initiative which aimed at accelerating the commercialisation and diffusion. This initiative was an *institutionalised public-private cooperation* coordinated by the project managing organisation. Here the project managers acted as *bridge builders and innovation managers with a clear commercialisation perspective*. Main topics include the financial and organisational barriers to innovation such as risk, and uncertainty regarding business models based on LED. These barriers have been evaluated against the current institutional and regulatory environment, thus feedback to design conducive regulations was provided by the project managing organisation. Throughout the lead market program, *demonstration projects, application programs and well as public-private instruments* (e.g. standard energy service contracts for lighting application) have been developed. Further results include *guidelines for LED modernisation and certificates* to ensure quality.

Supporting policy makers to influence the financing environment

Due to their contractual relationship with government ministries and the resulting innovation agent characteristic of the institutional intermediaries, a major role revolves around institutionalised dialogue with political actors. In this respect, they act as consultants influencing the design of R&D programs (P1, P2). Resulting from their critical position between policy-makers and industry, the surveyed managers also engaged deeply with the review and extension of existing regulations (P3, P4). Most

study participants established the link between policy environment and their technology field, a few with consequences on advanced eco-systems, especially the finance environment (P5). However, some still regard their influence on accompanying regulatory environment as limited (P6), especially in the niche-market and supported commercial phases.

Within our narrative analysis, the interfaces between different stages of the innovation cycle that leave structural holes such as the 'valley of death', the responsible actors for the situation and the appropriate instruments to correct these failures returned as a major themes. This includes the responsibilities of different ministries along the innovation cycle as well as coordination of support mechanisms (P7, P8). Most of the intermediaries address the structural holes in the innovation process, notably the transition from basic R&D to applied R&D and the 'valley of death' at the edge towards commercialisation (P9). Still, several R&D managers did not see the transition towards commercialisation as their responsibility or even considered their perceived neutral position between public and private actors at risk. Although the corresponding mandate from the ministries entitles them to create synergies and foster innovation, support for market creation seemed beyond the scope for some of them (P10).

Financial instruments and cooperation with financiers

The R&D project managers possess a set of instruments to support the innovation process respectively to address the above mentioned barriers. They include varying subsidies schemes, socio-economic research and start-up support schemes, as well as instruments targeting the later stages of the innovation process, e.g. commercialisation which requires contact with public or commercial funds. These contacts might take various forms and are seen as a new competence for R&D project managers (F1, F2). Additionally supporting tools such as roadmaps were highlighted. These tools make the technology development process (including complementary assets such as infrastructure) understandable to third parties and help in coordinating actors (F3).

Others argue in favour of integrating VC as an instrument for effective support of SMEs and start-ups, to signal quality towards potential financiers (F4) as external capital is often missing (see example: 'Smart grids innovation program (E-Energy)'). However information used as signal for potential financiers or other private actors might be confidential or unavailable in aggregated form (F5). Supplying these materials could mean a conflict of interests for the intermediaries (F6). Still, R&D project managers could provide complementary research to reduce the risks of private financiers (F7). In sum, two possibilities to address financial barriers emerged. The intermediaries could either directly use their instruments to address financial barriers, especially relevant in the presence of SMEs or they could shape the policy environment address regulatory risks and uncertainty in the later stages in order to provide incentives for larger companies to invest into innovative capacities.

During the workshop held, the participants highlighted their systemic perspective and their financial mobilisation functions to address specific structural gaps and financing needs. Two solutions have been revealed. First, the integration of market perspective in the design of R&D programs was

considered, that would permit a smooth transition between R&D and commercialisation. Second, they highlighted their bridge-building and gatekeeping functions later in the innovation process to provide interfaces between the market participants.

Example: 'Smart grids innovation program (E-Energy)'

The smart grids innovation program aimed at a demonstration of feasibility using existing and novel clean technologies in intelligent model regions. Thus the initiative focused explicitly on the *outset between applied R&D and commercialisation*. It specifically addressed *SME and start-ups* which have been particularly active in this cleantech subsector. The project managing organisation took an *innovation management approach*, focusing on problems that SME highlighted as barriers for an accelerated commercialisation: Missing business models and the limited access to VC for a quick scale up. They consequently applied instruments such as *prizes for founders and a holistic model region approach*. The combination of *VC and R&D grants* as financial instruments has not yet been implemented, although the responsible project manager framed it as a possibility to address financial barriers. *Standardisation* as a technological barrier was further translated back to the corresponding ministries to be addressed on a regulatory level.

