EPG & CP Working Paper*
August 2016

The role of state investment banks in technological innovation systems: The case of renewable energy and energy efficiency in Australia, Germany and the UK

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Renewable energy and energy efficiency (REE) technologies are considered essential to help mankind achieve its climate change mitigation goals. In order to meet these goals and simultaneously become competitive in the long term, further technological change i.e. the invention, innovation and diffusion of new technology, is needed. However there is a significant financing gap for the REE projects required and many are concerned that investments for the large-scale deployment and diffusion of REE will not materialise. Both public support and utilities' balance sheets are constrained and, given the necessary scale of investment, private finance is required. To analyse the role of finance in the deployment of new technologies we leverage the Technology Innovation Systems (TISs) framework. We look at the special role of a single type of actor, state investment banks (SIBs), across several REE TISs in 3 countries: Australia, Germany and the UK. Firstly we see that aside from providing capital, the de-risking activities of SIBs can play an instrumental role in mobilising additional private finance. Secondly, when trying to mobilise finance via both capital provision and de-risking activities, we see that SIBs actively strengthen other functions within the TISs. The financing of REE deployment is about more than the mobilisation of capital. It is a systemic issue that needs to be addressed by systemic solutions. Our findings indicate that SIBs could be one of these solutions provided that a clear mandate for deploying innovation is implemented. Only then will SIBs help to diffuse innovations throughout the energy system, supporting the technological change needed to mitigate climate change.

Keywords: Energy Finance and Investment, Renewables, Energy Efficiency, State Investment Banks, Green Investment Banks, Technological Change, Technological Innovation Systems, De-risking

1 Introduction

Mitigating climate change, one of modern society's great challenges, will require a rapid and significant transition of our energy system in order to reduce emissions (IPCC 2014). Technological change i.e. the invention, innovation and diffusion of new technology, especially in renewable energy and energy efficiency (REE) technology fields, is considered key to this transition (Pizer and Popp 2008) and so there is a need for policy to speed-up and re-direct this technological change (Schmidt *et al.* 2012). But there is a significant 'financing gap' for the REE projects required to reduce global CO_2 emissions to target levels and many are concerned that investments for the large-scale diffusion of renewables will not materialise (IEA 2014, IFC 2010, SE4ALL 2014). The International Energy Agency estimates global investments in low carbon technologies will need to total US$730 billion by 2035, tripling today's figure of $255 billion, and will then need to reach over US$1.6 trillion a year from 2030-2050 to meet global climate targets (IEA 2014, Shlyakhtenko and La Rocca 2012). In order to reach its renewable energy goals, the Sustainable Energy for All (SE4ALL) initiative estimates that by 2030 US$320 billion will be required annually from a baseline of US$154 billion (SE4ALL 2014). However, public support and utilities' balance sheets are currently constrained and, given the necessary scale of investment, private finance is required (FS-UNEP and BNEF 2016, GIBC 2010, Mathews *et al.* 2010, ODI 2014, Schmidt 2014, Shlyakhtenko and La Rocca 2012). But financial actors and investors still often perceive renewables as risky and more innovative projects are not financed: hence de-risking is required (Jacobsson and Jacobsson 2012, ODI 2014, Oxera 2011, Sadorsky 2012, Schmidt 2014, Sonntag-O'Brien and Usher 2006). Public finance is being called for in order to address these risks and to leverage this private sector finance (Jacobsson and Jacobsson 2012, Mathews *et al.* 2010).

In recognition of this issue, some industrialised governments have appointed state investment banks (SIBs) to help close their financing gap and help green their economies. For example the UK's Green Investment Bank (GIB) and Australia's Clean Energy Finance Corporation (CEFC) were both founded in 2012, independently but with a similar goal: to assist their country's transition towards a greener economy by mobilising private sector capital into REE projects. Both banks are government funded with a remit to make capital available to clean projects in their respective countries whilst leveraging additional private financing and/or a wider range of institutional investors. Germany's KfW, although originally established as the country's development bank after WWII, has also been very active in its support of REE technologies and projects. These SIBs operate within different political, geographical and historical contexts and have varying explicit and implicit policies around supporting the deployment of innovation. In general, rather than providing upstream funding for R&D or demonstration (innovation) phases, SIB investment activities usually fund commercialisation, which supports the deployment and diffusion phase of a technology's development. The diffusion of a technology enables important learning feedbacks (learning-by-doing and -using) to the innovation stage, considered to be essential for the improvement of technologies (Carlsson and Stankiewicz 1991, Rosenberg 1982). As such SIBs' role in accelerating the diffusion of REE technology also strongly affects the innovation of these technologies i.e. speeding up and re-directing technological change.

One of the literatures analysing the development and diffusion of new technologies is the Innovation Systems (IS) literature and within that we are particularly interested in the Technology Innovation Systems (TISs) literature. The TIS approach helps to inform policy makers about mechanisms that either block or drive the development and deployment of technologies (Carlsson *et al.* 2010). "A core feature of the TIS approach is that it identifies a set of functions that need to gain strength for successful development and diffusion of a technology" (Karltorp 2015). Although mobilising finance is recognised as an important function that needs strengthening in REE TISs, it is still somewhat overlooked in the TIS literature, where only recently have TIS studies begun to analyse the role of finance in depth (Jacobsson and Karltorp 2013, Karltorp 2015). Our work aims to help address this gap via an in-depth analysis of how SIBs strengthen the TIS function of mobilising finance in order to better understand the role of public finance in enabling technological change.

