The importance of project finance
for renewable energy projects

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Abstract:

Given the magnitude of investment needs into low-carbon power generation, the availability and cost of capital is crucial for successful energy transitions. Recently, a strong increase of non-recourse project finance (as compared to corporate finance on a project sponsor's balance sheets) could be observed for power generation projects. Classical economic motivations for project finance are the prevention of contamination risk, and agency conflicts – however, these reasons do not apply for comparably small projects in low-risk environments, such as many renewable energy projects being realized today. This paper therefore assesses the importance of project finance for renewable energy projects in investment-grade countries, and the underlying drivers to use this kind of finance. Eight potential reasons for using project finance are distilled from economic and finance theory, and then empirically evaluated using a novel dataset for new power plant investments in Germany 2010–2015. Results show that in this extreme case with particularly low investment risks, project finance has much larger importance for renewables than for fossil fuel-based power plants. It is not used to reduce contamination risk or agency conflicts, but, instead driven by the "debt overhang" of non-utility sponsors such as independent project developers. We discuss implications for policy makers, the financial sector, as well as energy scholars concerned with power generation investment decisions.

Keywords: Investment decision, special purpose vehicle, renewable energy, solar PV, wind, yieldco

JEL classification: G32, G38, L94, Q42, Q48

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1 Introduction

The global demand for electricity continues to grow, fueled by industrialization and urbanization in many parts of the world. At the same time, power generation is the largest single source of CO_2 emissions (IPCC, 2014) and needs to be transformed fundamentally. Hence, many governments aim at substantially expanding renewable energy in order to reach the 2°C goal committed in the Paris Agreement. While power generation has always been an asset-heavy industry, capital intensity is even higher for most renewable energy sources as compared to fossil fuel-based plants (Schmidt, 2014). Thus policy makers worry about the availability and cost of capital for low-carbon power plants.

Globally, investment in power generation doubled between 2005 and 2015, reaching about 420 billion USD p.a., about 70% of it for renewables (IEA, 2016a). According to estimates, a comparable level of annual investment is needed throughout 2016-2025 to satisfy the growing demand and implement policies as pledged under the Paris Agreement. A pathway in line with the 2°C goal will require even further investment, likely in the magnitude of additional 250 billion USD p.a. over the next decade (IEA, 2016b). While capital provision is crucial in facilitating the transition to renewables, research on the role of financial markets in capitalizing low-carbon power systems is still at an early stage (Hall et al., 2015).

The structure of owners currently raising capital for new power plants is well understood: On a global scale, 61% of new conventional power plants (fossil fuels, nuclear, hydropower) have been commissioned by state-owned enterprises in 2015, compared to only 35% from private companies (the remaining 4% being households/communities). For non-hydro renewables, in contrast, the private companies have a share of 53%, and households/communities another 16% (IEA, 2016a). The importance of private sponsors for renewable energy is even higher in OECD countries – in Germany, for instance, 59% of 2012 investment in renewable power plants have been made by institutional and strategic investors, and another 26% by private individuals (Trend Research, 2013).

Much less however is known about the financing structures used for these power plants. Following decades of debate on Modigliani and Miller's (1958) irrelevance proposition, it is now generally accepted that financing decisions matter for the value of a firm and as such need to be considered to assess investment projects (Myers, 2001). Whether sponsors are public or private, the first decision they have to make is between two main alternatives for a new project: Taking it on their balance sheet (i.e. using *corporate finance*), or opening a separate balance sheet drawing on *project finance*. When using corporate finance, a project sponsor utilizes all assets and cash flows from the existing firm to guarantee the credit provided by lenders (in case the sponsor is a public entity, including cash flows such as future tax returns). This is the classical way to finance investments for private or public enterprises, making up 85-90% of total capital investment in developed countries like the U.S. (Esty, 2004). When using project finance, in contrast, sponsors create a new entity (i.e. a special purpose vehicle) to incorporate the project; lenders will then depend on cash flows of the new project alone, with no or very limited claim on sponsor's assets.

Compared to the classical way of corporate finance, using project finance comes with significantly higher transaction cost. As the project performance is all a potential lender can rely on, the projected cash flows and cost need to be examined carefully. Thus bills for technical, commercial and legal advisors can sum up to 5–10% of the total project value. Hence, traditionally project finance has mainly been used for large, high-risk projects where sponsors need to protect their core firm from a potential project failure. Large and complex power plants, especially

in developing countries, have been a "textbook case" for projects where this protection against a contamination of the core firm is worth the price (Gatti, 2013).

Recently, however, a surge of project finance could also be observed for less complex, relatively small and low-risk projects in technologies such as onshore wind and solar[2]: Globally, the use of project finance in new renewable energy plants increased from 16% of all projects in 2004 to a remarkable share of 52% in 2015 (FS-UNEP, 2016). While country-level data is hardly available, there is some evidence that project finance also plays an important role in investment-grade countries such as Germany (Arnold and Yildiz, 2015; Enzensberger et al., 2003), Chile (Nasirov et al., 2015), and Australia (Kann, 2009).

A clear understanding on the importance and motivations for project finance in low-risk environments is required for all parties concerned with renewable energy investments: Policy makers striving to design regulation that attracts private investment in renewable energy technologies, project sponsors and financial intermediaries thinking about how to innovate power generation financing, and energy scholars dealing with power plant investment decisions in the transition to low-carbon energy systems. This article therefore addresses the following questions:

1. How important is project finance for renewable energy projects in developed, low-risk countries?
2. What are the drivers and underlying reasons to use project finance in such settings?

