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Financing renewable energy: who is financing what and why it matters*

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June 15, 2016

Abstract

Accelerating innovation in renewable energy (RE) requires not just more finance, but finance servicing the entire innovation landscape. Given that finance is not 'neutral', more information is required on the quality of finance that meets technology and innovation stage-specific financing needs for the commercialization of RE technologies. We investigate the relationship between different financial actors with investment in different RE technologies. We construct a new deal-level dataset of global RE asset finance from 2004 to 2014 based on Bloomberg New Energy Finance data, that distinguishes 10 investor types (e.g. private banks, public banks, utilities) and 11 RE technologies into which they invest. We also construct a heuristic investment risk measure that varies with technology, time and country of investment. We find that particular investor types have preferences for particular risk levels, and hence particular types of RE. Some investor types invested into far riskier portfolios than others, and financing of individual high-risk technologies depended on investment by specific investor types. After the 2008 financial crisis, state-owned or controlled companies and banks emerged as the high-risk taking locomotives of RE asset finance. We use these preliminary results to formulate new questions for future RE policy, and encourage further research.

Keywords: renewable energy finance, direction of innovation, financial actor types, deployment, technology risk, investment portfolio

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1 Introduction

Mobilizing investment and innovation in low-carbon energy is one of the key challenges regarding successful climate change mitigation (Dangerman and Schellnhuber, 2013; Grubb, 2014; Semieniuk, 2016). The fact that cumulative carbon emissions determine the intensity of climate change means that speed matters. Proposals for massive investment plans have been floated (King, 2015) and, at the 2015 Paris UN Climate Change Conference, major governments pledged to double their spending on innovation in clean energy to USD 20 billion by 2020 (Mission Innovation, 2015), while a private philanthropic coalition has announced it will invest several more billions of dollars (Gates, 2015).

However, fossil fuel investments still dwarf those into renewable energy (RE). [1] In 2013, RE received less than USD 260 billion, which was only 16 percent of the USD 1.6 trillion in total energy sector investments (Figure 1). Meanwhile, investment in fossil fuels in the power sector, where they compete directly with electricity from RE, rose by 7 percent from 2013 to 2014 (UNEP and BNEF, 2015). Clearly, fossil fuels still dominate energy investment; therefore, a major concern in the transition to low-carbon energy provision is how to obtain enough finance to steer investments into the RE direction.

However, a closer look shows that the news is not all discouraging. Total funding for RE has been rising at a remarkable rate. According to Bloomberg New Energy Finance (BNEF), the amount of RE finance along the entire innovation chain, from R&D for new technologies to asset finance for full-scale power plants, rose from USD 45 billion in 2004 to 270 billion in 2014 globally (Figure 2). This represents a compound annual growth rate of 18 percent. Moreover, in 2014, net investment into new capacity, as opposed to replacing depreciated assets, was

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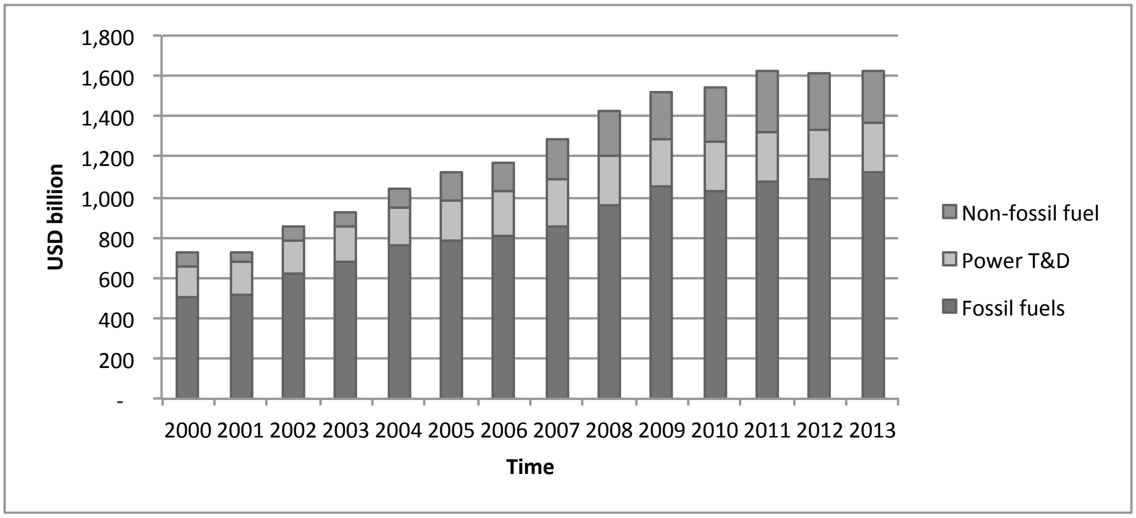
[1] Renewable energy sources comprise wind, sun, water (both as river flow and marine waves and tides), biomass, and geothermal. Alternative low-carbon energy technologies are nuclear fission or fusion, as well as carbon capture and storage for fossil-fuel plants. This paper only considers renewable energy.

Figure 1: Global investment in the energy sector: fossil fuels, power transmission, and distribution (T&D) and non-fossil fuels (mostly RE). Source: (International Energy Agency, 2014).



twice as large for RE as it was for fossil fuels in the power sector; this trend is forecast to continue for the rest of the decade (International Energy Agency, 2015). Therefore, although investment in RE remains low relative to that in fossil fuels, the trajectory is a positive one. The question is how it can be accelerated.

In this paper, we argue that in order to answer the question of RE scale-up acceleration, we must better understand the relationship between types of finance and types of RE investments. A faster transition to a low-carbon-emission energy system does not simply require 'more finance', but finance that is spread across the entire innovation landscape. Not all finance is the same and finance for innovation is not neutral (Mazzucato, 2013a). Some investors may give preference to short-term efficiency gains, while others may pursue more long-run innovation targets, due to different risk tolerance or time horizons by which positive returns are required.[2] Some investors may predominantly invest in only one technology, others may spread their in-

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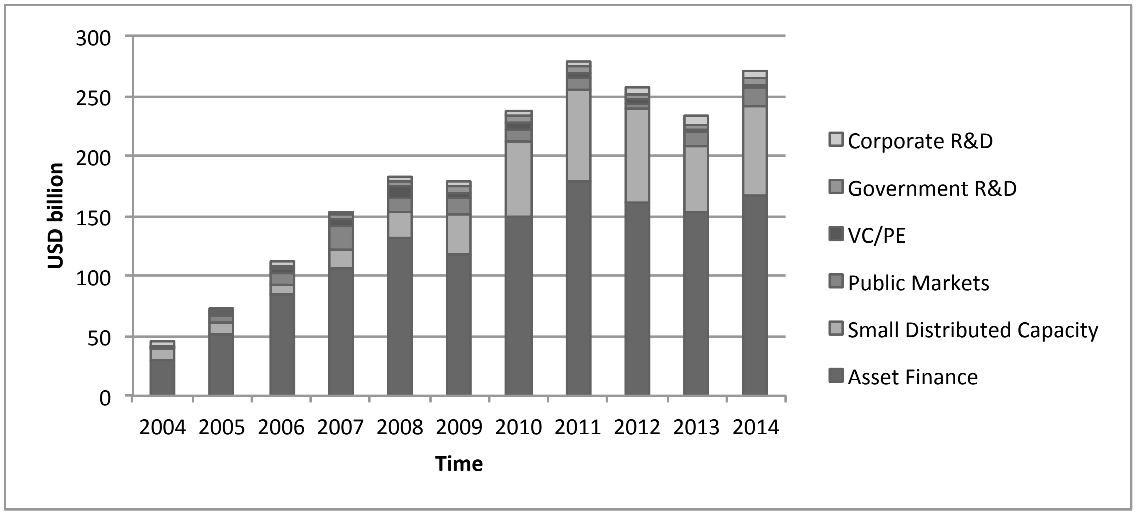
[2] In RE, short-run oriented finance may be appropriate for process innovations in more mature technologies, like onshore wind. Long-run oriented finance may be required to finance less incremental innovations in technologies that are not yet commercialized, such as marine energy.

Figure 2: Global investment into RE by financing type. Source: UNEP and BNEF (2015).



vestments over a spectrum (portfolio) of competing technologies. Therefore, different financial actors will create different *directions* in innovation. Better understanding that directionality is just as important as understanding whether the right 'amount' of finance is coming through.

In various industries, it has been found that non-incremental innovation in technologies with high risk and high capital intensity tend to be underfinanced privately (Auerswald and Branscomb, 2003; Block and M. Keller, 2011), and this is also the case for technologies with such characteristics in RE (Zindler and Locklin, 2010). RE project finance for full-scale powerplants with new and unproven technologies is too capital-intensive for venture capital funds. Banks and project finance have also eschewed this high risk **deployment** of new technologies, and instead focused more on less risky **diffusion** of more mature technologies characterized by incremental innovations (Ghosh and Nanda, 2010), thereby reinforcing the direction towards already deployed technologies.[3] Policies have therefore been aimed at 'de-risking' these invest-

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[3] Terminology is ambiguous, with terms like deployment, commercialization, market formation, diffusion and production/marketing used in different senses across publications, compare for instance Auerswald and Branscomb (2003), Gallagher et al. (2012) and Zindler and Locklin (2010). We will use **deployment** for high risk and **diffusion** for low risk investments.

ments to attract also more risk-averse investors (OECD, 2015). However, some deployment *has* been financed, and rather than asking only how to de-risk deployment, one may also ask what investor types are more willing to invest in risky technologies, and what policies may direct them to do so in greater quantities. Yet, we do not know what investor types are active in deployment because because existing analysis lumps high-risk deployment finance together with lower-risk finance for diffusion into the category of asset finance (see Figure 2 above).