The paper is structured as follows. Section 2 introduces the literature around the topic and indicates where our work sits within it. Section 3 describes our cases, method and data. Section 4 presents our results and observations, we discuss our findings in section 5 and future work in section 6.

2 Literature

Technological change, the invention, innovation and diffusion of REE technologies, is considered essential for the energy system transition needed to address climate change (Pizer and Popp 2008) and a significant driver of innovation is the financial innovation system that sits beneath TISs (Wonglimpiyarat 2011). We wish to improve the understanding of the role that finance plays in technological change in the field of REE technology.

The role of finance and public financial support for REE technology development has until recently focused on the direct funding of research and development (R&D), demonstration and early commercialisation phases of the technology (Auerswald and Branscomb 2003, BNEF 2010, Murphy and Edwards 2003). During recent years however there has been an increased focus on the flow of finance for the deployment and mass diffusion of REE technologies and projects (Hoppmann *et al.* 2013, Karltorp 2015). The CPI (2015) reports on the sources and intermediaries, instruments, recipients and uses of climate finance in order to contribute to the understanding and transparency of global climate finance. They reported "global climate finance flows reached at least USD 391bn in 2014 as a result of a steady increase in public finance (USD 148bn or 38% of total flows) and record private investment in renewable energy technologies (CPI 2015). According to the FS-UNEP report 2015 saw a record year for the dollar amount invested in renewables as well as the amount of new capacity installed (FS-UNEP and BNEF 2016). Despite these encouraging figures, there is still considered to be a significant 'financing gap' for the REE projects required to reduce global CO_2 emissions to target levels (IEA 2014, IFC 2010, SE4ALL 2014) and public finance is being called on to leverage in private finance (Jacobsson and Jacobsson 2012, Mathews *et al.* 2010). Mazzucato and Semieniuk (2016) investigated which types of financial investors have invested in the deployment of different renewable energy technologies and found that public owned entities and SIBs have invested heavily in high-risk projects. The OECD studied the ways SIBs have leveraged private investment by examining their rationales, mandates and financing activities (OECD 2015, 2016). Mazzucato and Penna (2014) Mazzucato and Penna (2014) investigated the roles that SIBs play in the economy and determined that they shape and create markets, rather than merely fix their failures. They same authors also show that KfW and BNDES (Brazil's development bank) play a 'mission-oriented' role making key investments in new technologies and sectors in order to address 'grand societal challenges', such as climate change (Mazzucato and Penna 2015). These studies examine the flows of finance, including public finance, for the deployment and diffusion of REE projects but there is little regarding the impact of this finance, or of SIB activities, on technological change.

In general SIB investment activities usually fund commercialisation, which supports the deployment and diffusion phase of a technology's development. The diffusion stage of a technology's development is important because learning feedbacks (learning-by-doing and -using) for complex technologies such as REE are considered to be essential for their improvement (Bergek *et al.* 2008, Hekkert *et al.* 2007, Huenteler *et al.* 2015, Lewis and Wiser 2007, Rosenberg 1982). Karltorp (2015) looks at the mobilisation of finance across the entire development, innovation and diffusion progression for offshore wind and biomass gasification in Europe, using the Technological Innovation Systems (TIS) approach. The TIS approach was developed in order to inform policy makers about obstacles to the development and/ or deployment of a technology type (Bergek *et al.* 2008, Carlsson *et al.* 2010). Carlsson and Stankiewicz (1991) define a TIS as a "dynamic network of agents interacting in a specific economic/ industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology". TISs comprise of four structural blocks: technologies, actors, networks and institutions (Jacobsson and

Karltorp 2013). Karltorp (2015) states that "a core feature of the TIS approach is that it identifies a set of functions that need to gain strength for the successful development and diffusion of a technology". These functions can be found in Table 1. Several researchers have identified the mobilisation of finance, part of function F6, Resource Mobilisation, as a key function in renewable energy TISs (Bergek *et al.* 2008, Jacobsson and Karltorp 2013, Karltorp 2015).

Table 1 Definitions of TIS functions based on (Carlsson and Stankiewicz 1991, Hekkert *et al.* 2007, Karltorp 2015, Wieczorek *et al.* 2013)

Function	Definitions
F1 Entrepreneurial activities	"Entrepreneurs are essential for a well functioning innovation system. The role of the entrepreneur is to turn the potential of new knowledge, networks and markets into concrete actions to generate and take advantage of business opportunities."
F2 Knowledge development (learning)	"Mechanisms of learning are at the heart of any innovation process where knowledge is a critical resource and learning is a fundamental process. This function includes 'learning by searching' and 'learning by doing'."
F3 Knowledge diffusion	"To learn relevant knowledge needs to be exchanged between actors in the system. This function refers to 'learning by using' but also refers to 'learning by interacting' within networks. The essential function of networks is the exchange of information "
F4 Guidance of the search	"This system function refers to those processes that lead to a clear development goal for the new technology based on technological expectations, articulated user demand and societal discourse. An example is the announcement of the policy goal to aim for a certain percentage of renewable energy in a future year. This grants a certain degree of legitimacy to the development of REE technologies and stimulates the mobilization of resources for this development. Expectations are also included, as occasionally expectations can converge on a specific topic and generate a momentum for change in a specific direction."
F5 Market formation	"A new technology often has difficulties to compete with incumbent technologies, as is often the case for REE technologies. Therefore it is important to create protected spaces for new technologies. This process refers to the creation of markets for the new technology. In early phases of developments these can be small niche markets but later a larger market is needed to facilitate cost reduction and incentives for entrepreneurs to move in."
F6 Resource mobilization	"Resources, both financial and human, are necessary as a basic input to all the activities within the innovation system. We focus on financial resource mobilization in this work."
F7 Creation of legitimacy	"Innovation is by definition uncertain. A certain level of legitimacy is required for actors to commit to the new technology with investment, adoption decisions, etc."