This article draws on economic theory on rationales for project finance in general, as well as an empirical analysis of project finance prevalence in a specific country – namely Germany, a country with a particularly low-risk environment for renewables, as well as substantial investment in both conventional and renewable power generation capacity over the last years. The analysis is structured as follows: The next section recaps key characteristics of project finance and summarizes previous research regarding its use in the energy sector. Section 3 carves out eight potential reasons to use project finance based on economic literature, which are then assessed in the empirical part: Section 4 describes the data for the German case study and the empirical approach, section 5 summarizes the empirical results. Implications are discussed in section 6, and section 7 concludes.

2 Project finance in the energy sector

2.1 Definition and global trends

There is some variety of what is considered "project finance" in certain industries or jurisdictions, but two key characteristics are generally accepted (cf. e.g. Gatti, 2013; Yescombe, 2013) and most relevant for economic analysis, and are the basis for the subsequent discussion:

- Project finance means the use of a special purpose vehicle (SPV), which is legally and commercially self-contained and serves only to realize the project.
- The SPV is financed without (or very limited) guarantees from the sponsors, such that lenders to the SPV depend on future project cash flows only and cannot recourse on the sponsors' other businesses.

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[2] In contrast to onshore wind and solar, offshore wind (deployed in Germany since 2010) is characterized by large and complex projects, and during 2010–2015 still prone to a high technology risk, cf. section 4.2.

This understanding is in line with the definition that is part of the Basel II framework, defining project finance as *"a method of funding in which the lender looks primarily to the revenues generated by a single project, both as the source of repayment and as security for the exposure. […] In such transactions, the lender is usually paid solely or almost exclusively out of the money generated by the contracts for the facility's output, such as the electricity sold by a power plant. The borrower is usually an SPE that is not permitted to perform any function other than developing, owning, and operating the installation. The consequence is that repayment depends primarily on the project's cash flow and on the collateral value of the project's assets."* The framework also acknowledges that project finance is typically used for large and complex installations and mentions power plants, chemical processing plants, mines, as well as transport/environmental/telco as most common applications (BCBS, 2006, Art 221-222, p. 53). In this article we therefore adopt the Basel II definition.

Project finance dates back to the development of American railroads in the 19th century. Its use grew rapidly to develop oil & gas fields in the 1970s, and got a further boost as mean to realize transport projects such as bridges and tunnels from the 1980s on (Yescombe, 2013). While still making up only a small part of overall capital investment, the global project finance loans market is estimated at USD 277 billion in 2015. Three sectors account for the lion's share: Power generation, oil & gas, and transport infrastructure (Thomson Reuters, 2016).

A relatively recent development is the increasing use of project finance for renewable energy projects such as solar and onshore wind, many of which are smaller in scale and less complex than conventional power plants that traditionally used project finance (offshore wind projects, in contrast, resemble more conventional plants concerning size and complexity). Figure 1 breaks down the investment in renewable energy by type of financing – on a global scale, project finance increased dramatically in importance over the last ten years, being used for more than half of all new investment in 2015[3]. Its share increased in parallel with the general increase of investment in renewables, meaning that a disproportionally high share of additional annual investment was channeled into the sector through project finance. Part of the shift towards project finance is driven by the expansion of renewables in emerging markets such as China. However this cannot explain the use of project finance entirely: In 2008, for instance, renewables investment was still dominated by Europe and the US, and project finance nevertheless accounted for 45% of all financing already. This article's analysis of a new dataset on project finance use in Germany will contribute to the understanding of project finance in investment-grade countries.
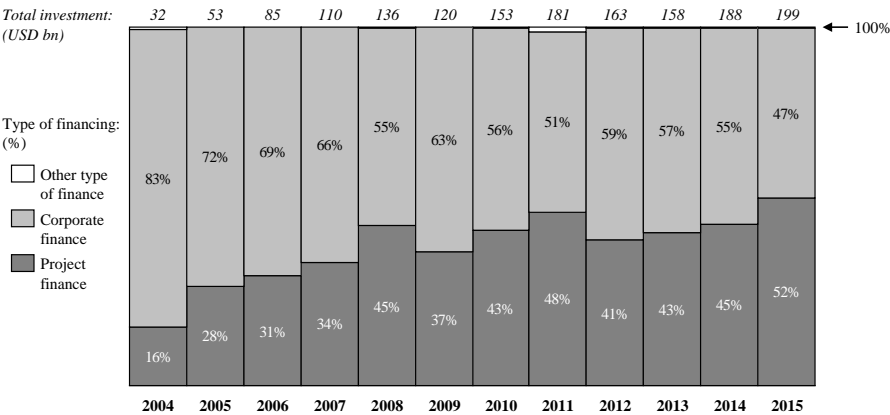
Figure 1: Global asset financing of new investment in renewable energy
(based on BNEF data provided by (OECD, 2016))

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[3] While there are some challenges using BNEF data to analyze the type of financing on a project level (cf. section 4.2), it serves reasonably well to illustrate the aggregate development, especially on a global level.

2.2 Previous research

While economic and financial theory addresses project finance in general (compare section 3), studies looking at its use specifically in the energy sector are rare. In an early article, Pollio (1998) discusses the preference for project finance in the global energy sector. Based on a literature review and a discussion of the interests of sponsors, commercial banks and host governments, he concludes that risk management features (i.e. preventing lenders to recourse on the core firm in case of a project failure) are the key reason for using project finance, and that "project finance has nothing to do with capital constraints" (p. 689). More recently, some papers discuss the uptake of project finance for renewable energy. They focus less on the question why project finance is preferred over corporate finance, but rather describe the emergence of specific structures and their limitations in a given context: For Australia, Kann (2009) notes that project finance is the dominant structure for onshore wind projects, which allows also small developers to pursue large projects, and thereby rejecting the view of Pollio (1998) that capital constraints play no role. For Germany, Enzensberger et al. (2003) describe a common structure for wind farm project finance in Germany, stressing that it allows individual households to invest in closed-end wind funds. Thereby, project finance is an alternative to the German energy cooperatives that engage in multiple projects (Yildiz, 2014).