We study which investor types have been financing the deployment of RE technologies through asset finance of different RE technologies. Our approach to dividing up finance by financial actors grouped into investor types (banks, utilities etc.) rather than source of finance (different types of equity, debt and grants) or the financing processes (project or corporate finance or venture capital) provides a new lens for distinguishing types of finance, that has yielded additional insight in other innovation contexts as we will review below. The aim is to gain a more granular understanding of the asset financing process. As innovation has not only a rate, but also a direction (Jaffe et al., 2005; Stirling, 2010), our unveiling of how different types of investors influence the *direction* of innovation is useful for future policy design that takes into account how different types of finance may affect what RE innovation stage of which technology will receive investments.

The remainder of the paper is structured as follows. Section 2 briefly reviews the literature on the relationship between finance and innovation, both in general and for the RE sector in particular. Section 3 introduces the methodology and the data from Bloomberg New Energy Finance. Section 4 presents the results at the level of private and public categories, and section 5 presents the results when disaggregating between the portfolios of 10 investor types' (6 private and 4 public ones) across 11 technologies. Section 6 concludes by discussing the implications of our results for future research and the underlying policy challenges and implications. Two appendices provide details on the construction of our database and the risk index, respectively.

2 Finance and (energy) innovation: a review of the literature

2.1 Alternative types of finance

Innovation must be financed. Joseph Schumpeter, a ground-breaking thinker on innovation dynamics, placed finance at the center of his understanding of the capitalist system, calling the banker the ephor of the exchange economy (Schumpeter, 1934). However, a more granular perspective on innovation and finance requires more attention to be paid to the relationship between the type of finance and the type of firms and investments being financed. This relationship is a two-way process: not only does innovation in firms have an impact on financial sources that are available for them, but the type of finance received may also impact in what direction innovation is undertaken (O'Sullivan, 2005; Mazzucato, 2013a). Due to increasing returns to scale in innovation (Arthur, 1994), what firms and technologies are receiving more finance affects the improvement of their costs and reliability, and through path dependencies the longer-run direction of innovation (David, 1985). Yet, it is primarily the first half of this feedback that has been studied at length (Hall and Lerner, 2009; Kerr and Nanda, 2015). For example, many studies have looked at the relationship between start-up firms and venture capital (Kortum and Lerner, 2000) and the differing reliance of companies on debt and equity (Brown et al., 2009), with established companies relying more on the former and new ones more on the latter.

We know less about the effect that different types of finance have on the subsequent nature of investments. Some initial insights are found in the work that has emphasized the perils of short-term finance in science-based industries (Pisano, 2006). The work of Lazonick and Tulum (2011), for example, has looked at the damaging role of short-term exit-driven (exit via IPO or buyouts) venture capital funds in the biotechnology industry, which they claim has produced many product-less IPOs (PLIPOs); that is, companies that go public on the stock market without having produced anything.

A focus on financial actors rather than the source of finance, financial instrument or financing process, helps analyze the feedback of finance on investments. Until the 1970s, the private banking system was the key to financing investment in the real economy; indeed, banks like Chemical Bank got their name from their role in financing the chemical sector (Mazzucato and Wray, 2015). However, since the deregulation of the 1970s, private finance has become increasingly short-termist and less willing to finance the long investment cycles in the real economy. In the American and British economies, short-termism has come to distort the perception of long-term projects' net present value in investors' eyes, and has altered the type of projects that receive funding (Haldane, 2016). In this context, projects that take a long time to mature – such as in technology development and innovation or in infrastructure – tend to be under-funded by the private banking system (George and Prabhu, 2003; OECD, 2007).

The fact that innovation is so uncertain, and can take a very long time, suggests that it is best served by patient, long-term committed finance. Indeed, finance for upstream R&D and downstream capital-intensive projects such as space exploration or health have historically come mainly from the public sector (Foray et al., 2012). In some countries, finance has been provided via innovation agencies like DARPA[4] and/or publicly funded company finance initiatives such as SBIR[5] in the USA. In countries such as Germany, China, and Brazil, and in the European Union, state investment banks have been providing patient finance for projects that aim to address 'great challenges' such as the current energy transition (Schapiro, 2012; Sanderson and Forsythe, 2013; Mazzucato and Penna, 2014; Mazzucato, 2015).

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[4] Defense Advanced Projects Agency (Abbate, 1999). See discussion of DARPA's role in US innovation in Mazzucato (2013b).

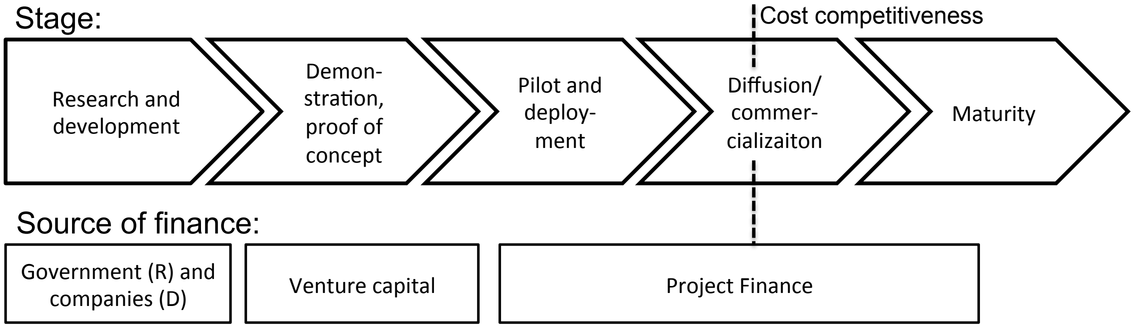
[5] Small Business Innovation Research Program, which provides early-stage finance to companies, through procurement (M. R. Keller and Block, 2013).

2.2 Alternative types of finance for RE

Financing the transition to a low-carbon energy supply requires patient high-risk finance due to the high uncertainty of the new technologies involved, and long cycles in innovation (Gallagher et al., 2012). The different financial actors providing finance in RE innovation have been studied extensively in R&D. While R&D in the energy sector has historically been low compared with other sectors (Costa-Campi et al., 2015), private R&D expenditures fell to historic lows in the at the beginning of the 21st century (Nemet and Kammen, 2007). Between 1990 and 2004, R&D expenditure in utilities dropped by 72 percent in the US and by 62 percent in Europe; the reduction was strongest in utilities after they were privatized (Sterlacchini, 2012). Similarly, venture capital fund investments into technology-developing companies have been falling from peak levels in the early 2000s, and VC-backed firms tend to produce low numbers of patents (Criscuolo and Menon, 2015; Parris and Demirel, 2010). There is growing evidence that public investment banks are active in financing energy R&D (Mazzucato and Penna, 2015), and in 2007 the US established ARPA-E, a dedicated energy R&D funding agency (Cunningham and Roberts, 2013).

The detailed knowledge about investors active in R&D and venture capital investing is not a coincidence. Innovation theory has long been influenced by the linear model of innovation and market failure theory. The former views innovation as passed on along a set of stages where causality runs from upstream to downstream stages (Godin, 2006). The latter starts from the assumption that markets provide innovation socially optimally, unless they are impeded from functioning properly; the impediment is typically located as an inability to capture rewards from inventions at the R&D stage (Popp, 2011), even though more careful analyses fine market failures at later stages (Jaffe et al., 2005). Depicted as an 'innovation chain' in Figure 3, this theory highlights the role of of private corporations and governments fixing the market

Figure 3: An innovation chain with types of finance



failure at the 'upstream' research and development stage, and that of venture capital funds 'midstream' at the proof-of-concept stage. Subsequent 'downstream' stages that see the pilot project deployed at industrial scale, and bring down cost through process innovation until a cost-competitive technology can be widely diffused, do not specify actors. In the case of renewable energy, project finance is added as a generic category through which finance should find its way to RE investments. The linear model and market failure theory skew attention to individual processes to the upstream part of innovation. Although these theories highly oversimplify the process of innovation (Gallagher et al., 2012) and non-linear feedback effects from learning during deployment to lab-based research make this downstream stage crucial for both diffusion as well as for further upstream development (Junginger et al., 2005; Watson et al., 2015), their simple structure is still invoked frequently.