Wieczorek *et al.* (2013) and Jacobsson and Karltorp (2013) use the TIS approach to analyse the European offshore wind energy innovation system and both highlight the mobilisation of financial resources as a key weakness and hence an obstacle to the development of this technology. Karltorp (2015) builds on the aforementioned work and goes a step further by focussing only on the function of mobilising financial resources for the European offshore wind and biomass gasification systems. She performs the analysis from the point of view of two actor groups, the technology developers and the financial actors, and in doing so presents the current challenges to mobilising finance for both technologies whilst also describing the different risks as seen by each actor group. Based on her findings, Karltorp then goes on to suggest ways to de-risk REE in order to further mobilise finance (Karltorp 2015). Given the calls to remove the financing bottleneck and strengthen the mobilisation of finance, further research on the role of de-risking actors who mobilise finance would be valuable. Karltorp (2015) does not examine in-depth the actors who both provide capital whilst simultaneously de-risking i.e. public finance actors such as SIBs. We aim to fill this gap by taking an in-depth look at how SIBs undertake a public finance role to mobilise finance.

Our work leverages the TIS framework but differs from previous studies in that, rather than examining one or two specific technologies and analysing their TISs, we look at the special role of a single type of actor, SIBs, across several REE TISs in 3 countries: Australia, Germany and the UK. We take the function of mobilising finance as a starting point for our investigation and analyse the role of SIBs in strengthening this function. Studies exist on why SIBs are being created and their role in the economy but there is little regarding their impact on technological change or their role in strengthening the functions of TISs. We aim to address the research gaps in both the TIS and SIB literature, improving the theoretical understanding of the role of SIBs in strengthening the mobilisation of finance for renewable energy and energy efficiency TISs. Hence we aim to improve the understanding of the role of public finance in technological change.

3 Cases, Method and Data

3.1 Case sampling and description

In order to examine the role of SIBs in mobilising finance we have chosen three different industrialised countries with SIBs as our sample: Australia and the CEFC, Germany and the KfW Group and the UK and the GIB. We chose these three countries due to the existence of an SIB in each and due to the differences in how established their REE TISs are.

Germany has very mature and established REE TISs and KfW (Kreditanstalt für Wiederaufbau, which roughly translates to Reconstruction Credit Institute), a first-mover in many ways in the industry, has been a very active supporter of REE projects, being the single biggest development bank investor in clean energy projects from 2007-2012, investing $147bn (EUR 108bn) (Louw 2013). KfW was originally founded as Germany's reconstruction and development bank and has been supporting the country's development in various ways since its establishment in 1948 after WWII. Originally established with Marshall Funds, it currently raises 90% of its funds in capital markets through government guaranteed bonds (KfW 2015, 2016, Kraft 2003, Mazzucato and Penna 2015). KfW Group currently consist of several business units and subsidiaries and we are interested in those that are active in the REE fields domestically: KfW Mittelstandsbank (servicing domestic SME enterprises and start-ups), KfW Kommunal-und Privatkundenbank/ Kreditinstitute (overseeing domestic housing programs, energy efficiency and financing public infrastructure) and KfW IPEX (promoting German companies globally by providing finance for large-scale infrastructure including renewables) (KfW 2015, Mazzucato and Penna 2015). For SMEs and households who wish to implement renewable and energy efficiency projects, and for certain larger scale renewables developers, KfW provide cheap or longer-term debt via local German banks (rather than supplying debt directly) and can also provide guarantees (Ecofys 2008). KfW IPEX on the other hand provides larger scale project financing to utility scale renewables directly. Germany's government has provided a very supportive environment for renewables via feed-in-tariffs and other complimentary support schemes that, as part of the country's Energiewende (Germany's energy transition from high-carbon and nuclear power to renewable energy) and in conjunction with KfW's available financing, are considered to have been essential to the country's advanced stage of REE TIS development (Lauber and Mez 2006, Mazzucato and Penna 2015).

The UK system is more of a mid- to late-comer to renewables and has experienced some technical and policy spill-overs from Denmark, Germany and other countries (Lako 2004). The UK's GIB was founded to foster a greener and more innovative economy by mobilising private finance into low carbon projects and was established much more recently, in 2012 (EAC 2011). The GIB takes a different approach to KfW. The GIB only invests in REE projects on terms equivalent to those of commercial banks (i.e. it provides no concessional finance) and EU commission approval of its establishment was made subject to it providing capital only to those projects and sectors where there was not considered sufficient private of commercial funding (EAC 2011). The UK government has also provided various different policy support schemes for renewables over the years including certificate schemes, feed-in tariffs and the soon to be implemented 'contracts for difference' scheme. However regular policy changes are often sited as a source of uncertainty for investors, partially contributing to the lack of required investment in renewables (Foxon *et al.* 2005). It was announced in March 2016 that the GIB would be moved into the private sector and its government shares sold, however there is now some uncertainty as to the final outcome in light of the Brexit referendum (Ares 2015, Holmes 2016).