5 Discussion and conclusions

The research question guiding our enquiry was: How can institutional innovation intermediaries to address the complex set of barriers surrounding (eco-) innovation from R&D to commercialisation? In this section we will reflect upon this research question and mirror our findings to previous insights from the literature on innovation finance and innovation intermediation, to show the specific role of intermediaries in mobilising finance and how this relates to the addressing of barriers to innovation.

5.1. Addressing financial barriers requires a holistic perspective

Due to high public-private uncertainty, R&D complexity and learning in the early stages eco-innovations need increased support, coordination of activities and the development of complementary assets (e.g. infrastructure, standards, etc.) (Kenney & Hargadon 2012; Haley & Schuler 2011; Mathews et al. 2010). Thus, especially in the case of eco-innovation more systemic efforts are needed to escape lock-in effects and path-dependency and to accelerate the commercialisation and diffusion of clean technologies by balancing regulation, innovation and complementary financial mechanisms. According to our results, institutional innovation intermediaries possess the instruments that address the underlying financial barriers along the innovation cycle, such as capital intensity, scalability, infrastructure, lock-ins, regulatory risk and policy coordination failures.

Our findings complement earlier work that has been looking at single public and private instruments to finance innovation (Auerswald & Branscomb, 2003), notably research programs and grants (SBIR/ ATP) (Link & Scott 2010; Chang et al. 2002) and VC or business angels (Leete et al. 2013; Kenney & Hargadon 2012; Nightingale et al. 2009). Our research confirms the utility of individual funding

instruments; however we highlight restrictions of these instruments with regard to their coordination and embeddedness within the overall innovation system and process, in order to thicken up the thin financial markets for (eco-) innovation. This requires a focus on the interfaces between the innovation process stages and its connection with the policy environment. So coordination of the variety of policy instruments aimed at financing innovation by an innovation intermediary addresses the lack of specific focus on financial mobilisation intermediation in many innovation systems, which results in many technologies failing to research the market (Jacobsson & Karltorp 2013; Mathews et al. 2010; Bergek et al. 2008). Our findings hence provide empirical support for the argument put forward by Wonglimpiyarat (2011), who found that the 'financial innovation system' underlying the national and technological innovation systems is a significant driver of innovative activity. We show that financial barriers interact with technological as well regulatory barriers along the innovation cycle.

Hence financing (eco-) innovation requires a holistic perspective on the innovation cycle including commercialisation and diffusion stages as well as the transition between the phases and possible barriers. Each phase requires different forms of financing and support to address the underlying financial and non-financial barriers along this cycle. For example major barriers to the successful commercialisation of fuel-cells cars revolve around infrastructural barriers. By bringing together partners from the automobile and gas industry and assisting in developing technologies and business models for infrastructure the intermediaries could address major technological and institutional barriers that ultimately translated into financial barriers and prevent commercialisation. In the next section we discuss the key strategies by institutional intermediaries that emerged from our results.

5.2. Exploring the financial mobilisation functions of (institutional) innovation intermediaries

Based on our analysis of intermediary roles and instruments we derived a set of functions that permit institutional intermediaries to influence the finance environment for (clean) technologies and consequently accelerate the commercialisation and diffusion process. 'Financial mobilisation functions' comprise not only strictly financial instruments but also instruments that indirectly influence the finance environment for (clean) technologies.

Firstly 'classical' innovation intermediation functions indirectly impact the financing environment, as intermediaries are able to accelerate the commercialisation process by establishing and managing strategic research partnerships and by using supportive instruments such as roadmaps, strategic public procurement or production support measures which makes the technology innovation process more transparent. This contributes the reduction of uncertainty about future market opportunities and thus increases commercial viability. Previous literature on innovation intermediation has highlighted the direct impact of these policy instruments upon the innovation process (Kivimaa 2014; Edquist & Zabala-Iturriagagoitia 2012; Link & Scott 2010; Klerkx & Leeuwis 2009). Based on these results, we argue that these instruments used or operationalised by intermediaries determine the attractiveness for private financiers to invest into companies and complementary assets.