Recently, practitioner-oriented gray literature has also provided anecdotal evidence regarding renewable energies: Henderson (2016) mentions that project finance is used by small, cash-constrained project developers, whereas larger utilities typically prefer corporate debt as it can be sourced cheaper – which seems counterintuitive given the high cost of capital of many large utilities in Europe these days (cf. Helms et al., 2015). Alonso (2015) notes that the classical drivers for project finance (large scale, and high political risk) cannot explain the use for renewable energy projects, and assumes that instead the characteristics of project developers matter.

To our knowledge, the drivers of project finance in today's energy projects in investment grade countries have not been rigorously addressed by economic research – this paper addresses this gap by synthesizing economic motivations and providing an empirical analysis for the case of Germany.

3 Economic rationales to use project finance

Corporate finance using the balance sheet of the sponsor is the classical way to finance new projects. Opting for project finance instead requires additional time for setting up a new entity, and causes significant transaction cost for structuring its financing: Given that project creditors cannot recourse on the sponsors debt, the evaluation of the project cash flows requires additional scrutinizing and thus time and effort from legal, technical and insurance advisors, as well as careful negotiations of contract terms between all parties (Gatti, 2013). The related additional transaction costs depend on the project characteristics, but are often in the magnitude of 5–10% of total project costs (Esty, 2004)[4]. Hence, a strong economic rationale is needed to explain the broad use of project finance. Economic theory and finance literature developed several models to that end, typically focusing on one characteristic of projects or financial markets that opens a door for a value-increasing use of project finance. This section summarizes learnings from theory by distilling eight reasons that could explain the use of project finance for power generation

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[4] Also for renewables plants, project finance-related transaction costs are significant, even if projects are set up in a way allowing for a higher degree of standardization. For a typical project finance-based wind power plant in Germany, practitioners estimate the cost for financial analyses, legal concept, and financial marketing at 3–5 % of total project value (cf. e.g. PNE Wind AG, 2016).

projects, and discusses for which type of projects one should expect to see project finance if the reason is decisive. We clustered the reasons in three groups, covering financial synergies with existing business, general market imperfections, and considerations regarding organizational structure, respectively.[5] In practice there is likely no unique decisive reason – the empirical question what matters most for projects in Germany is addressed in section 4.

3.1 Negative financial synergies with existing business

When companies consider projects such as a new power plant, synergies with their existing business often are a key concern. While operational synergies are typically positive (e.g., in the case of economies of scale), financial synergies are often negative – the finance literature discusses three reasons to use project finance to prevent such negative financial synergies:

Reason 1: Contamination risk. If new projects are financed through corporate finance, they become part of the risk-return prospects of the developing company. Assets and cash flows from the existing business serve as guarantee for additional lending used to finance the project, thus poor project performance can affect the existing business severely, increasing the bankruptcy risk of the core firm especially if the project is large compared to the existing business. (Esty, 2003; Gatti, 2013; Leland, 2007). Financial theory implies that in perfect markets, companies should not be concerned about idiosyncratic bankruptcy risk as portfolios are diversified at the shareholder level (Sharpe, 1964) – in real markets, though, bankruptcies come with irreversible costs (Bris et al., 2006) and managers are risk averse (Lewellen, 2006), so bankruptcy risk matters. Realizing the project in a separate entity via project finance can preserve the existing business from contamination and thereby reduce financing cost for the core firm – the textbook reason for using project finance (de Nahlik, 1992; Gatti, 2013; Nevitt and Fabozzi, 2000). The effect is especially likely to occur if the new project comes with high investment compared to the existing balancing sheet, and if its cash flows are risky and correlated with the existing business (Leland, 2007). Capital-intense power plant projects can obviously meet these characteristics. Thus in cases where contamination risk motivates project finance, it will be used for power plant projects with certain characteristics, namely of large size and high financial risk (i.e. the risk of a financial loss for project investors)[6].

Reason 2: Debt overhang. Using corporate finance, projects are financed through equity and debt on the sponsor's balance sheet. The ability to finance new projects hence depends on the strength of that balance sheet and can be limited if its debt ratio is already high, especially if many new projects are planned in a row. Stulz and Johnson (1985) show that profitable projects might not be undertaken in such situations, but the availability of secured debt helps to realize them by providing an additional security beyond the general recourse on the balance sheet. Following the same rationale, project finance is an even more effective instrument to finance such projects as it decouples the project completely from the sponsor's balance sheet (Esty, 2003). Following this argument, project finance not only allows a sponsor to realize projects that are otherwise unviable, but also potentially allows that sponsor to choose a higher debt ratio for the project than feasible under corporate finance, creating value through higher tax shields (John and John, 1991). In the power sector, some companies specifically focus on developing

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[5] To our knowledge, no comprehensive overview on the economic rationales to use project finance exist – with the notable exception of Esty (2003) who focusses on large-scale projects and discusses agency conflicts (roughly reasons 4-6 below) as well as distress cost-related underinvestment (roughly our reason 1). Surprisingly, only few textbooks on project finance discuss the motivation for using it in some detail, positive examples being Gatti (2013) and Yescombe (2013).

[6] This reason can also be described in an option-theory framework, where project finance creates an option for project sponsors to abandon a project without causing bankruptcy of the core firm, see Pollio (1998).

new power plants, extending rapidly their cumulative investment. Also groups of individuals and cooperatives that do not have a balance sheet or sufficient personal credit-worthiness realize projects ("civic" plants). Thus in cases where debt overhang motivates project finance, it will be used by sponsors with certain characteristics, namely companies with small balance sheets such as fast-growing project developers or groups of citizens.