2012 also saw the establishment of Australia's CEFC, another SIB founded to foster a greener and more innovative economy by mobilising private finance into low carbon projects (Act104 2012, CEFC 2016). The CEFC also has a mandate to invest on terms similar to commercial banks. In contrast to the UK and Germany, Australia's renewable TISs are considered to be very nascent (apart from household rooftop solar), with most technologies and projects considered to be new to the country and its actors. Each state and territory has offered support policy for renewables, mostly targeted at household level generation. However, apart from the Renewable Energy Target (RET) scheme, a certificate-based scheme for utility and medium scale renewables, in general there has been limited policy support for REE technologies (Talberg 2013). Australia's industry and exports are heavily dependent on cheap coal and gas and a recent Prime Minister, Tony Abbott, a climate sceptic, repealed the country's carbon pricing scheme within 2 years of its launch (Taylor 2014). In 2012 and 2014 Australia saw the same government review and revise the RET scheme twice, an action that saw the renewables industry falter in the face of this uncertainty (Talberg 2013). In spite of the uncertain political environment the CEFC has continued to operate and invest in Australia's REE industry.

3.2 Methods and data

We undertook a qualitative case study design, iteratively collecting and analysing data on the three SIBs. The primary data was sourced mostly from semi-structured interviews and secondary data was sourced from publicly available literature on each bank and the projects they have undertaken in each country. We performed in-depth interviews with project developers of renewable energy and energy efficiency technologies (to reduce bias we include both developers who had and hadn't engaged with their SIBs), equity and debt providers, bankers (including those from SIBs) and industry experts. We gathered further secondary data on SIBs and their projects from publicly available documents and developer and project websites. In total we performed 41 semi-structured interviews with a total of 50 interviewees from late 2015 to mid 2016, shown in Table 2. Interviewees were found from SIB websites, renewable energy associations, internet searches and snowball sampling. To assist with the analysis, interviews were transcribed and then coded along with the additional literature data.

Table 2: Interview breakdown by country, total of 50 interviewees

Interviewee	UK	Australia	Germany	International[2]
Developer	6	12	4	5
Expert Intermediary[1]	5	4		1
SIB	1	4	2	
Investor		2		4
Total	12	22	6	10

[1] Intermediaries include deal arrangers, due diligence experts and expert consultants. These are interviewees who are heavily involved in the development process but would not be considered developers, SIBs or investors themselves.
[2] Indicates interviewee's activities overlap with at least 2 of our case countries, mostly Germany and the UK.

4 Results

4.1 Capital provision

Mobilising finance into the project development stage of renewables and energy efficiency technology has been flagged as a key weakness in these TISs. A key part of the mandate for the CEFC and GIB SIBs is to provide capital to low-carbon projects where sufficient or commercial funding isn't available and where possible to simultaneously leverage in private or alternative finance to projects (Act104 2012, EAC 2011). KfW has a similar mandate as it supports Germany's Energiewende however not all business units have an explicit mandate to leverage private finance. As part of this work we investigated the capital availability for projects in these countries over the last 10 years, as seen from the point of view of developers and financial actors. Both the UK and Germany have seen capital markets struggle to provide liquidity during and just after the global financial recession of 2008 and markets didn't see capital availability improve again until around 2011-2012. The last 1 to 2 years, however, has seen a greater surge in interested investors, both equity and debt providers (with some variance depending on technology and project size). Although the financial crisis had a much smaller impact on Australia, developers there struggled to raise capital in 2014-2015 due to the government repealing and reallocating the national Renewables Energy Target (RET). This caused levels of uncertainty that saw both investors and many developers exit this country's industry, only to start returning in the last year or so.

The years 2013-2015, have seen the GIB invest £2.7bn in 80 green infrastructure projects (and 7 funds) worth £10.9bn, leveraging approximately £3 for every £1 that they invested (GIB 2016a, b). In a similar timeframe the CEFC has made cumulative investment commitments of $A1.4bn in projects worth $A3.5bn, leveraging approximately $A1.8 for every $A1 invested (CEFC 2015). In 2012-2014, the entire KfW group invested €26.6bn in climate and environmental protection projects (approximately 36% of its total promotional business volume in 2014)(KfW 2015). SIBs are not just merely making capital available for developers (and homeowners in KfW's case), but are also attracting co-investors directly into projects. We especially see this where the GIB and KfW IPEX have invested in offshore wind projects in which they are never the sole debt or equity provider, but leverage in other investors, forming consortiums (or syndicates). The GIB has also set up an offshore wind fund to attract institutional investors to refinance offshore wind projects in their operational stages, freeing up developers' capital for new investments. Institutional investors are more likely to invest in operational assets (due to their regulations around risk requirements) rather than investing in riskier development and construction phases. Developers say this is very useful to them as they often struggle to source refinancing elsewhere. The GIB has also been attracting co-investors on a smaller scale for waste-to-energy (WtE) and biomass projects. When KfW IPEX entered the offshore wind project market, they identified a gap in funding in the market that neither they nor any other financier could fill due to the very large sums required for development and construction of offshore wind projects. KfW IPEX submitted a proposal to the other units in the KfW Group, requesting that they find a way to provide the additional funds. KfW responded by creating a fund just for topping up the KfW IPEX offshore wind projects, which also in turn helped to bring in new private investors who saw this as a further de-risking measure.