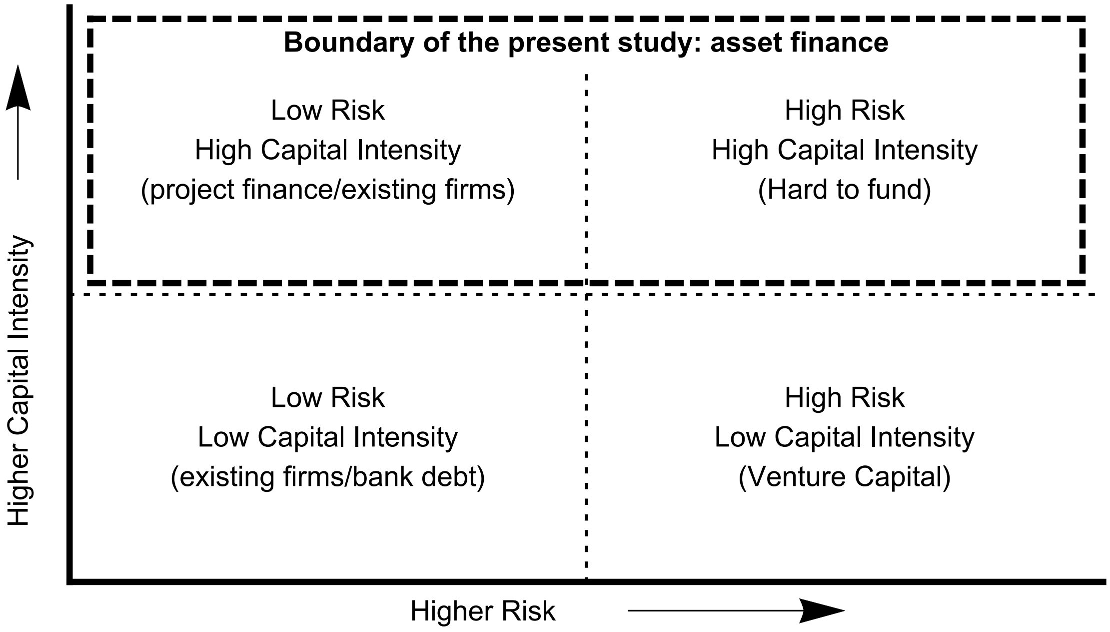
Energy researchers have paid less attention to the downstream innovation stage, comprising deployment and diffusion, than to the R&D stage (Sagar and van der Zwaan, 2006; Popp, 2011). However, several RE technologies are now sufficiently developed through research to have entered a pilot and demonstration stage and be deployed at scale. The fact that finance for such capital-intensive high-risk projects is often missing (European Commission, 2013; Veugelers, 2012; Zindler and Locklin, 2010) shows that a better understanding of potential investor types for this stage of the innovation process is pivotal to avoid financing bottlenecks in the renewable energy scale-up.

The literature explains who is *not* investing in risky deployment. It is not part of venture capital's activity (Ghosh and Nanda, 2010), as the capital required per investment is typically an order of magnitude larger than that of technology development (Zindler and Locklin, 2010). At the same time, these projects are too risky for banks (Kalamova et al., 2011). In fact, Ghosh and Nanda (2010) proposed a classification of RE investments that comes closest to associating particular investor types with particular stages in RE innovation based on expert interviews. Figure 4 is an adaptation of Ghosh and Nanda's results: they propose that the development of new, high-risk technologies that require small amounts of capital is funded by venture capital, while the deployment of high-risk technology has no obvious funder. According to them, project and existing firm internal finance only becomes available when deployed technologies have become commercially viable and the risk is reduced. The Ghosh-Nanda graph exemplifies our ignorance of the quality of finance needed for deployment. The present study examines the upper two quadrants for what investor types have been helping to bring technologies through the high-risk deployment stage towards lower-risk diffusion. This focuses our analysis on capital-intensive asset finance for both low and high-risk technologies.

2.3 Financing RE deployment: towards a granular analysis

Before moving to the details of our study, we survey the literature on RE deployment financing. Although there is a growing empirical literature on finance for RE deployment through asset finance with both aggregate and micro-data, it does not distinguish types of finance or the riskiness of investments in any detail. The most granular distinctions are public and private actors and broad technology sectors such as solar and wind. With aggregate data, there is

Figure 4: Risk-capital intensity classification of RE finance



mounting evidence that upstream innovation policies by government positively impacts private finance for RE deployment (Johnstone et al., 2009; Popp et al., 2011), and that the same holds for policies aimed at private downstream activities (Eyraud et al., 2013).

An increasing number of studies have used micro data to further distinguish the flows of finance. Public policies are found to mobilize finance from institutional investors (Polzin et al., 2015), and to have a positive effect on cross-border merger and acquisition activity (Criscuolo, Johnstone, et al., 2014). It has also been found that certain types of policies are more conducive to company spending on renewable energy innovation than others (Veugelers, 2012), and may induce venture capital investments into renewable energy companies (Criscuolo and Menon, 2015).

Apart from studies focusing on public policies, two contributions have considered public investment explicitly. These studies have found that both public investments and policies have a significant positive impact on private investment (Cárdenas Rodríguez et al., 2014; Haščič et al., 2015). In addition, Cárdenas Rodríguez et al. (2014) found that public investments are taking place within those technologies where other public policies have had little effect on mobilizing private finance. This suggests a more differentiated investment behavior across technologies and investor types, which may be linked to the risk profile of the technologies.

(Dinica, 2006) emphasized that potential investors chiefly weigh the risk and profitability potential of different support policies; other studies have found, for a sample of European investors, that beliefs and risk preferences influence their investment behavior (Masini and Menichetti, 2012; Masini and Menichetti, 2013). While these studies do not distinguish investor types, (Bergek et al., 2013) studied Swedish power plant builders – utilities, farmers, cooperatives – and highlighted that different builder types may have various non-profit maximization objectives that influence their investment choices. This builds on early work that identified six investor types (anonymous, industry, large utility, house owner, municipality, energy community) and discussed how each type's appetite for risk varies with their motives for investment (Langniss, 1996).

2.4 Our study in the context of the literature

In summary, although there are conceptual arguments for why different investor types may display varying behavior in renewable energy asset finance for deployment of RE technologies, quantitative empirical studies have not followed up and investigated these hypotheses at a disaggregated level. Historically, certain types of investors have been more likely to provide the risky, patient, and large amounts of finance needed to achieve innovation. Yet, for RE technologies, the patterns of finance in deployment – who finances what – are not well understood. We know that the landscape of renewable energy finance consists of a heterogeneous set of actors (Buchner et al., 2015), but we do not know much about what their role is.

The present paper attempts to fill this lacuna by studying the heterogeneity in financing decisions of investor types in the asset finance of RE technologies. By grouping investors into types, and financial deals into technology and risk classes, we analyze the risk characteristics of investors' portfolios. In particular, based on the puzzle of who funds high-risk deployment identified in Figure 4, we ask which types of investors have financed the high-risk, high-capital-intensity deals; and which ones have preferred financing lower-risk diffusion deals. Our goal is to better understand which investors have enabled new technologies to come to the lower-risk diffusion stage, and as a consequence how the characteristics of finance can affect the nature of investment patterns such as their direction towards certain technologies in RE innovation. Given the rising number of RE investments, we hope that by studying this dynamic the policy question will move beyond the quantity of finance and more towards the quality.

3 Methodology and data

3.1 Methodology

We take a portfolio perspective and analyze risk patterns of types of investors in RE asset finance cross-sectionally and over time. We require a definition of investor types and of risk. For investor categorization, our analysis proceeds in two steps of growing granularity. First, we group investors into public and private categories based on whether they are owned mainly by private or by public entities. Second, we distinguish functional types within each of the two categories that are salient in the context of RE finance such as utilities. The 10 types selected are described with the dataset below.

That leaves a definition of risk. In the finance literature, risk of an asset is conventionally defined as the variance in its returns (Markowitz, 1952). With risk-averse investors, an asset with higher variance in returns requires a higher mean return to attract investment. Hence, the rate of return required by an investor to be willing to invest into an asset is a good indicator of risk. This is the required rate of return for corporate finance decisions, the internal rate of return for project finance sponsors, and the interest rate for loans.

However, with our asset finance data, the rates of return or interest remain undisclosed. In the absence of a direct risk measure for each deal, we construct a technology and country specific risk measure. In principle, as a technology is deployed more often, the experience in building and operating power plants grows and the uncertainty, and therefore the risk, of the technology fall. One measure of success is whether assets live for their projected lifetime (often 20 to 25 years with RE power plants). In addition, market risk impinges on the decision to invest through the cost of the RE technology. RE technologies compete with each other and fossil fuels for the provision of electricity (and vehicle fuel in the case of biofuels). The cost of technology is typically estimated as the 'levelized cost of electricity' per unit energy produced, which divides the total capital expenditure and maintenance cost by the expected units of electricity produced over the lifetime of the power plant. Finally, country or regulatory risk refers to the uncertainty over whether countries' RE support policies may be reversed.

We collected information on each of these categories of risk through publications and existing estimates of technology and market risk for 11 distinct technologies, and through the "Renewable Energy Country Attractiveness Index" (RECAI) published by Ernst & Young for every quarter from 2004-2014 for 40 countries for regulatory risk (Ernst & Young, 2016). Based on this information, we assigned a risk indicator to each asset finance deal depending on the technology used and the year, and shifted it by a transformation of the Ernst & Young country risk score for the quarter in which the investment was made. The indicator is one-dimensional, like a risk premium to be added to an interest rate. Since the measure is a heuristic proxy, in line with existing literature we only distinguished low, medium or high risk, represented by the numbers $\{\frac{1}{6}, \frac{1}{2}, \frac{5}{6}\}$, which are only modified by country risk scores that range between $-\frac{1}{6}$ and $+\frac{1}{6}$. Hence, any actor's portfolio has a risk exposure of between 0 (low) and 1 (high). The risk R of the investment portfolio of type i for year t is calculated as the weighted average

$$R_{it} = \frac{1}{I_{it}} \sum_{j=1}^{11} (r_{ijt} I_{ijt} + c_{ijt}), \quad i = 1, ..., 10, \quad t = 2004, ..., 2014 \tag{1}$$

of investments I per technology j, weighted by its low, medium or high risk, r, and shifted by the country risk score c.

The details of the risk assignment procedure are provided in Appendix A. The resulting risk measure for technologies in every year before country weighting are displayed in Table 1. While most technologies display a stable low, medium, or high risk over time, the risk of photovoltaic solar energy technologies (numbers 3 and 4) falls during the period. Albeit heuristic, our characterization of risk is more thorough than any we have found in the literature.