Secondly, the results highlight support functions for STI policy and regulation surrounding the technologies under development. In addition to the beneficial effects of adequate STI policy and regulation for innovation and commercialisation (Kivimaa 2014; Klerkx & Leeuwis 2009; van Lente et al. 2003), this indicates that support for favourable STI policy mechanisms and regulation directly determine the ability of private investors to invest into young, small and more mature companies. These investments are especially relevant in the context of eco-innovation as these technologies exhibit a strong regulatory dependency and asset heaviness.

The third component of 'financial mobilisation functions' revolves around the cooperation with private financiers to improve their competences regarding innovative (clean) technologies and thus strengthen their ability to evaluate future market opportunities. Reduction of information asymmetries has been highlighted in the context of markets for technologies (between producers and users) (Hoppe & Ozdenoren 2005); through our analysis we found that it is especially relevant in the context of financing (eco-) innovation since the information asymmetries between financiers and innovators are greater.

Fourth, direct financial instruments represent probably the most obvious part of financial mobilisation functions to alleviate financial constraints for innovating firms and research institutes. These include subsidies, grants, tax credits and support for demonstration projects (Yusuf 2008; Howells 2006). Our analysis adds to this earlier work by indicating that it is critical use an adequate finance mechanism (public, private or PPP – based on the risk/return profile to allow a seamless transition between the phases of the innovation cycle. This includes a combination of public (e.g. grants) and private (e.g. VC) instruments in later stages to leverage the publicly invested money.

5.3. The synergic role of financial mobilisation intermediation with other intermediation functions

As discussed in section 5.1, we argue that in order to address the interwoven barriers highlighted above, intermediaries need to apply different roles and corresponding instruments for each stage of the innovation cycle. We highlight the fact that financial mobilisation functions represent critical instruments to support and accelerate the innovation process for clean technologies by intermediating between public policy makers, private financiers and innovators. From our results we derived a model which is depicted in Figure 2.