We also see SIBs show a level of flexibility around the type of capital they make available for developers. Many of the developers we talked to indicated that they often have struggled to source equity not just debt. The GIB offers flexible capital, across the full capital structure from debt to mezzanine debt to equity and has shown flexibility towards the needs of developers when needed, even mid-deal. In one waste-to-energy (WtE) case the developers managed to source further debt after the GIB had already committed debt, but then in turn found they didn't have enough equity. The GIB changed its offer to the desired equity. However some UK and Australian small developers have stated that they need subordinated debt or the 'first loss piece' for projects but that they have been unable to source this anywhere, not even from the SIBs. In general there is a gap in support for residential, small and community scale renewables projects, especially by the CEFC and they do not yet offer equity (although they are intending to in the future). Our findings also show that when an SIB is flexible with the type of finance it offers a developer it sends an encouraging signal to other investors. Investors we spoke to have said that it sends a good, even stronger, de-risking signal when they see equity provided by an SIB (rather than debt). KfW offers limited equity however it does have a history of offering very competitive and low lending rates (1-2% in 2012, due to KfW's top credit rating plus further government subsidy of the interest rate), especially to SMEs and households, as well as long-term loans at market rates and guarantees (Carrington 2012, Ecofys 2008, Kraft 2003). KfW have a history of offering many low interest loans to homeowners for energy efficiency and some renewable and heat generation as well as various support schemes for community scale projects such as the "Energy in Urban Neighbourhoods" scheme providing financial incentives to municipalities for district-wide energy retrofits and heating (Morris and Pehnt 2016). It should be noted that the GIB and CEFC do not offer concessional finance, but offer terms equivalent to commercial banks.

Apart from during and just after the financial crisis of 2008 however, our findings agree that in recent years it's not a lack of liquidity in the capital markets that has had such an impact on limiting capital availability to projects but that its the risk profile of these projects, both perceived and actual, that limits capital availability. This matters because investors, especially debt providers like commercial banks and, more recently, institutional investors, are risk averse. Investors and even the developers themselves mention a lack of 'bankable' projects: projects with a risk profile acceptable to investors. In particular smaller and community scale projects are seeing a lack of equity in both the UK and Australia, whereas even larger utility scale projects in Australia are considered very high risk for a variety for reasons, including policy uncertainty, a lack of power purchase agreements and a high level of inexperience with these types of projects. The TIS literature assumes that the role of (public) finance contributes almost exclusively to the function of mobilising finance (F6) via provision of capital. However our observations show that the SIBs contribute in many other ways, as presented below.

4.2 De-risking activities and capital provision

We started this work expecting to see the SIBs providing capital to projects where sufficient or commercial funding isn't available and to also simultaneously leverage in private or alternative finance. But we have found that SIBs play a much wider role as much of their work falls under the umbrella of de-risking activities. For example recently it has been very difficult to get longer-term (>5 years) power purchase agreements (PPAs) in Australia for utility size renewable projects of any technology type. This is generally agreed to be due to Australia's projected flat demand growth, traditional utility-type counterparties still being somewhat vertically integrated and dependent on cheap coal and also because of the previous policy uncertainty around the RET. Both debt and equity providers see projects without PPAs or with only shorter-term PPAs as too risky to invest in. So to address this the CEFC has been repeatedly investing in projects that can't get longer term PPAs, or who can only get PPAs for part of their generation. Once the CEFC started investing in projects with only partial PPA contracts, other investors soon followed and copied this model, seeing the CEFC's investments as a de-risking signal. We have also seen the CEFC provide debt to projects with a higher counter party risk than commercial banks would accept, such as geographically remote solar PV projects that have a high counterparty risk because of their limited access to a lone counterparty. KfW also providing guarantees, a traditional de-risking tool for projects.

We are also seeing SIBs taking the risky role of 'first mover', investing in projects that in some way are among the first of their kind or contain some sort of innovation. Both the GIB and the CEFC have invested in projects with developers who have never previously developed a project. Banks and other investors have little interest in investing with inexperienced developers and usually want to see evidence of a track record. The same goes for projects that contain something new or innovative, such as a technology or business model that is new to a country or its actors. Debt providers in particular are very risk averse and rarely accept the role of first mover. The CEFC has invested in projects with technology providers that have never been seen in-country before. They have also invested in a Solar PV project that implemented a combination of diesel and solar PV in a way that has never before been seen in Australia and that no bank would invest in. The GIB invested in a successful biomass (gasification) project developed by a new, inexperienced developer who also utilised a new type of feedstock in the project. After the first project was implemented, the developer was able to attract capital with ease for subsequent projects. When SIBs are the first mover in these projects, taking on the first mover risk, it allows those innovations, technologies and developers to establish a track record, gain legitimacy in the industry and in turn attract private and commercial investment.

As mentioned earlier, risk perception plays a huge role in whether a project is financed and we see that SIBs perform other non-financial de-risking activities in addition to providing capital and attracting alternate finance. When the GIB entered the WtE gasification sector they soon realised that original equipment manufacturers (OEMs) weren't providing guarantees on their specialised feed stock quality equipment, something that investors (and developers) had indicated they needed in order to more readily providing finance. Apart from making capital available to the WtE gasification developers, the GIB actively encouraged all OEMs to provide these guarantees. These OEMs now provide these guarantees, essentially de-risking those projects and making them much more attractive to investors. Developers and investors we spoke to indicate that the GIB was instrumental in making this happen.