Table 1: Technology risk classifications 2004-2014

	Technology	Sub-technology	Risk
Wind			
1	Onshore		Low
2	Offshore		High
Solar			
3	Crystalline silicon photovoltaics (PV)		High (2004-06) Medium (2007-09) Low (2010-14)
4	Other PV	4a) Thin film PV	High (2004-09) Medium (2010-14)
		4b) Concentrator PV (CPV)	High
5	Concentrated Solar Power (CSP)		High
Biofuels			
6	1st-Gen		Low
7	2nd-Gen		High
All other technologies			
8	Biomass and Waste	8a) Incineration	Low
		8b) other sub-technologies	Medium
9	Geothermal		Medium
10	Marine		High
11	Small hydro		Low

With a risk measure in hand, we analyzed portfolios' riskiness visually and with descriptive statistics in every year. We first compared public and private sources' risk taking, as a lot of the theory tends to distinguish only those two actor categories. In a second step, we compared the risk of 10 investor types. Although we computed a simple proportion test in one case, we abstained from further inferential statistics, for two reasons. First, we recognize the qualitative nature of the risk measure and the significant gaps in our data where quantitative statistics would convey an artificial precision. Second, we want to place more emphasis on presenting the heterogeneity in results and open up these issues for further research.

Table 2: Technologies, ranked by share of investment received in 2004-14

	Technology	Share of finance received in %
1	Onshore wind	49.2
2	Crystalline silicon PV (c-Si PV)	18.1
3	Biomass and waste	8.5
4	Conventional biofuels	6.7
5	Offshore wind	6.7
6	Concentrating solar power (CSP)	3.7
7	Other PV (thin film, CPV)	2.5
8	Small hydro	2.2
9	Geothermal	1.4
10	Advanced biofuels	0.7
11	Marine	0.2

3.2 Data

Our study is global in scope, covering the actor and technology patterns of asset finance for the planet's RE power plant deployment over the period 2004-2014.[6] We used a rich dataset that we constructed from three different Bloomberg New Energy Finance (BNEF) asset finance databases (of sponsor, lead arranger, and syndicated lender participations), and one database with organization characteristics (BNEF, 2015b; BNEF, 2015c).[7] We improved the quality of the data by adding information from a dataset on state bank finance (BNEF, 2014a) and from extensive research of publicly available sources (news or investor websites) about specific deals and organizations. We used Ernst & Young's RECAI for the country risk assignment. Our final dataset presents asset finance in terms of individual investors' contributions to individual deals for newly built RE capacity additions of different technologies. The details of the dataset construction are provided in Appendix B.

We distinguished investment flows to 11 different technologies, which are listed with their

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[6] The data comprise 39,135 participations in 28,395 unique asset finance deals. BNEF estimates that coverage is upward of 80 percent of all deals in 2004-2014.

[7] Asset finance excludes investments into small distributed capacity of less than 1MW. A typical household rooftop solar module has a capacity of 1-4kW.

shares in Table 2. Cumulatively, half of asset finance supported onshore wind power plants, followed by 18 percent for crystalline silicon photovoltaic (c-Si PV) module power plants, which reveals a clear direction of finance towards those technologies. All other technologies received less than 10 percent of total investment each. We disaggregated technologies more than typical analyses, which highlights the heterogeneity in terms of finance received between technologies within broader technology sectors.

We distinguished 10 investor types: six different private and four public ones. Private investors are split into three non-financial and three financial types that differ by their function with respect to the energy sector. The non-financial types are RE sector companies (component manufacturers, project developers, and a few fossil fuel firms with investments in RE), utilities, and companies that have their main business in other sectors, and are thus more diversified.[8] The financial types are commercial banks, non-bank financial firms such as private equity firms and pension funds that are also called institutional investors, and not-for-profit investors such as foundations or co-operatives.[9] The public investors have been split up into government agencies, which include a small number of research institutes, and three types of state-owned or state-controlled entities that match their private counterparts: state banks, which include state-owned investment funds; state-owned/controlled utilities; and other non-financial state-owned/controlled companies.[10]

Any interpretation of the data must account for the fact that the underlying databases

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[8] 77 percent of the investments in the dataset made by energy firms come from companies whose main market exposure is in RE, and the remainder are typically fossil energy companies. Only 14 percent of investments in the dataset made by companies classified in other sectors is from those whose main market is in RE – and these are biofuel producers that are not classified in the RE sector.

[9] The non-profit investors include a small number of non-financial cooperatives able to finance large projects included in asset finance.

[10] A company is state-controlled if it is stock market-listed but the government or its agencies retain a controlling stake. The French utility EDF is an example, where the state owned 84.9 percent of the share as of December 2015 (EDF, 2016, 487, Table 7.3.8). In the following, the term 'state-owned' includes companies that are state-controlled.

Table 3: Investor types

Category	Type (and abbreviation)	Share of finance provided in %
Private	Energy firms	11.3
	Private utilities (Priv. utilities)	17.1
	Other non-financial firms (NFF)	10.4
	Commercial banks (Banks)	11.7
	Non-bank financial firms (FIN)	7.2
	Charities/not-for-profit (Charities)	0.8
Public	State Banks	* 15.0
	State utilities	12.6
	Other state corporations (State corps)	4.4
	Government agencies (Gov. agencies)	2.5
Unclassified	Unclassified	* 7.6

* After correcting using aggregate state bank statistics (BNEF, 2014a). State banks provide 7.6 percent of disclosed deals, and 15 percent are provided by unclassified investors.

have substantial amounts of missing data with respect to investors, and yet these are the most comprehensive data available. We improved data quality as follows. Firstly, shares of actors are missing, so unless we were able to find shares from publicly available data – for example from European Investment Bank reports – we imputed shares by distributing asset value equally across participants.[11] Secondly, there are significant gaps in the industry classification of actors. We manually added type information for unclassified investors based on information found on organization websites and corrected a number of data entry errors.[12] However, even after these corrections, 15 percent of all invested funds could not be attributed to any actor

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[11] The raw BNEF asset databases record deal value, debt value, and investor shares. Although 55.8 percent of deal values and 77.2 percent of participant shares have not been disclosed/recorded, the actual missing participant shares are only 23 percent, because the remaining missing shares belong to projects financed by a single equity sponsor without debt, which means the share is 100 percent. When there are sponsors (equity) and lenders (debt), the debt value is subtracted from the total deal value to arrive at the residual of equity. BNEF imputes equity and, if a debtor is known, debt for undisclosed deal values. However, shares of individual investors remain to be imputed or are left blank.

[12] A number of data entry errors have been corrected in the ownership structure data, such as switching the 100 percent government-owned State Bank of India from a ‘quoted company’ to a ‘state-owned commercial entity’, and in the industry classification, such as moving the World Bank Group from the ‘consumer discretionary’ sector to the ‘financials’ sector.

type. Thirdly, lenders (debt) are underrepresented because many deals do not report their debt sources, in which case BNEF attributes the entire deal to the sponsor (equity). That this is an overstatement can be shown for state banks; aggregate renewable energy finance statistics show that state banks invest significantly more in asset finance than the deal-level data reveals (BNEF, 2014a). Accounting for these investments doubles the share invested by the state banks (and subtracts an equal percentage from other investors that benefit from this debt finance).[13] Because the deal-level datasets omit these important debt providers, the detailed portfolio analysis cannot make use of this correction and inevitably overstates the role of (mostly private) sponsors.[14]

With these caveats in mind, Table 3 shows the cumulative shares of each investor. No single investor is dominant, with most shares being between 10 and 18 percent; charities are the only investor class that invests less than one percent of the total. Government agencies are the second smallest actor, but their actual impact on total investment is understated because this data does not reflect government loan guarantees to individual projects or investment grants. The result sections will trace these figures in more detail over time and technologies, and will associate investment with the risk measure, both for the broad public and private categories, and the 10 investor types.

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[13] We assumed that 15 percent of the state banks' undisclosed portfolio finances large hydro, based on reported large hydro investment volumes (Louw, 2013) and that 70 percent of the total portfolio finances new build, large-scale asset as opposed to refinancing or small-scale investment. The resulting figures tally with the KfW's reported renewable energy finance provided for businesses.

[14] For instance, there are 6194 equity participations in China in deals that do not show any debt and sum to USD 308 billion. However, the state bank deployment data shows that this equity volume veils around USD 25 billion in undisclosed renewable energy loans by the China Development Bank over the period 2007-2013 alone. When aggregating investments, we added undisclosed state bank investments to their total, and subtracted it from the unclassified investors, the remainder of whose investment is counted in the private category.

4 Results part one: public and private finance

Although splitting asset finance into public and private figures is still aggregative, it is also instructive, for two reasons. First, discussions about RE finance informed by a market failure theory assume that mainly private actors are active in the deployment stage while public actors invest in upstream research. The split into private and public investments will test this assumption's usefulness. Second, this split will provide an introduction to the more detailed analysis in the subsequent results section looking at more granular investor types. While lumping together state-owned enterprises with government agencies conflates very different types of investors, from an ownership perspective both of these types are 'public', and display similarities in their risk taking, as the results by investor type will reveal.

We first analyze total annual private and public investments in asset finance, an elementary statistic that is not available for this timespan in the flagship publications of global RE finance trends (UNEP and BNEF, 2015; Buchner et al., 2015). The left panel of Figure 5 shows that over time, a dramatic shift took place from an asset finance market supplied in 2004 to 90 percent by private finance to a market with almost equal splits between private and public sources in 2014. The decisive year was 2009, when public investment rose while private investment fell due to the impact of the Great Recession. In other words, since 2009, public actors have provided almost half of all RE asset finance in the world. This division of finance is similar to that in R&D (BNEF, 2015d), which the innovation chain would identify as the locus of public investment.