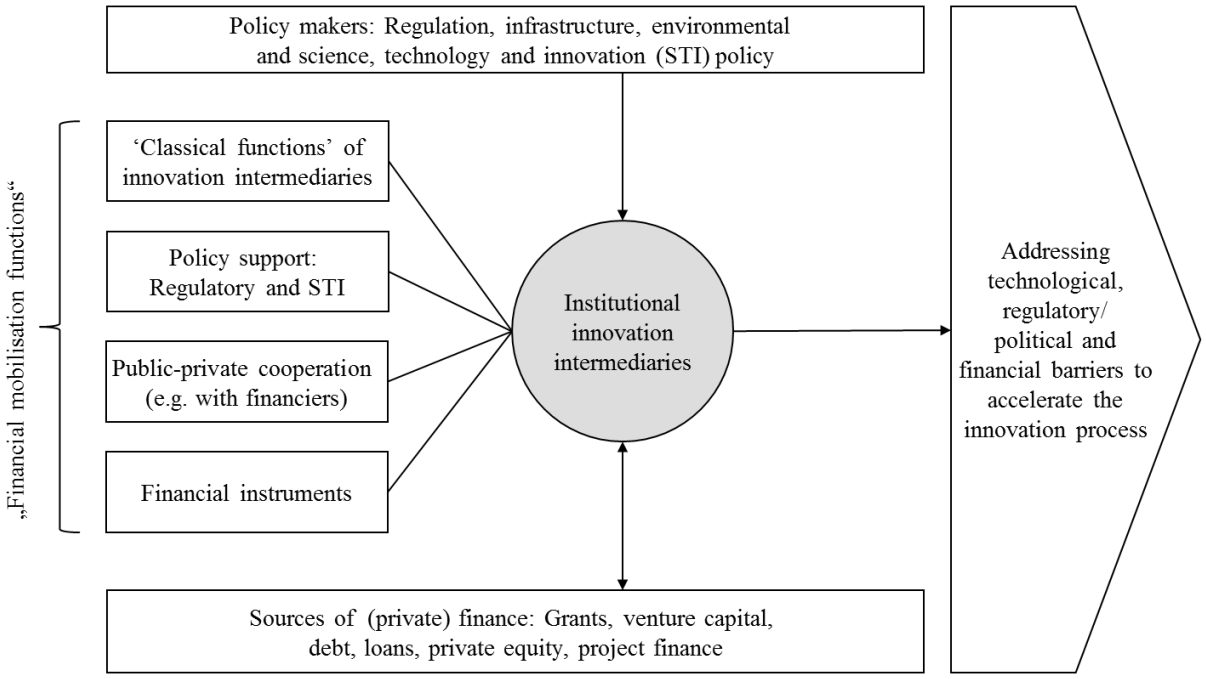

Figure 2: Model for intermediaries to address barriers to (eco-) innovation

These different roles and functions are synergic, as becomes clear from the results in different ways. First, and this could be called a 'first-order effect', they capitalise on their strength of public-private cooperation (i.e. innovation intermediation – acting as expert, bridge builder, innovation manager) focussing on bottlenecks along the innovation process to bridge the 'valley of death' and other structural holes which goes beyond funding basic or applied R&D and demonstration. Howells (2006) described this as generic role throughout the commercialisation phase. Institutional intermediaries coordinate different sources of capital in the early stages (e.g. research grants, PPP, private sources of capital) that represent the direct financial instruments component of our concept. The focus on bottlenecks additionally addresses barriers such as policy coordination and reflexivity failures, highlighted by Weber & Rohracher (2012).

Second, as a 'second-order effect' they accelerate the innovation process by supporting the design of the policy environment that is conducive to the innovation process spanning from complementary assets towards regulation to indirectly change the finance environment (Klerkx & Leeuwis 2009). This supports work that argues that as a whole financial mobilisation functions could act as a lever for publicly invested money and permits them to thicken up thin finance markets for (eco-) innovations (Kleer 2010; Nightingale et al. 2009). Our results reveal that a technology specific assessment of policies is necessary to facilitate financing (cleantech) innovation. The development of complementary assets (e.g. infrastructure, standards) or research to reduce risks enables private financiers to more seamlessly invest into the commercialisation phase of (clean) technologies and thereby overcome corresponding barriers.

Thirdly, there is a synergy between public and private actors in the sphere of innovation finance, as the intermediary bodies take the form of government funded institutional agents which act in a translating,

moderating and mediating way between market and non-market actors. This form of intermediary, complements informed investors (which to some extent may also be considered intermediaries) such as VCs (Leete et al. 2013; Da Rin et al. 2006; Repullo & Suarez 2000) as they possess the capability of reducing uncertainty and risk. Financiers (such as VCs and banks) are not able to grasp the complexity of the whole innovation processes, systemic innovation, or only perform certain types of investments such as complementary assets (e.g. infrastructure), especially for clean technologies. Hence, here the link between VC and institutional intermediaries takes the form of what Stewart and Hyssalo (2008) have dubbed an 'ecology of intermediaries'.

5.4. Conclusion and implications for policy

Based on the findings of this study, we show that institutional intermediaries with their 'financial mobilisation functions' accelerate the commercialisation and diffusion of (eco-) innovation. These functions may catalyse other innovation policy instruments, and vice versa. The coupling of policy instruments for supporting innovation and private finance via institutional innovation intermediaries addresses the missing function of 'financial mobilisation intermediation' (Bergek et al. 2008; Jacobsson & Karltorp 2013; Mathews et al. 2010). We therefore contribute an intersection between the financing innovation literature and the innovation intermediaries literature (Howells 2006; Klerkx & Leeuwis 2009; Wonglimpiyarat 2011).

From our study, two important policy recommendations can be derived. First of all policy makers should consider (financial) barriers and related technological, cooperative and regulatory or political barriers as intertwined. By ignoring the linkages between financial and other barriers, i.e. considering innovation and finance separately policy makers lose the potential to support critical industries such as cleantech in an efficient and effective way. Second, institutional intermediaries with specific financial mobilisation functions represent a crucial instrument for policy makers to operationalise and enhance eco-innovation. Policy makers should therefore extend the mandate of institutional intermediaries beyond the applied research phase towards commercialisation and diffusion (including the focus on policy environment and consequences for finance) as many barriers occur at the beginning or the in the transition between phases. They could capitalise on the intermediaries' position in the innovation system to facilitate exchange between financiers and innovators at an early stage, to optimally coordinate public support for the development of technologies along the innovation cycle and correspondingly support market development.