4.3 Capabilities and new knowledge

We have repeatedly heard from developers and investors that SIBs actively employ some of the best people in the country so that they are specialists both financially (bankers and financiers) and technically (technology specialists and in-house engineers). In doing so they harness specialty capabilities in order to help developers close deals, and to focus on accurately assessing risk. The idea is that by bundling this experience they may more accurately assess the risks of projects and can provide finance accordingly, especially to those projects that contain something new and innovative. The due diligence (DD) and risk assessment performed by these banks is therefore specialised and well trusted by other investors in the industry due to the high capabilities and specialised technical knowledge of their staff. For example KfW IPEX are considered "a real opinion leader" in their field. They are known to be the 'technical' bank in any consortium and their due diligence processes, risk assessments and registers are considered to be technically excellent and accurate. They then help to bring these DD processes and risk assessments to other investors, making them familiar with the risks around the technologies and projects. In addition to assessing risk, specialised knowledge is used to assist developers. The GIB used specialised knowledge to help push biomass and WtE projects through to closure with developers when certificate deadlines were looming. The banks' capabilities were seen as a significant help to the developers for pushing through final approvals and closing deals. Additionally KfW has launched many programs to help support the diffusion of learnings from REE projects. One of its mandates is to provide 'advisory services and the implementation of promotional measures in the field of technical progress and innovations' (Mazzucato and Penna 2015). It also provides consulting services, has launched training for external consultants in energy efficiency and provided grants for SMEs who need to contract external consultants in energy efficiency (Mazzucato and Penna 2015).

Secondly the SIBs and their specialist teams also innovate, creating new ideas and innovative deal structures in order to help projects become bankable. As part of this process they help to standardise innovations for projects, creating knowledge that they then diffuse into the investment and developer community. The GIB has used its highly skilled personnel to help set up structurally complex energy efficiency (EE) deals (and in turn to attract investors to EE projects). EE income models are not always as straightforward as for other projects and the GIB has helped bring some standardisation to these types of projects. The CEFC has helped a rooftop solar PV developer introduce an innovative leasing scheme that had not been seen before in the industry. After the project had been installed, many of the commercial banks teamed up with both the original and competing rooftop developers to roll out projects with the exact same leasing and income deal structure. KfW has used an even more direct way of standardising DD and risk assessments by offering loans to SMEs and households by providing debt via the local banks. In doing so, KfW set up standard project risk assessment profiles and DD processes for these local banks to follow when considering whether to lend to the SMEs and households, standardising the way banks can assess risk. Finally the CEFC chose to participate in the first issuance of a Green Bond in Australia. Although it was not the CEFC that instigated the issuance of this first bond, (in fact it was a commercial bank) the CEFC then shared its experience from this issuance and went on to work with other commercial banks to help with their green bond issuances.

Essentially we've seen SIBs build and develop their own capabilities and collect specialist people and knowledge in order to better assess risk and assist developers. They also develop new knowledge whilst also creating standards, which are then diffused to developers and investors. These knowledge spill-overs also relate to something else we've observed; SIBs, risk bias and the creation of trust.

4.4 Creating trust

Many of our interviews confirmed that investors lack experience, or technological understanding, when it came to renewable energy projects and that in general this lack of experience led to a lack of capabilities in assessing the risk around a project. This in turn usually led to an overestimation of risk by many debt providers; a risk bias in fact. It is very difficult to estimate and analyse the risks for a project that you have no familiarity with or knowledge of. As mentioned above, risk perception plays a huge part in whether capital is available for projects or not, and this overestimation of risk, or risk bias, in combination with the natural risk aversion, of for example debt providers, is a big problem in mobilising finance. In spite of inexperience and a lack of knowledge what we have seen is that there has developed an understanding within the investment community that the SIBs' decisions to invest in projects, and the DD processes they perform, are worthy of trust. As seen previously SIBs have used their specialty staff to develop technically excellent and well-respected DD and risk assessment processes.

In fact we have seen that projects that involve SIBs don't even need to be completed for them to be seen as legitimate by other investors. For example one UK biomass gasification developer found that as soon as the GIB signed up to their project, previously disinterested debt providers were now happy to provide debt. Even though the industry admitted that it was still uncertain about the risks involved with the technology, the debt providers knew the GIB had performed good DD, so they thought the developer and their project must be worth investing in. In the CEFC solar PV example in the section above, banks had started to roll out similar projects within a couple of months of the initial project completion, long before the original project had 'proven' itself to be profitable. This was because the banks trusted that the SIB had performed the appropriate DD and had accurately assessed the risks. Time and again we have seen that when SIBs announce they will participate in a project, very soon after other investors jump on board, often leading to an oversubscription of supply of finance within that project.

5 Discussion

As the starting point for this work we aimed to look at how SIBs strengthen the function of mobilising financial resources (F6) in renewable energy TISs. This function, one of seven considered essential for the successful development and diffusion of a technology, has been highlighted as weak by several renewable energy TIS studies (Karltorp 2015, Wieczorek *et al.* 2013) and the mobilisation of finance in general is critical to fill the estimated financing gap for the REE projects required to address climate change (IEA 2014, IFC 2010, SE4ALL 2014). Our observations confirm that SIBs mobilise resources via capital provision however we also see that their de-risking activities play a significant role in leveraging additional private finance. In addition, when trying to strengthen F6 via capital provision and de-risking activities, we have seen that SIBs actively strengthen other functions within the TISs. We discuss how SIBs address certain TIS functions below, along with observed contrasts between different SIBs and related policy implications of our work.