While private finance has been greater in volume, public finance has provided more high-risk deployment finance as a share of its total investment. The right-hand panel of Figure 5 measures the risk exposure of public and private actors in every year. Private exposure to high risk hovered consistently around 15 percent, but peaked in 2009-2011. Meanwhile, public risk fluctuated around 20 percent, except in 2004. To make the difference more precise, a simple proportion test checks whether the public risk exposure is significantly higher than private investment. The null hypothesis that the share of public money flowing to high-risk investments is no higher than for private money is rejected in six years at the 95% confidence level as the inset plot shows.[15]. Only in 2010 was private risk-taking significantly higher than public risk-taking.

One reason why private finance took higher risks in the years 2009 trough 2011 may be to take advantage of additional government spending not reflected directly in the asset finance data. In 2009, during the Great Recession, an additional USD 38 billion was committed by governments to boosting renewable energy investment as part of bigger Keynesian stimulus packages (Robins et al., 2009). These stimuli operated not only through direct investments, but also through grants and loan guarantee programs (Mundaca and Richter, 2015). Although an analysis of causality is beyond the scope of the present study, the data suggest that these stimuli may have had an impact not only on the volume, but also on direction of private investment to more risky asset finance.

The most important change over time in RE finance was China's rise. In 2004 only 8 percent of global RE asset finance were invested in China. By 2014, this share had risen to 46 percent. China has an especially large proportion of state-owned enterprises; therefore, the results for the world may be skewed towards the Chinese case while misrepresenting what is happening in the rest of the world. For that reason, the same set of results is shown with the exclusion of Chinese asset finance in Figure 6. The left-hand panel shows that while the volume of non-Chinese public investments did not quite catch up as much with private ones from 2009 onwards, public investors are far from insignificant outside China, and recorded a growth of 230 percent from 2006 to 2014, while private investments shrank by 12 percent over the same

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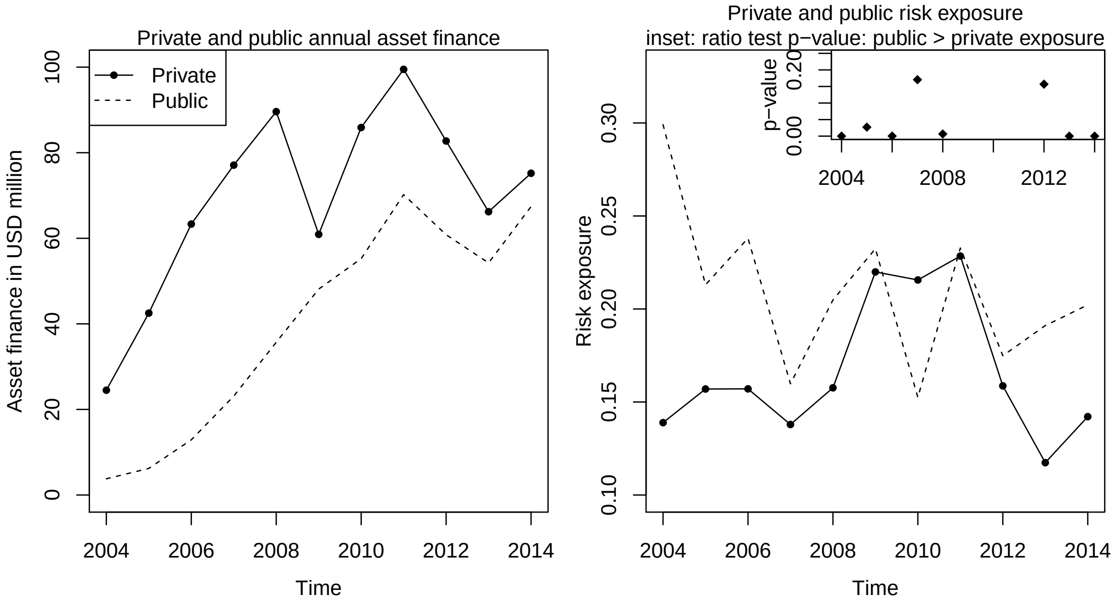
[15] The number of deals is used as the number of trials for the test.

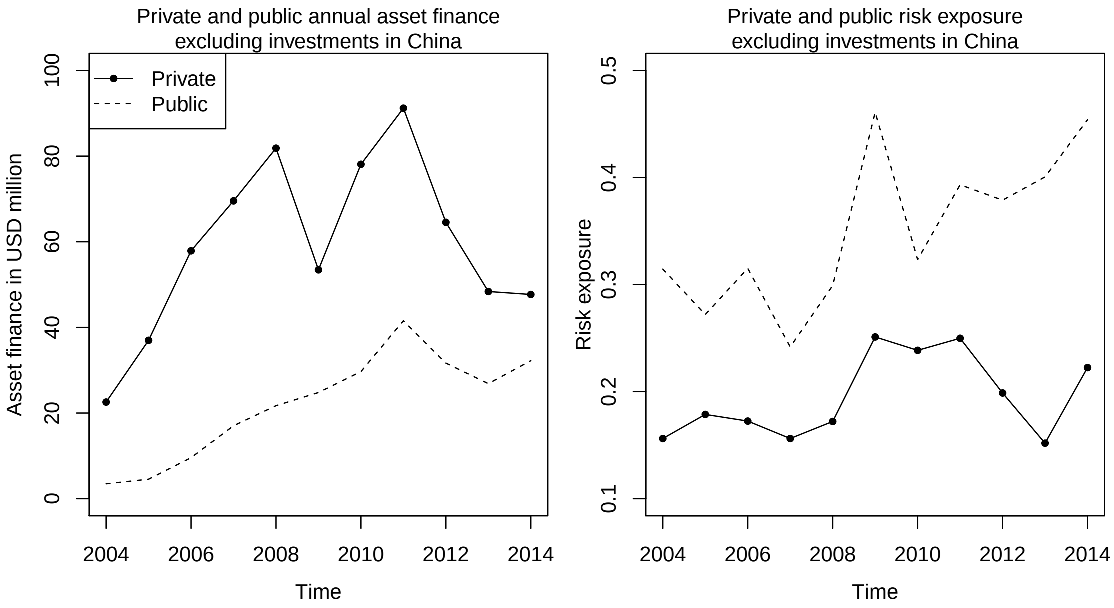
Figure 5: Volume of annual public and private asset finance, exposure to risk, and p-value of a proportion test for public risk exposure being greater than private e



period. As a result, even in the market economies of the OECD, which make up the bulk of the investment in Figure 6, public sources of finance are playing an increasingly pivotal role in stabilizing the investment volume.

The private risk exposure in the right-hand side plot of Figure 6 is slightly higher and similar in trend when excluding China. However, the public risk exposure is entirely different when Chinese state-owned enterprises are excluded. After an initial drop, public risk exposure followed a rising trend to almost 50 percent. The proportion test reports that public investment was significantly more risk-taking than private finance in every year as a share of its portfolio. In absolute terms, that is the total of money invested that was exposed to high risk, deployment was financed to three quarter by private actors until 2008, while almost half was financed by public actors in 2009. Subsequently the public share saw a slightly increasing trend, to end at 56 percent of all deployment financed by public actors with and 58 without investments made

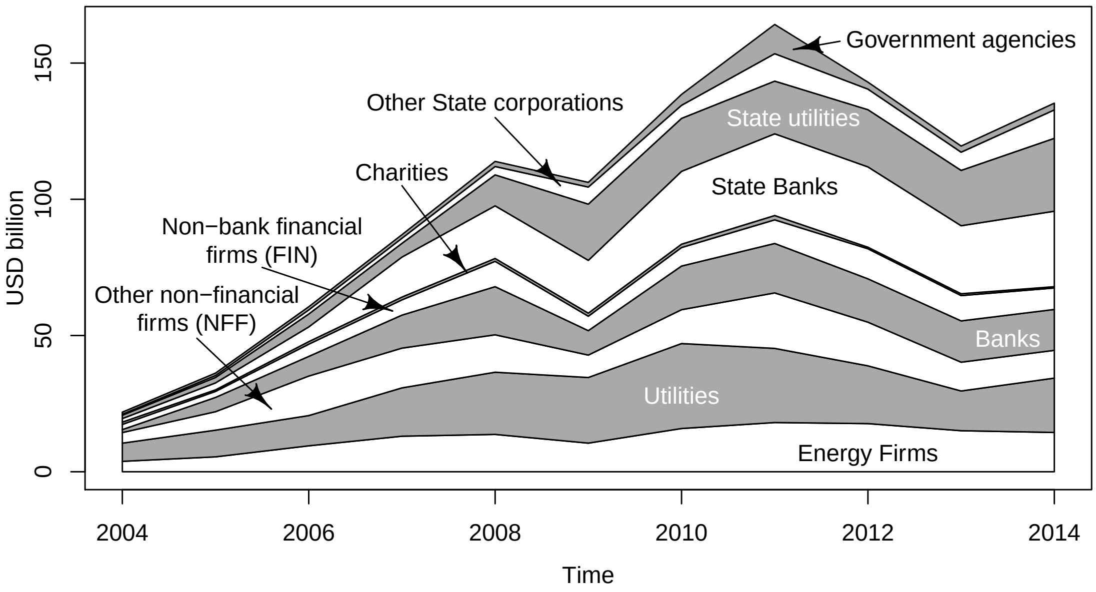
Figure 6: Volume of annual public and private asset finance and exposure to risk, excluding investments made in China.



in China in 2014.

These results are striking from the point of view of innovation theory. On one hand, they confirm the preconception that public actors help direct innovation finance more towards deployment by taking on more risky investments due to their ability or willingness to be patient with returns. On the other, they contradict the theoretical view that 'downstream' innovation stages are outside the scope for direct public intervention. In spite of widespread energy sector privatization and public sector austerity, public investors are playing an increasingly important role, both in financing the deployment of high-risk technologies and the diffusion of lower-risk ones. We discuss the implications for future public policy in the concluding section. Before that, the second results section delves deeper into these results by disaggregating the private and public categories into more granular investor types.