Since intermediation is a context dependent phenomenon, we acknowledge limitations to our study. The study's qualitative nature prevents us from generalising results. Still, the surveyed partnerships represent typical cases for high technology research. Thus the model based on our findings could be transferred to other forms of organisations or government agencies in other contexts, as the functions remain universal. Organisations that have similar responsibilities and face similar barriers exist in other countries. They include the Department of Energy National Laboratories in the US, the Finnish Funding Agency for Technology and Innovation (TEKES) or the Department of Trade and Industry

(DTI) in the UK. However, depending on degree of influence from institutional conditions i.e. structural R&D support in the national innovation system, the transferability of our findings might be limited. To gain deeper understanding of the interaction between institutional intermediaries, innovators and financiers, additional studies need to be conducted in other highly uncertain fields of technology.

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8 Appendices

8.1. Supplementary data (i.e. organised quotes)

Table A.1: Representative quotes

Antecedent	Characteristic	Representative quotes
Barriers to eco-innovation	*Technological*	The production technology area is complex. Tasks are complex, equipment is complex and finally we need partners who buy the products, meaning reliable partnerships. (Research project manager, Carbody technologies) (B1)
		I see a deficit in the 'Mittelstand'. How do we make those companies more innovative? (Head of research, Biotechnology) (B8)
	Regulatory/ Political	Recently we have been overwhelmed with bureaucracy. Nowadays we need to document why we support mature companies. (Research project manager, Advanced materials) (B2)
		We are limited by rules for granting support, public procurement law etc. We are not allowed to support individual firms but we can take measures that enhance innovation in Germany as a location for businesses. (Research project manager, Smart grids) (B3)
		Infrastructure is a technical and a cost challenge. We have access to comprehensive analyses. (Research project manager, Fuel cells) (B13)
		Regarding the vehicles [the main barriers] are costs. In terms of technology we rather see an optimisation problem which is the case for all new technologies. [Fuel cell cars] are disadvantaged compared to incumbent technologies. The incumbent technologies respond to user demands but ignore other challenges. (Research project manager, Fuel cells) (B15)
		Only political barriers remain for CCS, especially acceptance among the population. Nobody would initiate a demonstration project if it was not safe (Research project manager, Carbon capture and storage) (B16)
		The cost target is not yet achieved. The question is, what to do in-between [R&D and commercialisation]. Financial incentives to account for the higher upfront investment are desired by industry. […] However a feed-in tariff as for the renewables would not be adequate. (Research project manager, Fuel cells) (B17)
	Cooperative	In that case we have to assure confidentiality, especially towards our project partners. We know interesting numbers. […] The goal is to move beyond R&D. (Research project manager, Photovoltaics) (B6)
		As you can imagine, these information [market developments, expertise, evaluations of technologies] are confidential. We only report aggregated data. But the companies also have limitations in terms of what they can share. (Research project manager,

	Carbon capture and usage technologies) (B9)
	Financiers have built up competences since the 1990s, especially in banks and venture capitalists. However we are not asked for advice. (Head of research, Biotechnology) (B14)
Financial	We had good projects which we could not fund due to insufficient budgets (B4).
	The industry is not willing to invest. That is critical. […] We hear this a lot from our project partners (Research project manager, Solar energy technologies) (B5)
	We need to find someone who is willing to invest and bear the risk. We need to find someone who is willing to do that in Germany. I do not think that taxpayers will be excited if we fund a German company which establishes its production facility in Asia, the US or elsewhere. (Research project manager, Battery technologies) (B7)
	The feedback from our demonstration projects, where smart homes are deployed, is that there is only a business case when the pay scale fits the user needs. (Research project manager, Smart grids) (B10)
	R&D is important, but we have realised that apart from supporting technology policy an industrial policy monitoring is necessary. […] What kind of instruments could we use? Loans for market introduction? After the R&D phase, technologies need 5-10 times more investments for commercialisation. Can companies bear this burden? Do they get private finance or not? (Research project manager, Smart grids) (B11)
	The problem is credit-worthiness [for co-financed R&D projects and for commercialisation efforts]. It is a real financing problem. When they apply for a R&D project they need collateral. Sometimes banks give guarantees, but this is rare. There I see the main problem for our companies. (Research project manager, Smart grids) (B12)
	[The company] has left the R&D phase early. At some point in time they did not have enough financial resources. They built a production facility early without actually knowing what they are producing. So the costs where high and the market did not take the products. (Research project manager, Organic LED) (B18)
	Currently [potential buyers of the innovative technology] rather go with the subsidies instead of private energy service contracting. If we do not subsidise the products anymore contracting will be used. (Research project manager, LED) (B19)