5.1 Effects of SIBs on TIS functions

SIBs play an active role in mobilising finance (F6) into low carbon TISs. SIBs are doing this by providing capital to (high risk) projects where sufficient private or commercial funding isn't available and often by simultaneously leveraging in additional private investment to these projects. We also often see SIBs taking the 'first mover' role, investing in higher risk innovative projects and helping new developers, new technologies and innovations to gain a 'track record' in the industry, something that is essential when trying to attract private investment. SIBs also provide flexibility, offering different types of capital and deal structures according to developers' needs (debt vs equity vs mezzanine finance etc.). Our findings indicate that risk plays a key role in the weakness of TISs in mobilising finance. Additional private capital is limited because the risks are high, or at least are perceived as high, and private investors are risk averse. SIBs strengthen F6 by performing activities in addition to, or even instead of, capital provision that assist in de-risking or transferring risk. In particular we see SIBs attempt to address the de-risking needs of developers in order to send de-risking signals to investors. Apart from Karltorp (2015) who suggests potential de-risking activities to assist with mobilising finance in off-shore wind and biomass gasification TISs, there lacks explicit analyses of the risks and uncertainties that arise within REE TISs, which might have to do with TIS studies' past-looking perspective when uncertainties no longer prevail. This is an issue because risk and uncertainty play an important role in how financial actors decide whether to finance REE projects and hence how finance is mobilised within a TIS. With this work we have attempted to show how SIBs address risk and uncertainty within REE TISs.

A key contribution from SIBs is their ability to both develop and diffuse new knowledge throughout the TIS (F2, knowledge development, and F3, knowledge diffusion, of the TIS framework). SIBs utilise their financial and technical specialist staff to develop new knowledge, especially via financial innovation creation. SIBs have created technically excellent due diligence processes, risk assessments and risk registers and are also working closely with developers and investors to create new deal structures and other financial, technological and organisational innovations (learning-by-doing). Having gathered together specialists in their countries they develop the capabilities to better assess the risk of low carbon projects. SIBs also actively participate in projects where they may lack experience and knowledge in order to develop their specialist capabilities further. Importantly we are seeing SIBs take their knowledge, existing and new, and create standards, which they can then diffuse through to the developer and investment community. In particular SIBs are addressing investors' lack of capabilities and experience of technologies and projects by spreading their expertise throughout the TIS (learning-by-using and learning-by-interacting). The SIBs we examined pursued various methods of diffusion as a reflection of the type and scale of project. Most SIBs, especially for large-scale projects, interact directly with other investors within consortiums, leading to direct learning spill-overs and diffusion of knowledge. However knowledge is also diffused indirectly via the SIBs when other investors and developers witness successful developments over time and via word of mouth (renewable energy industries are 'small' and stakeholders quickly become aware of new developments). Knowledge spill-overs or the diffusion of new knowledge is a key function in a successful TIS and a key function in enabling technological change. SIBs are actively strengthening these two functions.

SIBs are given mandates that direct which low-carbon technologies they will finance and that influence their approach to financing innovation. Hence the types of technology that an SIB invests in sends signals to both developers and investors, influencing what they in turn eventually develop and invest in. SIBs help shape the expectations of an industry around the direction a TIS may move in and in turn have an impact on TIS function F4, guidance of the search.

Renewable and low carbon technologies often face difficulties in competing with incumbent technologies. Developers see a lack of supply of project finance and from the investors' point of view, they see a lack of supply of 'bankable' projects. It is in essence a circular problem, where if more finance were available to develop projects, then more bankable projects would in the longer term become available as technologies develop further, knowledge spills over, projects gain a track record and risks are more easily assessed and mitigated. SIBs' activities address both supply lacks here, in fact contributing to a co-evolution of finance and project supply. SIBs identify gaps of supply of financing in the market and make capital available to fill these gaps. In cases where they themselves cannot supply the finance they then go on to help develop additional finance supply. Additionally they work with developers, OEMs and O&Ms in order to de-risk projects and make them 'bankable', hence supporting project supply. This supports work by the OECD (2015) that shows SIBs can play a market transformation role and Mazzucato and Penna (2014) who argue that SIBs can play a market creation role rather than just addressing market failures. Through a co-evolution of finance and project supply SIBs are actively supporting the formation of markets, strengthening function F5, in REE TISs.

Finally we see that SIBs are helping to create legitimacy, strengthening function F7, for REE technologies. SIBs have done this by creating trust with financiers, both in the SIBs themselves and the projects they invest in. Firstly SIBs' specialist capabilities have led to DD processes and risk assessments that financiers' trust. We see in fact that there is a 'labelling effect' on projects that include investment from SIBs. Projects that involve SIBs don't even need to be 'closed' or 'completed and operating' for them to be seen as legitimate by other investors. The mere presence of an SIB generates trust in other investors and attracts additional finance. This is especially powerful when an SIB acts as the first mover in a project and is able to bring legitimacy, and then additional private finance, to projects containing 'innovations'. Legitimacy is also being generated because SIBs share their specialist capabilities with investors, an overlap with the knowledge diffusion function F3 in TISs. By helping to increase the capabilities of financial actors their trust in the respective technologies and projects will also increase, bringing greater legitimacy to the technologies, projects and in fact each entire low carbon TIS. SIBs are actively creating legitimacy for low carbon technologies and projects, especially with financial actors.