Figure 7: Stacked volumes of annual asset finance by investor type



5 Results part two: ten investor types

A more granular view of financial actors distinguishes 10 types. A theory of financing innovation that distinguishes the types of investors is useful if types display distinct investment behaviors. The following results are a first test of such usefulness in terms of the direction of investments.

5.1 Investor type finance volume

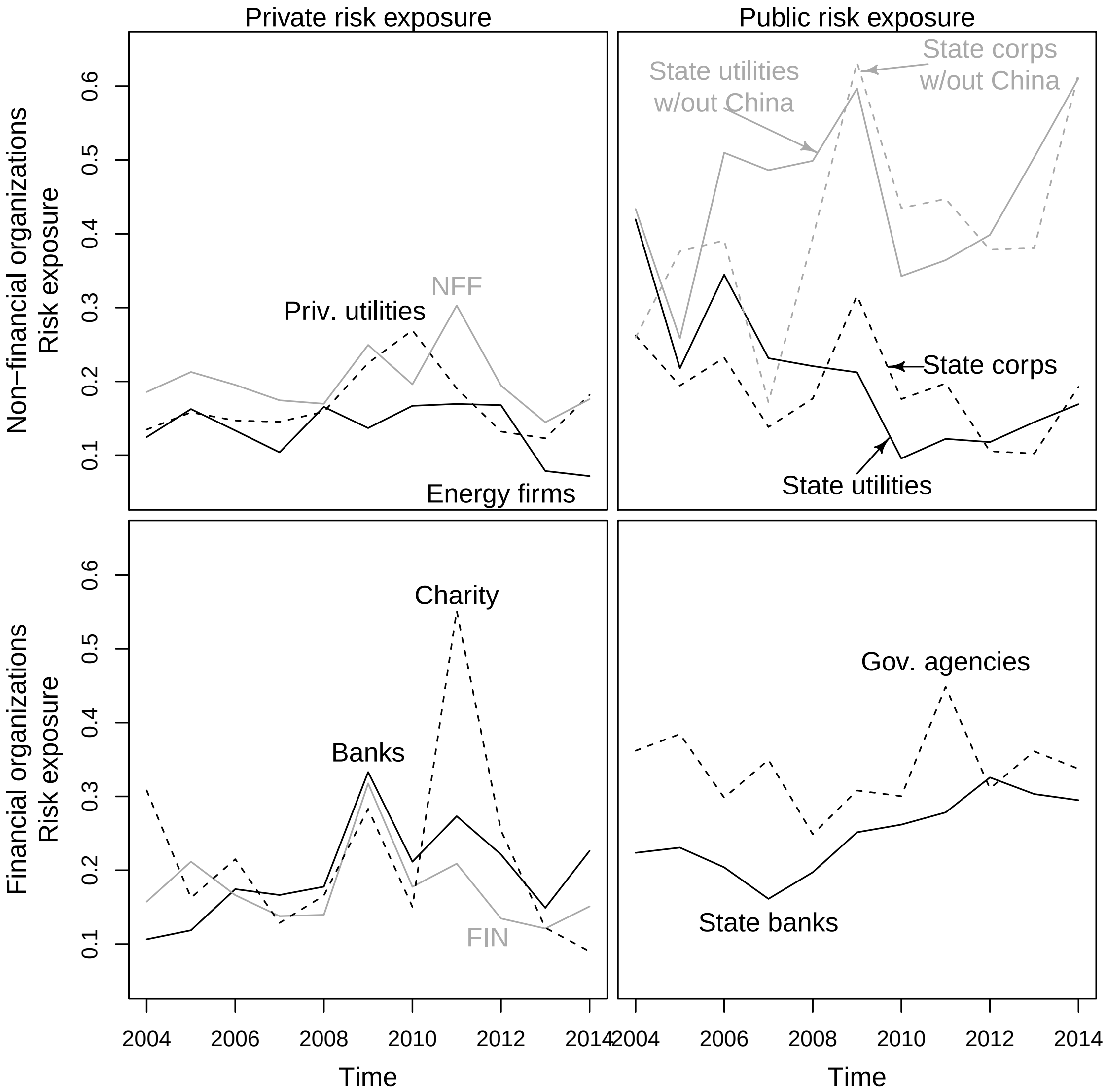
We split up the total private and public investments by investor type in Figure 7. Private types experienced strong investment growth until the financial crisis hit in 2008. The overall private trend of sluggish growth and decline after 2008 translated into its component investor types; the 2008 investment levels of any type were hardly surpassed in the remainder of the period with the exception of one or two years. On the public side, one can see that investment growth was mainly driven by the rapid expansion of state banks and state-owned utilities. While the latter stagnated between 2009 and 2013 due to collapsing European utility investment (counterbalanced by Chinese investments), state banks and utilities emerged in 2012 as the first and second largest investors in RE asset finance. Governments and their agencies invest a very small share in all but the year 2011.

5.2 Investor type risk

In order to analyze risk exposure, we group investor types into four groups: private non-financial and financial actors, and public non-financial actors and banks and government. Their risk exposure by investor type is shown in Figure 8. The entire plot shows that risk exposure was heterogeneous in cross sections and over time, with risk exposure ranging from less than 10 percent to above 50 percent. Looking more closely, the left column of private types shows that, on average, financial organizations took on more risk in their investment portfolios than non-financial organizations. Among non-financial institutions, the more diversified companies not from the energy sector (NFF) took on the highest risk on average, energy firms the least and utilities were in between. On the financial side, banks invested in a riskier portfolio than institutional investors (FIN). Not-for-profit organizations, almost negligible in volume, did not finance a riskier portfolio than the other types, 2011 being an outlier. In the right panel, too, financial public actors seem to have financed a more risky portfolio than nonfinancial companies; however, removing investments in China by non-financial state-owned companies clearly shows that public non-financial institutions in the rest of the world invested into the most risky portfolios (the series in the other panels barely change when the Chinese investments are removed).

Comparing the plots in one row, there is a sharp divide between private and public non-

Figure 8: Time series of investor type portfolio risk exposure



financial institutions. The latter invest in highly risky deployment, while the former are engaged in diffusion of more established technologies, with a slight increase in risk in the post-crisis years of 2009-2011. In China state-owned corporations played the diffusion role, too. The lower row shows a less clear-cut divide between private and public financial institutions and the government. Until 2011, the risk profile of commercial and state banks was not widely divergent (with the caveat that half of state bank investments are not disclosed and therefore cannot be assigned a risk), and private banks' portfolios took on a relatively high-risk profile around the time of the crisis. State banks only left commercial banks behind in terms of risk after 2011. Government agencies maintained a consistently high risk profile. Meanwhile, institutional investors, had one of the least risk-taking profiles overall.

These results show clearly that investor types build heterogeneous investments portfolios, and some are more risk-averse than others. Among private investors, commercial banks and non-financial non-energy firms take on more risky investments, while after excluding China with its different market structure, state-owned non-financial corporations turn out to be the most risk-taking deployment investors of all actor types. Energy firms and institutional investors are low risk takers, making them unsuitable candidates for scaling up deployment. The results ratify that distinguishing investor types yield new insight into RE finance, by showing how differently they direct their investments. The remaining subsection explores an additional consequence of heterogeneous investor types: how they have driven finance towards different RE technologies.