Reason 3: Securitization. While it is commonly assumed that project finance allows the financing of risky projects without negatively affecting a less risky core business (cf. reason 1), also the opposite can be true. Leland (2007) for instance refers to a bank with core banking activities that are high risk, and mortgages that have a low cash flow risk. If the low risk assets are securitized into a separate entity (i.e. project finance is used), they can be financed at lower cost[7]. The same rationale can apply in the energy sector: Some utilities have financing cost characterized by past high risk-high return investments into merchant thermal power plants, which are too high for low risk projects such as regulated renewable energy plants (Helms et al., 2015) – project finance could be a remedy. Compared to reason No. 2, using project finance as "securitization" is not just about realizing a project otherwise unfeasible because of a "debt overhang" on the core firm balance sheet, but for achieving lower financing cost for a less risky type of business. Thus, in cases where securitization motivates project finance, it will be used in specific combinations of project- and sponsor characteristics, namely for low-risk projects conducted by "high-risk players" such as distressed utilities.

Beyond motivating the use of "classical" project finance on the debt side, it is worth noting that the securitization motive can also explain the recent emergence of the *yieldco* model on the equity side (mainly in the U.S.): Sponsors – often large utilities or independent power producers that own a mix of renewable and conventional generation assets – create a yieldco by carving out renewable energy plants with stable cash flows and low financial risks into a separate, publicly-traded corporation, attracting equity investors as minority shareholders (EY, 2015; Urdanick, 2014). Beyond U.S.-specific tax considerations, a key reason for choosing the yieldco model is to "replace high-cost capital with lower-cost capital", if the financial risk of operational solar and onshore wind plants is much lower than the sponsors' core business activities (Varadarajan et al., 2016, p. 7).

3.2 Market imperfections

Beyond financial synergies with existing business, a second group of reasons can motivate the use of project finance to address market imperfections in a broader sense. Economic literature discusses three ways in which project finance can help to address asymmetric information and agency costs.

Reason 4: Information asymmetry between sponsor and lenders. A company realizing a project always has better information about its prospect and actual performance than outside creditors. The oldest economic explanation for project finance considers it as a tool reducing these asymmetries, by allowing lenders to better distinguish project performance from general firm performance. In their classical paper, Shah and Thakor (1987) postulate that it can be advantageous to use project finance instead of costly revealing information about the entire firm that would provide a comparable level of transparency – especially for risky projects, which require a high level of scrutiny that consequently has to be applied to the project only (and not to the entire firm). Thus, if the information

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[7] In the case of mortgage-backed securities, a special purpose vehicle typically pools cash flows from various projects, and then issues multiple tranches of debt with different seniorities; the high complexity of these instruments played a role in the 2007-2008 global financial crises. The term "securitization" here only refers the initial step of moving the assets to a self-contained entity, as described by Oldfield (2000, p. 447): "Securitization is a more basic process. The originator passes the loans into an entity and it issues one class of simple pass-through instruments rather than a set of derivative claims."

asymmetry between sponsor and lenders motivates the use of project finance, it will be used especially for risky power plant projects.

Reason 5: Agency conflicts between project owners and contractual parties. Projects like power plants depend on contractual relationships with parties such as a fuel supplier and the electricity offtaker. If these relationships are characterized by bilateral monopolies, parties might opportunistically threaten the project to realize better conditions after completion (the "hold up" problem)[8]; project finance with a carefully-crafted set of non-financial long-term contracts and a joint vertical ownership can mitigate these agency conflicts (Corielli et al., 2010; Esty, 2003). A different agency conflict potentially occurs with host governments, who might pursue measures leading to creeping expropriation after infrastructure assets such as a power plant are completed. Project finance can mitigate such risks by allowing for a high debt ratio and syndication of debt that improves the ex-post bargaining position of project owners (Sawant, 2010). It also opens the way to include international financial institutions such as the World Bank's IFC into the asset-specific financial structure, which provide a "political umbrella" to deter creeping expropriation (Hainz and Kleimeier, 2012; Steffen and Papakonstantinou, 2015). While empirical studies showed the relevance of these agency conflicts as driver for project finance in developing countries (cf. Hainz and Kleimeier, 2012; Sawant, 2010), they should be less relevant in settings with a stable regulatory environment and reliable contractual counterparties (as analyzed in this paper).

Reason 6: Agency conflicts between project owners and managers. The interests of corporate managers are not necessarily aligned with the business owners' – especially in companies with high free cash flows (such as capital-intensive power plants), managers might prevent the payout of cash to shareholders and instead maintain the resources under their control by pursuing value-destructing re-investments (Jensen, 1986). Using project finance allows to set up a tight project-specific governance structure and implement a very high debt ratio to discipline managers (Esty, 2003; Jensen, 1986). Such a "disciplining" effect would be most useful in projects with high upfront investment and low operating cost. Thus, if agency conflicts between owners and managers motivate the use of project finance, it will be used especially in power plant projects with this characteristic, i.e. with a high CAPEX to OPEX ratio.

Beyond the mentioned market imperfections, occasionally tax considerations are mentioned as motivation for project finance, if the project entity can be offshored to a different jurisdiction (cf. Pollio, 1998). However, such tax-optimizing legal setups are likewise possible if projects are financed through corporate finance, so this is typically not a reason for project finance in itself[9].