Roles, competencies and mandates	*Expertise*	It is not the case that we could go into the laboratory ourselves and take over the work there but we know the main research streams and their contents very well. We need to know where the problems are and what the solutions could look like. (Research project manager, Organic LED) (C1)
	Knowledge broker	We see ourselves as brokers. We work for the ministries but somehow also for the industry. That means we attempt to bring together different points of view. That is our strength because we are familiar with different sectors. We are in best sense mediators and we try to advance the opinions of others rather than our own. (Research project manager, Photovoltaic) (C2)
	Technology transfer	We funded these technology centres for ten years. There is a lot of know-how, numerous highly ranked publications and eminently respectable researchers, […] but what we originally intended, the next step, technology transfer into the firms [did not happen] the firms acted very conservatively. (Head of research, Biotechnology program) (C3)
		That is the mission of most funding programs, it is about technology transfer. On one hand we have industrial R&D which is done autonomously. On the other, we have university R&D, Max-Planck-Society – basic research. The Government tries to close the gap by using project funding and to support technology transfer. (Head of research, Biotechnology) (C4)
	Bridge builder	It is our task to make sure that everyone gets a word in edgewise, to ask critical questions and to determine what is important. In general representatives from the corresponding ministry are present. […] It makes sense that they concentrate on content. So in the end it is our duty to collect information, to channelize it and to question what is really needed. (Research project manager, Organic photovoltaic) (C5)
	Manager	I think we don't need to do cost-revenue-control, the firms are doing that already. And we get ambiguous feedback. There are companies saying that it is helpful what you do and others do not feel informed enough. (Research project manager, LED) (C6)
		We evaluate [projects] according to a matrix, e.g. market perspective 40%, congruency with national fuel cell initiative and sustainability. It is not about proof-of-concept, we want to prepare the market […] in the field of transport and infrastructure. (Research project manager, Fuel cells) (C7)
Policy support	*Influence on STI policy*	It is not that we dictate something […]. We rather make our point and summarise things, which is already an interpretation. But we also get to know political aspects that we are obliged to include in our evaluation. […] We cannot influence it unidirectionally,

	we rather help them build their opinion. (Research project manager, Geothermal energy) (P1)
	It is our task to set the stage. We would like to have this technology field and not the other. […] We need visionary systems – what can they look like? […] We sketch what cooperative research projects could look like and what kind of actors should participate and how close to the application phase they should be. (Research project manager, Advanced materials) (P2)
	Many projects produced meaningful results, but there were no business models. The regulatory framework does not permit to incorporate the results into business models. (Research project manager, Smart grids) (P3)
	[The regulation] is coordinated here, that is a huge advantage. The standardisation took place including discussions where the counter would be installed – at the car or at the motoring pump. That will be a crucial advantage in the future. (Research project manager, Fuel cells) (P4)
	It's about acceptance, not only the tank vs. plate discussion, also whether the introduction of renewable resources and fuels […], could create disadvantages regarding ecology or quality of life. (Research project manager, Biofuels) (P5)
	[The regulatory environment] exhibits positive and negative influence on the innovation behaviour. Sure, companies follow trends if they are clearly visible. Production research respectively the production industry is conservative as the processes are highly complex. […] (Research project manager, Carboy technologies) (P6)
Interfaces between public authorities	A concrete example was the coordination between ministry X and ministry Y. In the first place the competencies are marked off, ministry X does the research and ministry Y the application. But in the end it is a very fuzzy field. (Research project manager, Lithium-Ion-Battery) (P7)
	I think the most critical point is what happens at the end of projects concerned with basic R&D. We are not responsible anymore because we funded the basic R&D. Another ministry might still not be responsible because the application is not visible. […] You often come across the situation that the innovators do not know about the follow-up process. (Research project manager, Organic photovoltaic) (P8)
Interfaces between innovation	In any case we have to answer the question: What comes afterwards? We work for ministry X and fund the research but we do not work for the department that deals with finance and industrial policy. The transition from funded research to industrial policy is no fast-selling-item. (Research project manager, Fuel cells) (P9)