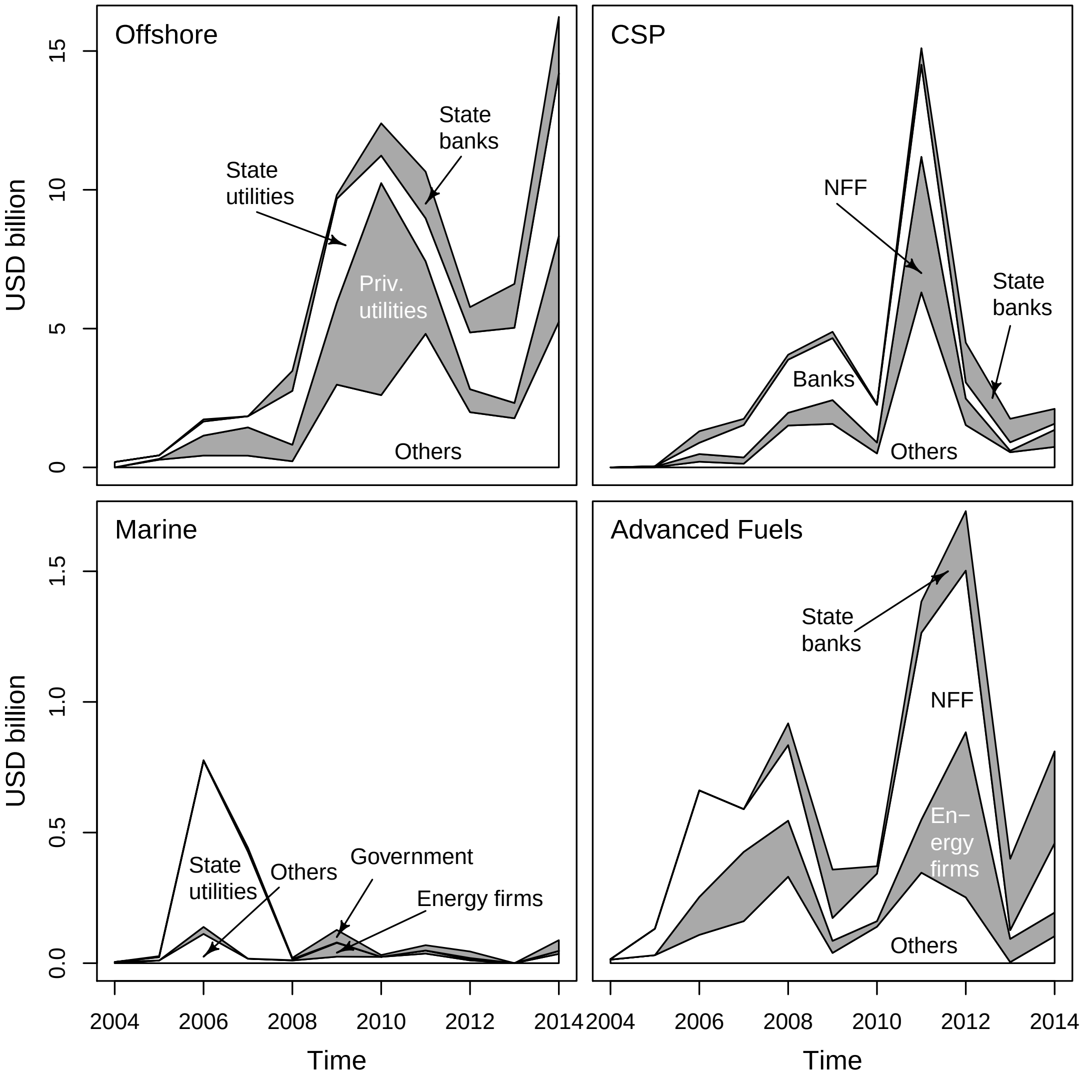
5.3 Risk taking and technology choice

Underneath the risk taking lies a real technology direction within RE investments. Looking not only at high risk and low risk but also which of several high or low-risk technological alternatives helps understand whether investor types set a direction even within one stage of innovation.

The evidence suggests they do. Although most investor types invest at least some funds in at least one year in each of the 11 technologies, there are vast differences between how different investor types allocate their investments across technologies, and hence particular types skew the direction of innovation towards one or another technology. Figure 9 illustrates this for the four high-risk technologies – offshore wind, concentrating solar power (CSP), marine and second generation fuels. The offshore plot shows that private and state utilities, and state banks have together invested more than 70 percent of cumulative investments into this sector, and an even higher percentage in the years before 201. In CSP, the biggest three investor types invest two thirds of the total, and almost all of it before 2008. They are commercial banks, non-financial non-energy firms, and state banks in this order, although huge government investment only in 2011 almost brings this actor to the state bank investment level. In marine technologies, where the total investment is almost two orders of magnitude lower, the imbalance is even bigger with the top three investors (state utilities, government and energy firms) investing 80 percent of all funds, dominated by an early investment into a pilot facility by one state utility. The share of 80 percent is also achieved by the three top investors into advanced fuels: energy firms, non-energy non-financial firms and state banks.

All plots in Figure 9 illustrate that how much finance a particular high-risk technology receives is depends largely on only a few investor types, and therefore the cumulative investment and the experience and ability to bring down costs does, too. Investment volume also varies more strongly over time for high risk technologies than the total. Moreover, most types are only strongly active in one or two high-risk technologies, hence they are pushing particular directions within RE. They also differ in the shares they allocate to different low risk technologies (not shown), but the concentration of investments in in diffusion is lower and different type's shares remain more stable over time, suggesting that which actor type allocates finance to particular technologies matters most during the high-risk deployment stage.

Figure 9: Stacked volumes of annual investments by top 3 investors in 4 high risk technologies; the lower plots have a y-axis scale an order of magnitude smaller.



6 Conclusion and policy implications

In this paper, we have used the Bloomberg New Energy Finance data of global RE asset finance between 2004 and 2014 to study heterogeneity in financial actors in the renewable energy (RE) sector. We have begun with the aggregate separation of public vs. private, and then moved to a disaggregated analysis of different types of public and private investors. We have constructed a risk index, across different technologies, and focused on better understanding which investor types are financing the most high-risk investments during the diffusion and deployment phases of renewable energy. Our results must take into consideration the holes in the data and the heuristic nature of the risk index. Yet, the patterns are clear enough to shift the emphasis from the total amount of finance to its composition by investor types and its quality, that is how investment is directed toward different technologies at different stages of maturity, and to address the question of accelerating the scale up of RE finance from the vantage point of investor types. We report three main findings and discuss their implications for policy and theories of financing innovation.

First, we find that in our dataset investor types differed, both cross sectionally and over time, in terms of the share of their portfolios that they allocate to risky deployment of not yet commercialized technologies versus diffusion of less risky more mature technologies. Applying our risk measure, we find that public investors have allocated a significantly larger share of their investments to deployment on average than private investors in 6 out of 11 years. Excluding China where public investors are particularly pervasive also in diffusion, public risk exposure is significantly larger in every year. Breaking down the broad categories of public and private further, we find that private companies active in building RE power plants (energy firms) invested a persistently smaller share in high-risk deployment than more diversified companies from other sectors. Among financial companies, banks and institutional investors started out with a similarly risky portfolio in 2004, but from 2010 onwards banks invested in higher risk portfolios. Seen over time, almost all private investor types invest the largest share in deployment during the period 2009-11, which coincides with government investment incentives. State-owned or controlled companies display a falling trend in their risk exposure, but the trend is reversed when taking out Chinese companies, rendering them by far the most risk taking investor types. State banks start out similar to private banks, but from 2008 display an almost unbroken upward trend, catching up with constently high-risk exposed government agency portfolios after 2011. It is striking that from 2012 onwards, every single public investor type (barring the Chinese state-owned companies) had a higher average risk exposure than any of the private investor types.

Second, investor types also differed in the technologies they invest in. In the high-risk technologies, utilities and state banks provided most of the offshore investment, while concentrating solar power was financed predominantly by energy firms and commercial banks. The predominance of a single investor type in the high risk technologies that received the least cumulative investment – second generation biofuels and marine energy – was even higher. Non-energy sector companies financed 40 percent of the former, and state-owned utilities 66 percent of the latter. In other words, investor types pushed innovation within RE into different directions. The less mature a technology, the bigger was the influence of single investor types.

Both of these results together suggest that one rather than another type of investor may better serve particular policy objectives. Given the varying risk aversion in different actors, it may be that a particular investor type should be identified for a particular innovation phase that is targeted (along the risk space). For example, if more funding is needed for the riskier deployment stage, it would be relatively futile to focus only on institutional investors, as these have shown little interest in this stage. Rather than only attempting to 'de-risk' technologies as has been suggested to attract institutional investors into deployment (OECD, 2015), policies could also seek ways to encourage already less risk averse investor types to invest more, such as diversified technology companies or state banks. Similarly for technology choice. Given the propensity of particular types to finance particular technologies more than others, an effective policy that targets particular technologies, e.g. concentrating solar power, may need to consider that in the past this technology?s deployment has received finance mainly from commercial and state banks and diversified technology companies.

In general, the problem of accelerating the scale-up of the RE supply involves the question of what combinations of actors are needed to achieve given energy supply portfolio objectives, so that too much hope is not placed on types of finance that are unrealistic to fund a particular stage of innovation. Moreover, absent clear portfolio objectives, the cumulative finance by the prevailing combination of investor types may help lock in incumbent technologies. A policy debate about direction and diversity should take place if such pathways are to be negotiated and tracked (Stirling, 2009; Stirling, 2010).

As a third result, public sources of investment have been providing a significant share of total investments both in high risk deployment and low risk diffusion. Since the Great Recession, state-owned or controlled investors accounted for almost half of global asset finance globally. Even excluding China, where state-owned enterprises are particularly important, the public share has reached 40 percent in 2014 of total investment; it is only thanks to a rise in public funding that overall asset finance is above its 2006 level. And because of the higher public risk exposure, those public investors provided 58 percent of all deployment in 2014. Over time, total RE investment, but particularly deployment finance has come to rely increasingly on public funds.

This third result raises the question of whether the private investor category is equipped for the task of further scale up of renewables. Since investment into RE has been kept at its current level only by increasing public funds in all risk classes since 2008, it should be recognized that discussions about reducing public spending and increasing privatization may have implications for the transformation of the energy system. The public sector has so far stepped in and absorbed risks in downstream innovation finance. With available evidence it is not clear that a decrease in public funding could be replaced by private investment.

Finally, all three results together bear on theories of innovation. The heterogeneous patterns of investment directions – in terms of risk and technology – support the use of an analytical lens that distinguishes financial actors as a complement to the more traditional distinction between different sources of finance (equity vs. debt) or process of financing (e.g. venture capital vs. project finance). Furthermore, our analysis shows the limits of market failure theory which would suggest that as technologies move towards maturity, the role for public intervention diminishes. The sheer amount of public investment, on diffusion and deployment is difficult to explain through a theory that locates public actors mostly at the research stage, while reducing the public role to 'demand-pull? regulation at the downstream stages. Theories that see the public sector as taking part in the creation of a RE technology market, rather than just fixing it, may be more useful in this context (Mazzucato, 2016).

Our results are preliminary and we focused on descriptive statistics to bring out the actor perspective on finance for innovation. Future research might investigate why financial actors have different investment risk profiles, and how this translates into particular types of portfolio choices. Private actors may behave differently if motivated in their investment choice by the perception of future opportunities (and profitability) in areas, especially based on the evidence that what matters is not current profits but expectations about future growth (Dosi and Lovallo, 1997). It would be important to understand how public policies or investment choices affect these perceptions. Another option is to consider how public and private investments interact at a more granular level. There are heterogeneous actors within both categories, so research could examine how individual public actors differ in their ability to leverage private investments or how different private investors are responding to public co-investment. This can provide insights on different types of *crowding in* processes, and how they differs across technologies and/or periods in the technology life-cycles. Finally, the question of how the diversity, or lack thereof, of the RE supply of the future is influenced by financial decisions, and how these may be steered towards one or another configuration of energy technologies merits further attention. One obstacle to more precise econometric analyses of financial actors' role is the large amount of missing data on investor participations as opposed to deal values. A Bayesian missing data analysis may go some way to improving our understanding of 'who is doing what' quantitatively, but ultimately better data reporting and collection will have to be implemented alongside more narrowly focused research (UNEP, 2013).