3.3 Considerations regarding organizational structure

Finally, using project finance can allow for organizational structures that are advantageous from a company-internal point of view, as discussed in the strategic management and stakeholder literature:

Reason 7: Allowing for horizontal joint ventures. Structuring a project as a non-recourse separate entity allows to realize a project as a vertical joint venture, e.g. including contractual parties to reduce agency cost (cf. reason 5). However, projects such as power plants have also been realized as *horizontal* joint ventures between companies at

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[8] For details cf. Hart and Moore (1990) and Sanford J . Grossman and Hart (1986).
[9] Tax considerations do play a role, of course, in defining the optimal debt ratio for a project. Depending on the financing of the existing business, project finance might allow for a higher debt ratio and thereby increase a valuable tax shield, cf. reason 2 (debt overhang).

the same stage of the value chain such as several utilities – explained by strategic considerations, for instance acquiring tacit organizational knowledge like the operation of a specific power generation technology (Kogut, 1988). Thus if horizontal joint ventures motivate the use of project finance, it will be used for projects realized jointly by similar sponsors, e.g. in power generation jointly by several utilities.

Reason 8: Independence of civic project. Lastly, low-carbon energy technologies could be considered as social investments – some retail investors (such as citizens in a community where a wind farm or solar plant is considered) have been shown to take welfare aspects into account for investment decisions (Kalkbrenner and Roosen, 2016), going beyond risk-return comparisons with capital market alternatives as assumed in the reasons mentioned so far. Such aspects include the motive to advance the political project "energy transition" by civic ownership, and the motive to secure electricity supply independently from large companies (Holstenkamp and Kahla, 2016). Some investors thus might prefer to invest in a "civic" power plant with equity, taking an entrepreneurial role (which they would not have by providing debt). Even if a utility or a project developer are also involved, a non-recourse project finance setup is then necessary to ensure that "civic" wind or solar plants are indeed independent from outside energy players. Thus if social investment criteria such as "independence from energy players" motivate the use of project finance, it will be used especially for citizen-owned renewable energy projects.

3.4   Synthesis and hypotheses

In sum, economic, financial and management theory offers a broad set of reasons for project finance. Table 1 summarizes the different project- and sponsor-characteristics that motivate the use of project finance.

According to these reasons, project finance is more likely to be…		used for projects with…				used by sponsors that are…				…used in countries
		High risk[a]	Low risk[b]	Large size	High capx/opx[c]	Project develprs.	Distrssd. utilities	forming a horiz. JV	"Civic" orgs.	with unstable environment
Negative financial synergies	1. Contamination risk	X		X						
	2. Debt overhang					X			X	
	3. Securitization		X				X			
Market imper-fections	4. Info. asymmetry sponsor/lend.	X								
	5. Agency conflict owner/parties									X
	6. Agency conflict owner/manag.			X						
Org. structure	7. Allowing for horizontal JV							X		
	8. Independence of civic project								X	

[a] High financial risk   [b] Low financial risk   [c] capx/opx = CAPEX to OPEX ratio

Table 1: Project- and sponsor characteristics motivating project finance according to different reasons
(stylized synthesis based on theoretical literature, see section 3.1–3.3 for details)

The relevance of the different models for contemporary energy projects is an empirical question, thus we will assess the influence of the various characteristics on the probability that project finance is used along a stylized model:

$$p(PF_{ij}) = f(proj\_size_i, proj\_risk_i, proj\_capxOpx_i, spons\_type_j, spons\_ifJV_j) \qquad \textbf{(1)}$$

Where:

$P(PF_{ij})$	Probability that project finance is used for a project i realized by sponsor j
$proj\_size_i$	Measure for total investment required for the project i
$proj\_risk_i$	Measure for financial risk associated with the revenue and cost streams of the project i
$proj\_capxOpx_i$	CAPEX to OPEX ratio of project i
$spons\_type_j$	Measure for type of project sponsor j (esp. if project dev., "distressed utility", "civic")
$spons\_ifJV_j$	Measure whether sponsor j is a horizontal joint venture

Given that this paper strives to assess the use of project finance specifically in low-risk environments, we do not consider differences between countries, but focus on differing project- and sponsor characteristics within the same political environment instead (thus the impact of unstable environments is not covered).

Based on equation (1), the influence of project- and sponsor-characteristics on the probability that project finance is used will serve to empirically test the relevance of alternative reasons. If the reasons summarized above can explain the use of project finance in the German energy sector, the following hypotheses should hold true:

H1: Project finance is used more often for projects that are larger and are exposed to higher financial risk (should hold if *contamination risk* and/or *information asymmetry sponsor/lender* are decisive reasons for using project finance)

H2: Project finance is used more often for projects that are exposed to lower financial risk and are realized by players with high financing cost such as distressed utilities (should hold if *securitization* by distressed utilities is decisive reason)

H3: Project finance is used more often by projects that are realized by project developers or citizen owners (should hold if *debt overhang* or *independence of civic projects* are decisive reasons)

H4: Project finance is used more often by projects that are realized as a joint venture by two or more energy utilities (should hold if *allowing for horizontal joint venture* is decisive reason)

H5: Project finance is used more often for projects with a high CAPEX to OPEX ratio (should hold if *agency conflicts between owners and managers* is decisive reason).

Of course, different reasons to use project finance are not mutually exclusive, and there is no one-on-one mapping of project/sponsor-characteristics and reason to use project finance (cf. table 1) – if project finance is used more often for high risk-projects, for instance, this could be caused either by the contamination risk or the info asymmetry argument. Consequently, H1 and H3 cover more than one reason, and the relevance of different explanations requires a holistic discussion of regression results. In sum, H1–H5 span all potential reasons from theory[10].

The selection of our case study – Germany – as well as the data and empirical approach are described next.

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[10] Except for the *agency conflict between owner and contractual parties* such as host countries, which has been excluded from the assessment as it is mainly relevant in developing countries.