	phases	We strive for synergies and we try to reduce redundancies. But after all the transition from prototype or demonstration, from the R&D phase towards a mainstream product or service is a responsibility of the innovators. (Research project manager, Carbody technologies) (P10)
Financial instruments	*Combination of public support and private finance*	There are contacts with private actors. Of course we cannot say, this is the partner bank X, Y. That cannot be our task. It is rather the question where the [founders] turn to get own contacts. […] We are willing to establish contacts but we cannot act as handmaidens of a bank. (Research project manager, Biofuels) (F1)
		[…] I would see it as our task that if we cannot fund them that we use our relationships with business angels who know that we have expertise in the field. On the other hand many networks do not work, especially not between funding ministries. (Research project manager, Smart grids) (F2)
		We have developed [a roadmap] with confidential company data. Especially scenarios for infrastructure and joined these with roll-out scenarios of the automobile industry. That is different to the infrastructure for natural gas which has been conducted by the utilities that do not have an understanding of the main actors, consumers, automobile users and automobile industry. This has been done here in a coordinated way which represents a huge advantage. (Research project manager, Fuel cells) (F3)
		[Finance] is a support instrument. If the creditworthiness is missing we would have the routine […] to use venture capital or to give venture-capitalists a hint what we regard as innovative so that they get interested […]. We could also show that we expect growth in this sector over the next years or that we see a lead-market. We also show the sphere around, saying that these small companies are in a consortium with large firms. That is important information. One could also invite [private] funds for jury meetings or involve them in accompanying research. […] still this is not included in our mandate. We are limited in terms of budget. (Research project manager, Smart grids) (F4)
	Limitations	You can imagine that information is partially very confidential. That means the results we extract [from the projects] or hand down are more general. There you read medium-term commercialisation etc. But also from the part of the innovators there are limitations on what we can hand down and what not. (Research project manager, Carbon capture and usage technologies) (F5)
		We work as a contractor for a certain ministry, selling services to them, precisely giving project funding to the innovators. If we had the industry as a contractor at the same time, I would regard this conflict as critical as long as there is no organisational

	separation between the two processes. (Research project manager, Organic photovoltaic) (F6)
Complementary services	We supply preliminary seismic data according to model calculations, simulations; we have the opinion that with probability of 95% you will find the geologic conditions necessary for an insurer to insure the last 5%. (Research project manager, Geothermal energy) (F7)

8.1. Interview guide

General questions concerning R&D partnership

- What is the main focus of R&D partnership (R&D, commercialisation, diffusion)?
- How did the technology evolve?
- Who are the directly and indirectly participating actors (i.e. firms, research institutes etc.)?
- What are goals of project managing organisation and participants (industrial, academic)?
- How long does the R&D partnership last?
- Please describe the commitment of the participants (monetary and non-monetary).

Management R&D partnership

- Please describe your role regarding tasks, responsibilities, expertise, hierarchy, status and coordination.
- How is the selection of participants and resource allocation happening?
- What kind of criteria did you apply to select the participants (Expertise, commercialisation, competencies, work plan, risks, leverage effect, overall importance, and financial power)?
- Please describe the evaluation of R&D projects especially regarding transparency.
- Please describe your internal and external communication strategy.

Science, technology and innovation (STI) policy

- Which ministries are responsible for this R&D partnership?
- What are their goals?
- What kind of policy measures (e.g. lead markets) do they use?
- Please describe your influence on STI policy.
- Please describe the barriers to commercialisation and diffusion of technology X.
- Which policy instruments could reduce those barriers?

Cooperation

- Please describe the private-private cooperation (Actors, forms, barriers).
- Please describe the public-private cooperation (Actors, forms, barriers).
- Please describe the public-public cooperation (Actors, forms, barriers).

Financing

- Do you think finance is necessary for commercialisation?
- Do you discuss questions related to finance with industrial partners?
- What kind of follow-up finance do they need?
- Have participating actors successfully been (externally) financed?
- Have projects or companies been discontinued due to lack of finance?
- Start-up and growth finance (Business angels, VC, PE; Mezzanine, Banks)
    - Which are questions addressed? Who deals with it?
    - Is there a need for start-up and growth finance? Who are the contacts for the participating actors?
- Please describe your cooperation with financiers.

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