5.2 Policy Implications

We have seen distinct differences in how these three SIBs assist their country's transition to a greener economy and how they mobilise capital into REE projects. Whereas Germany's KfW claims that a combination of concessional finance (e.g. 1-2% interest rates for energy efficiency improvements to households) and guarantees are the 'workhorse' of mobilising private finance (Enting 2013), the CEFC and GIB take a different route, where it is argued that operating at commercial terms sends a greater de-risking signal to alternative investors that the projects they invest in are 'commercial' ready and bankable for the market. Another key difference is that KfW can borrow from markets freely, whereas the GIB and CEFC still cannot at this stage (although the UK government claims that its privatisation of the GIB will allow it to borrow on capital markets). This may have limited the impact that the GIB and CEFC have been able to have in terms of mobilising capital and widening their investment scope as the constriction on borrowing may limit their flexibility with their bank balance sheets. KfW have supported a lot of smaller scale initiatives, via low cost debt, from households to community scale, whereas there are still large gaps in supporting small and community scale renewables projects by CEFC and GIB. The GIB however has the flexibility to offer equity, often requested by smaller to mid sized developers, whereas the CEFC does not yet offer equity (it plans on doing so in the near future) and KfW also only offers equity in a limited fashion. This lack of flexibility means these SIBs can't always offer developers what they need in order to develop their projects. All three SIBs are able to offer other variety in terms of financial products and longer-term loans that match the lifetime of REE projects. KfW's activities and mandate have been more tightly aligned with its country's energy and climate change policy and also had as part of its remit a commitment to help promote German technology and businesses, supporting the deployment of REE technology and projects and having a direct and positive impact on technological change. The CEFC and GIB however have had to operate in a more politically hostile environment and one that isn't as directly aligned with energy and climate policy.

However there are some key similarities for these SIBs, especially in the way they strengthen the functions of REE TISs as discussed above. They are all well equipped in hiring the best industry experts, both technical and financial. They all develop new standards and products, which they then actively diffuse into the market, ensuring learning spill-overs occur, especially to TISs' financial actors. KfW has ensured even the smallest local banks have been exposed to learning spill-overs by distributing funding via these local banks rather than investing with households and projects directly. Finally all three banks go beyond commercial banks' roles by repeatedly being first movers in projects that contain something new or some sort of innovation, whether it be an updated technology or a developer without a strong track record. Australia's CEFC has recently announced that it's mandate has been changed to actively support more innovative technologies, business and organisational setups. It will be interesting to see how they go about this in the future and what sort of impact it will have on their activities and the industry. Our findings indicate that these SIBs can be used in a pro-innovation way. If a country has the political appetite and resources to establish an SIB that can offer concessional finance then the KfW model can have a strong impact on project deployment and diffusion of innovation as long as the SIB doesn't crowd out commercial banks. However the CEFC and GIB models show that an SIB can operate on similar terms to commercial banks and still have an impact on the deployment and diffusion of innovations within the REE fields. Either model can have a positive impact on technological change as long as they leverage their technical expertise and develop legitimacy whilst being a first mover with all types of REE project innovation in order to support the development of countries' REE TISs.

In terms of diffusing and supporting innovations, SIB mandates matter in many ways. When policy makers set up SIBs they should think not only about how these banks can make a difference in terms of capital provision and de-risking but also how they can have an impact on pulling innovation through the system, that is supporting the deployment and diffusion of innovation. SIBs should have guidelines on how to approach innovation and guidelines on being a first mover. However these banks also need the flexibility to respond to the market and to developers and co-investors needs, such as having the flexibility to provide innovative financing instruments or for example equity where needed etc. To have mandates focusing on capital provision and de-risking is too narrow and innovation guidelines are needed in order to better support the diffusion of innovation, assist the development of REE TISs and ultimately to support the desired technological change.

We've seen from the TIS literature and our work here that finance and financial actors are an integral part of any REE TIS and that mobilising financial resources needs to be strengthened in our TISs in order to accelerate the diffusion of REE technologies. SIBs are actively providing finance whilst also addressing risk in various ways that matter in terms of mobilising additional private finance. Our work has begun to look at the risk perception of investors, the de-risking needs of developers and in turn examines how SIBs address these needs. But SIBs also help to strengthen many other functions that are seen as essential within a TIS. Mobilising finance is in fact not about a single function within a TIS but is itself a systemic issue and therefore needs to be addressed by a systemic solution (Jacobsson and Bergek 2011, Wieczorek and Hekkert 2012). SIBs could be a systemic solution to this problem as they can help address systemic bottlenecks thrown up by finance and the financial system.

6 Future Research

There are several limitations to this work and areas that could be further investigated. This work doesn't include an explicit analysis of technology and country (SIB) differences. In order to gain a better understanding of SIB impacts in terms of technological change, future work could include an in-depth look at how well SIBs address de-risking needs for developers, broken down by technology and country. We haven't performed a detailed analysis of the impact each country's political context has had on the effectiveness of SIBs. Nor have we assessed the consistency and coherency of SIB mandates with the corresponding country's climate change and energy policy, which could also provide further insights into the impact and role of SIBs activities. Finally given the importance of learning spill-overs, a more detailed assessment of the mechanisms of how SIBs' activities and new knowledge spills over to private financial actors such as investors and commercial banks etc. would also be of value in determining the impact of SIBs in technological change.

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