4 Empirical analysis for Germany

4.1 Case selection

The choice of a financing structure for energy projects always occurs within a certain market environment. In this article, we are especially interested in the use of project finance in developed, low-risk countries. We therefore apply "least likely case sampling" by analyzing a case which is an extreme example for such environments (Flyvbjerg, 2006), while also being large enough to feature enough data points with variations in the characteristics of interest. To this end, Germany serves as an excellent case study:

First, general legal certainty in Germany is high, and the regulatory framework of the energy sector creates a low-risk environment especially for power generation investment, as illustrated by the fact that the United Nations Development Programme (UNDP) considers Germany as the "best-in-class" baseline for low-risk power generation investment environments (Waissbein et al., 2013)[11]. Also the domestic capital markets are well-developed, ranking in the top quintile for capital market efficiency in the World Economic Forum's (2016) competitiveness index.

Second, Germany has been a major market for investment in power generation capacity in this decade, both for conventional and renewable energy sources. During 2010-2015, almost 25 GW of new, utility-scale power generation capacity (10 GW of which renewables) has been connected to the German grid, taking into account plants of at least 10 MW installed capacity[12] (we limit the discussion to utility-scale plants in this paper, as project finance is not relevant for residential installations such as household-owned rooftop PV). Investment in new generation capacity was driven by the need to substitute nuclear power that is being successively phased out until 2022, the replacement of old coal plants, as well as the political momentum to expand renewables as key instrument of German climate policy (Lechtenböhmer and Samadi, 2013; Pahle, 2010).

Third, this push towards low-carbon technologies made Germany one of the most mature and diversified markets for renewable energy to date. Supported by a technology- and size-specific feed-in tariff (guaranteed for 20 years in most cases), projects in a broad range of technologies and sizes have been realized, brought forward by many different types of project sponsors (cf. Trend Research, 2013, and section 5).

Thus, the case study will not only explain the use of project finance in one of the most important markets for renewable energy, but also highlight more generally why project finance might be even used for small projects in low-risk industrialized countries.

4.2 Data

To analyze the choice of financing structures, project-level data is needed. Regarding low-carbon technologies, the Bloomberg New Energy Finance (BNEF) database is most commonly used, especially for research questions concerning renewable energy investments (recent examples include Cárdenas Rodríguez et al., 2015; Kim and Park,

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[11] In recent years, the increase of (renewable) generation capacity and a decrease of carbon prices led to lower wholesale electricity prices (which are relevant for merchant power plants that do not qualify for a feed-in tariff, such as coal or gas plants). Consequently, investment in new conventional power plants is now considered as unattractive by many actors. This is caused by the lower power prices, though, not by an increased uncertainty regarding regulatory changes (Kallabis et al., 2016; Traber and Kemfert, 2011).

[12] Based on Bundesnetzagentur (2016), cf. section 4.2. In addition, ca. 10 GW of onshore wind and ca. 27 GW of solar PV capacity in plants smaller than 10 MW have been added in the same period, especially rooftop PV (BMWi, 2016).

2016; Polzin et al., 2015). As BNEF is based on published data mainly on financing deals, there are challenges using it straightforwardly for our analysis: First, It is more likely that the financing structure is revealed in the case of project finance (as banks often issue a press release on that) as compared to corporate finance – which is reflected in BNEF's practice of typically classifying a project as "corporate finance"[13] if no other information is available. And second, generally less is known about smaller projects (which are in most cases renewables), that are consequently very often coded as "corporate finance/no further information" or are missing in the dataset at all. Consequently, using the BNEF directly for our specific research question is not appropriate, especially for a country like Germany with many smaller projects.

This article therefore uses a different approach: Our starting point is not a financial deal-based list, but a comprehensive list of power plants connected to the German power grid. This asset-based list is then enriched by financial data mainly from the German trade register and further sources (including BNEF), resulting in a database rich enough for the analysis. Given that our starting point is a comprehensive asset list, the dataset is also less affected by selection biases than a financial-deal based dataset.

The dataset is constructed in the following steps: First, we start with a list of power plants published by the German grid regulator, which is comprehensive for power plants not smaller than 10 MW installed capacity (Bundesnetzagentur, 2016)[14]. The list is maintained as part of the regulators mission to monitor the security of supply; it includes basic technical parameters such as energy sources, installed capacity, and the plants' location. For ca. 75% of entries it also gives the name of plant, and for some (ca. 35%) the name of the entity owning the plant.

We consider the period 2010-2015, to exclude the direct aftermath of the 2007-2008 global financial crisis. In total, 468 new power plants[15] with a capacity of at least 10 MW have been connected to the grid in Germany during the six year-period, with most projects using wind power (282 plants), solar radiation (111 plants) and natural gas (31 plants) as energy source, cf. table 2. Considering the installed capacity, also hard coal (6'957 MW) and lignite (2'830 MW) play an important role, although this capacity was realized through only 9 and 4 large projects, respectively.[16]

Technology	Installed capacity (MW)	Number of projects
Wind onshore	5'492	282
Hard coal	6'957	9
Natural gas	4'167	31
Wind offshore	2'968	12
Lignite	2'830	5
Solar PV	1'823	111
Other	740	18
Total	**24'977**	**468**

Table 2: New German power plants (>= 10 MW installed capacity) during 2010–2015
(own calculation based on Bundesnetzagentur, 2016)

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[13] Or „balance sheet" finance in BNEF terminology.
[14] The list also includes power plants in neighboring countries (Austria, Luxembourg) that are connected to the German grid – these are excluded from our analysis.
[15] Including new blocks added to existing power plants, in case they appear as separate entry in the grid regulator list. For wind, "plant" refers to the wind farm, not the individual wind turbine
[16] "Others" includes various forms of biomass, hydro run-of-river, petroleum products, furnace gas, and various forms of waste-to-energy.