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Appendix A: risk measure construction

Technology and market risk

We used studies about technology risk and cumulative investment for technologies by tech risk and LCOE estimates for market risk. The method for assigning country risk is described last.

We classified investment risk for every technology in 2009 into low, medium, and high, following (Szabó et al., 2010). We added the remaining technologies from the more comprehensive Altran and Little (2011) study by comparing their riskiness with those given by Szabo et al. and assigning them the same risk class (low, medium, or high). We then used level and changes in component prices and levelized cost of energy (LCOE) data from (BNEF, 2014b; BNEF, 2015a), the Kost, Christoph and Mayer, Johannes and Thomsen, Jessica and Hartmann, Niklas (2013) and the Salvatore (2013), and for earlier years up to 2009 and 2010 from the IPCC special report on renewables (Mitchell et al., 2011), as well as additional information about technological maturity to extend the 2009 risk classification backward and forward to every year between 2004 and 2014. Where there were significant risk differences within one of our 11 technologies – such as between thin-film PV and concentrator PV – we distinguished these sub-technologies.

The resulting classification in Table 1 in the main text is created as follows. Onshore wind is set to low for all years, with significant capacity already installed in 2004, and prices often competitive with fossil energy sources (Salvatore, 2013). Offshore wind is a high-risk investment throughout; until 2014, it continued to experience technical setbacks and difficulties, such as connecting power plants to the grid (KfW, 2014, 77; KfW, 2015, 100), and the oldest large-scale offshore wind farms have not yet reached the end of their estimated lifetime (European Wind Energy Association, 2016). Meanwhile, levelized costs remain significantly above those for onshore and fossil-fuel-generated power (BNEF, 2015a).

In the solar sector, c-Si PV's component price fell by almost 90 percent over the 11 dataset years. Non silicon-thin film technology experienced a similarly fast decline, leading Szabo et al. to classify c-si PV as low risk as early as 2009. The thin-film PV alternatives dropped to medium risk in 2010, with a similar cost structure but less information about technological performance. Only concentrator PV remains high risk throughout, as this technology is only now transcending the pilot stage and costs remain high relative to other PV technologies (Phillips et al., 2016). On the other hand, concentrating solar power (CSP) is high risk in every year. The high level of LCOE rarely dropped between 2006 and 2012 in most regions (Stadelmann et al., 2014) and a surge in US installations in 2011 was driven by public grants, and private loans underwritten by public loan guarantees, because the risk was too high for other types of finance (Mendelsohn and Kreycik, 2012). Moreover, technology designs are still in major flux (European Commission, 2013).

Biofuels are classified into first- and second-generation fuels, where second-generation fuels are high risk and first-generation (fermentation of edible plants into ethanol, and transesterification for biodiesel) ones are low risk, following the usual classification in the literature (Schwaiger et al., 2011; Sims et al., 2010). Biomass is split into low and medium risk in order to distinguish the widespread use of incineration plants from those using other, less experienced technologies. Marine energy is high risk throughout, as these technologies are only at the pilot stage, and levelized cost far exceeds that of any other technology in the sample (BNEF, 2015a). Geothermal technologies are medium risk. There is a long history of building geothermal power plants, but the need to commit large amounts of capital early on and build site-specific power plants makes individual investments risky (BNEF, 2014b). Small hydro is low risk in all years, as it is a well-tested technology (Mitchell et al., 2011) and its LCOE tends to be among the lowest of all technologies (BNEF, 2015a).

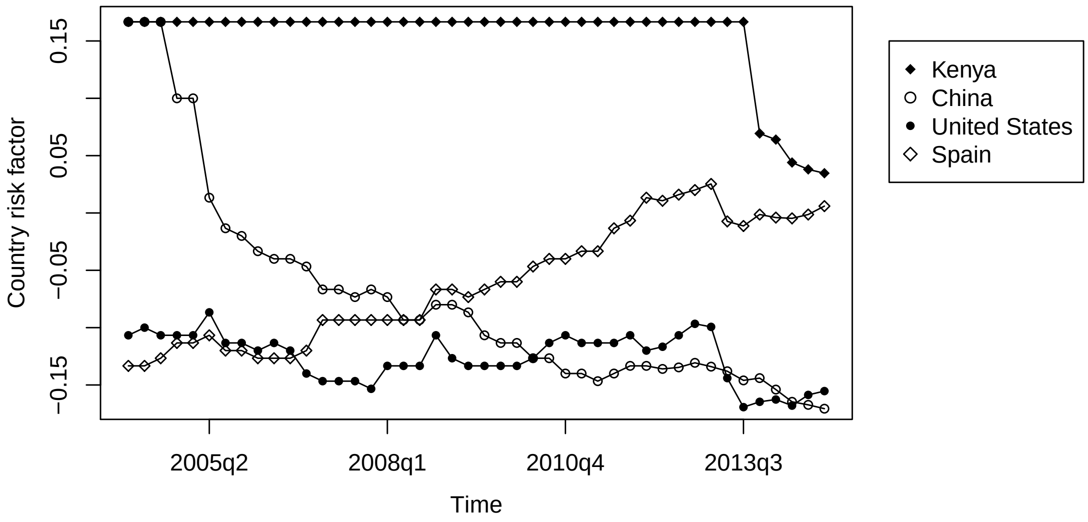
Country risk

The Renewable Energy Country Attractiveness Index (RECAI) compiled by Ernst & Young (2016) countries in every quarter for the entire dataset period according to their investment climate, political stability, ability to connect power plants to the grid, priority of RE over other low carbon energy forms, electricity prices, and renewable energy support policies for various RE, which are weighted according to the importance of different RE technologies in the electricity mix. Country scores vary between 25 (worst) and 75 (best). The RECAI starts with 17 countries in 2004 and by 2012 ranks 40 countries. In order to translate the RECAI into a country risk factor that is additive to the above risk index, the RECAI is centered around zero and scaled so that the maximal deviation from zero is $|\frac{1}{6}|$ and inversely proportional to the score. Hence, a high RECAI country score translates into a low country risk factor that reduces the risk of an investment in the country with that score. Countries not appearing in the RECAI account for only 3 percent of total investments; they are assigned a country risk indicator of $+\frac{1}{6}$. Figure 10 shows a selection of country risk factor time series.

Appendix B: dataset construction

The dataset is constructed as follows. We first merged three databases that together include equity and debt provision for asset finance deals (BNEF, 2015b). The dates of the deal closure are coarse-grained into annual intervals to avoid fluctuations arising from the lumpiness of investments. We then created the value of each investor's participation in an asset finance

Figure 10



deal by splitting deal values between equity and debt and allocating the value's share to the participating investors. Because some share values were missing, we distributed the unknown shares of each deal's equity and debt equally between sponsors and debtors, respectively, while assuming – whenever debtors are disclosed – that the share of debt is equal to the average share of debt in the disclosed data, with a gearing ratio of 66 percent.[16] Finally, we trim the dataset of all investments in the 'refinancing' and 'acquisition' categories to only count newly added capacity. The dataset without missing values is summarized in Table **??**.

Next, to create investor types, we merged our asset dataset, which only provides investor names and IDs, with the database classifying investors .[17] The latter distinguishes investors

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[16] Equal share imputation may misrepresent single investors' contributions. An example is the Gemini Offshore Wind Farm debt financing from 17 actors, for which BNEF does not provide shares. Equal imputation implies a share of less than six percent for each participant. However, other sources showed that the European Investment Bank provided 30 percent of the total EUR 3 billion, and the remainder was split between 16 private banks and utilities (EIB, 2014).

[17] Ownership structure distinguishes between publicly listed and privately owned companies, non-profit institutions, government agencies, etc. The Bloomberg industry classification system is similar to the Global Industrial Classification System (GICS), which has 10 sectors, 24 industry groups and is further subdivided at 'industry'

according to their ownership structure and their industrial classification. We used the ownership structure to sort investing organizations into public and private. We then used a combination of ownership structure (grouping subsidiaries under their parent company) and GICS classification at the 'sector' and 'industry group' levels to create investor types that distinguish organizations according to their function, while grouping as many different forms and industries as possible to reduce complexity. The result is displayed in Table 4 in the text.

Table 4: Summary Statistics

	Name	Type	Summary Statistics
1	Project Asset Finance ID	Categorical	24,827 categories
2	Country of Project	Categorical	164 categories
3	Year of deal close	Integer	bounded on [2004,14]
4	Participant Type	Categorical	3 categories Sponsor (equity), n = 27,006 Lead arranger (debt), n = 6,837 Syndicated lender (debt), n=1,212
5	Debt Value per participant*	Numerical, mUSD	Mean = 43.01 SD =70.86
6	Equity Value per participant	Numerical, mUSD	Mean = 34.84 SD =65.72
7	Shares*	Numerical	bounded on [0,1] Mean = 0.826 SD =0.296
6	Technologies*	Categorical	11 categories
7	Sub-technologies	Categorical	44 categories
8	Actor Category*	Categorical	2 categories Private, n = 27,111 Private, n = 6,057
9	Actor Type*	Categorical	11 categories

* Constructed, description in the text.

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and 'subindustry' levels (MSCI 2014).

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