Second, we investigate the names of the legal entity that owned the plant at time of commissioning and its sponsor through press research, based on the plant name and location. In Germany, typically local newspapers report on the construction and commissioning of power plants. Information available in BNEF (mainly for larger projects) is matched case-by-case. In sum, this resulted in entities known for ca. 80% of projects. The desk researched information has been checked following the four-eye-principle.

Third, the data was enriched by financial data, using financial statements at the end of the year where the plant was commissioned as main source of information[17]. Almost all project entities are legal entities under German law (e.g., AG, GmbH, GmbH & Co. KG), who are required to publish their financial statements in the German trade register within 12 months after the end of their fiscal year (EHUG, 2006), available electronically in the federal gazette Bundesanzeiger.
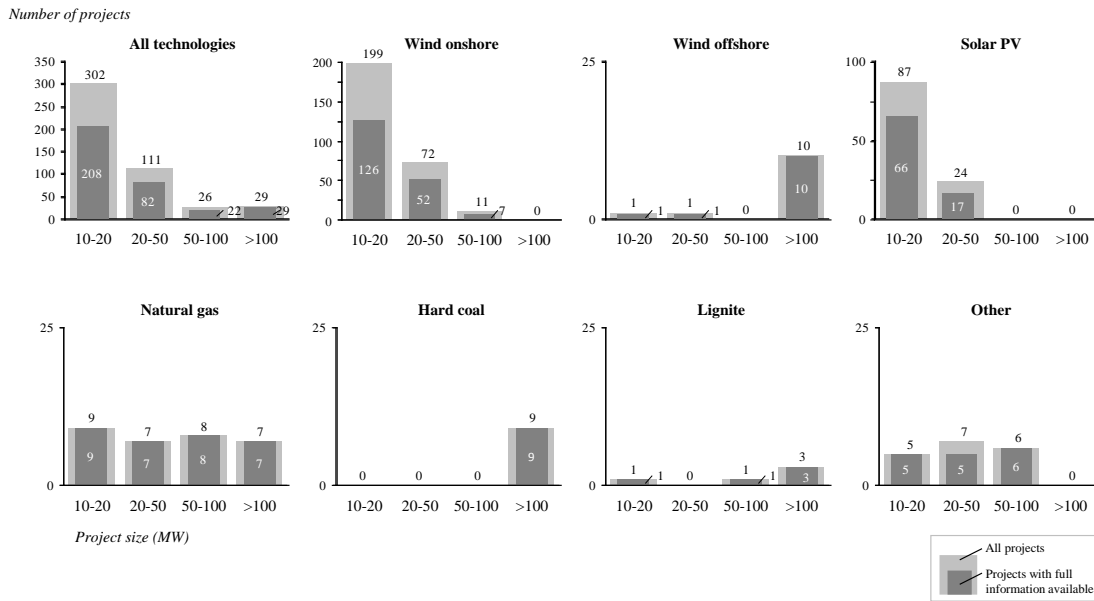
Finally, the available information is used to determine the financing structure (project finance or corporate finance) of a project as follows: Depending on the company size, the financial statements often include a description of the purpose of the company (which is in many cases also reflected in the name of the legal entity already). In case that the sole purpose of an entity is the realization of the project, the entry is a candidate for project finance. The pure legal setup, however, is not sufficient to conclude on the financing structure – in cases where the financial statement and other public sources do not explicitly mention the financing structure, we therefore consider an entry as using project finance only under two additional conditions: First, the balance sheet total implies an investment per MW installed capacity within a reasonable range for the given technology – which ensures that the asset is accounted for entirely in the project entity. Second, the project is realized using a high leverage ratio of at least 70%, which is common for project finance in power generation (Yescombe, 2013), including renewables (Alonso, 2015)[18]. The suitability of these criteria to identify the use of project finance has been confirmed in discussions with practitioners. While we cannot determine if project finance is used for all cases, the approach leads to data points with a high level of accuracy for entries where information is available, and thereby goes well beyond the data sources on project finance available so far.

In sum, we can determine the entity, sponsor and financing structure for 73% of the 468 projects in the comprehensive plant list, leading to 341 observations. Histograms in Figure 2 illustrate that information is available for more than 60% of projects for all technologies in all size clusters, including projects of 10-20 MW. Thus, the dataset most likely describes German power generation investments in general sufficiently well
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[17] In few cases where the entity's fiscal year has been different than the calendar year, we used the balance sheet at the end of the fiscal year during which the plant was commissioned.
[18] The leverage is calculated by dividing liabilities by equity + liabilities at the end of the fiscal year when the plant was commissioned. This serves well as proxy for the capital structure at times of commissioning, given that only limited depreciations or retained profits accrue during the comparably short period until the end of the fiscal year.

Number of projects

All technologies

302
208
111
82
26 22
29 29

10-20   20-50   50-100   >100

Wind onshore

199
126
72
52
11 7
0

10-20   20-50   50-100   >100

Wind offshore

1 1
1 1
0
10 10

10-20   20-50   50-100   >100

Solar PV

87
66
24
17
0
0

10-20   20-50   50-100   >100

Natural gas

9 9
7 7
8 8
7 7

10-20   20-50   50-100   >100

Hard coal

0
0
0
9 9

10-20   20-50   50-100   >100

Lignite

1 1
0
1 1
3 3

10-20   20-50   50-100   >100

Other

5 5
7 5
6 6
0

10-20   20-50   50-100   >100

Project size (MW)

All projects

Projects with full
information available

Figure 2: Overview data availability (no. of projects in size clusters by technology)

4.3 Model specification

The new dataset is used for both research questions. To assess the relevance of project finance (question 1), descriptive analyses are provided in the next section. They also provide some indication on the drivers to use project finance (question 2), which is then analyzed more rigorously in a regression analysis of hypotheses H1-H5: We estimate a model of the probability that project finance is used given a set of project- and sponsor characteristics. Using standard logistic regression, the model is fitted by maximum likelihood, with robust Huber-White-Sandwich standard errors. Based on the stylized economic model (equation (1)), the model is parameterized for the case of power plant projects in Germany as follows:

Dependent variable: Indicator whether project finance is used, compiled as described in section 4.2.

Independent variables: Following the stylized economic model in equation (1), project- and sponsor-characteristics potentially explain the use of project finance: To capture project size, we consider the installed capacity (*Installed capacity*), as well as the capacity squared to cover nonlinear relationship (*Installed capacity squared*) – to simplify a comparison with the coefficients of the binary explanatory variables, we follow the standard approach to scale the capacity by dividing by two standard deviations (cf. Gelman, 2008).

For project risk, the most important differentiator in Germany is whether revenues have to be earned on volatile wholesale markets (applicable for most conventional plants), or stem from a fixed feed-in tariff (applicable for most renewables) – which we include via an indicator *Merchant risk (no feed-in tariff)* that signals the higher revenue risk. Within the class of renewables, technologies are comparably new such that technology risk can lead to a significant overall project risk, even in the absence of merchant risk[19]. Mazzucato and Semieniuk (2016) construct a risk measure by technology and year – for the period 2010–2015, solar PV and wind onshore are already "low risk", while wind offshore is still considered "high risk" (a classification consistent with the general market view in

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[19] The conventional power generation technologies under study (lignite, hard coal, natural gas) are all mature technologies

Germany at the time, cf. Höpner et al. (2012)). We thus include an indicator variable *Renewable technology risk (wind offshore)* alongside the merchant risk variable.

In the same fashion as risk, the *CAPEX to OPEX ratio* is driven by the technology chosen. Based on review of European cost data provided by VGB Powertech (2015), ratios range from 8 for gas plants (low upfront investment, high fuel cost) to 96 for solar PV (high upfront investment, no fuel cost) – details on the calculations can be found in appendix A1. Analogously to *Installed capacities*, the *CAPEX to OPEX ratios* are rescaled to facilitate the interpretation of results.

To differentiate between sponsor characteristics, we include dummy variables describing the type of sponsor: *Big four utility* (the incumbent national utilities RWE, E.ON, Vattenfall, EnBW – which are strongly negatively affected by the energy transition and have very high financing costs during the observed period), *Regional/municipal utility* (regional or local utilities that are typically municipality-owned), *Foreign utility/IPP* (foreign utilities and independent power producers), *Project developer* (players that focus on developing renewable energy plants, often for sale soon after commissioning), *Industry* (non-energy industrial sponsors, e.g. automotive, chemicals, agriculture), *Financial investor* (institutional investors, specialized funds, etc.), and *citizen owners* (energy cooperatives and individuals). In case that a project is realized by several sponsors from different groups together, more than one dummy variable is true for this project (this is the case for 11% of the projects). Separately, *Horizontal joint venture* indicates whether a project is a horizontal joint venture including more than one energy utility (Big four or regional/municipal). Detailed definitions of the sponsor types are provided in appendix A.2

Further control variables. The project risk variables make use of differences between conventional (merchant) and renewable (feed-in tariff) plants, as well as between offshore wind and other renewables. Even though no risk differences are expected between the other technologies, additional indicators by technologies are included as controls (taking the most common technologies gas and onshore wind as reference in the groups of conventionals and renewables, respectively). Finally, we include year fixed effects to control for particularities that might occur in certain years.

Descriptive statistics and correlation coefficients for all variables are provided in appendix A.3.

5 Empirical results

5.1 Importance of project finance (descriptive analysis)

To evaluate the importance of project finance (research question 1), figures 3 and 4 show the share of projects that use project finance along project size and technology, respectively. Clearly, project finance is of great importance especially for comparably small projects – ca. 83% of projects that are smaller than 50 MW use it, but only 36% of projects in the cluster 50–100 MW, and just 28% of even larger projects. Of course the typical project size differs by technology – correspondingly, figure 3 shows that project finance is used especially for wind onshore (88%) and solar PV (96%), less for wind offshore (50%) or hard coal (22%), and in only very few cases for natural gas (6%). Recalling that renewables in Germany qualify for a feed-in tariff that takes away all the merchant risk, it is the generally smaller, less risky projects that rely on project finance – putting the *contamination risk* reason into question, which will be further assessed by the regression analysis.
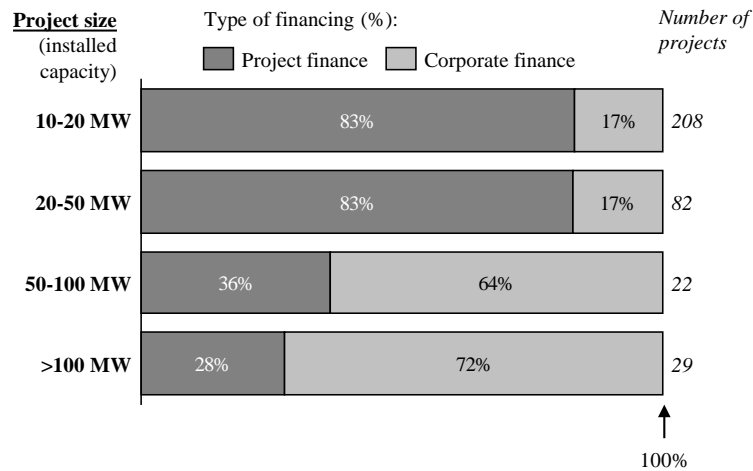
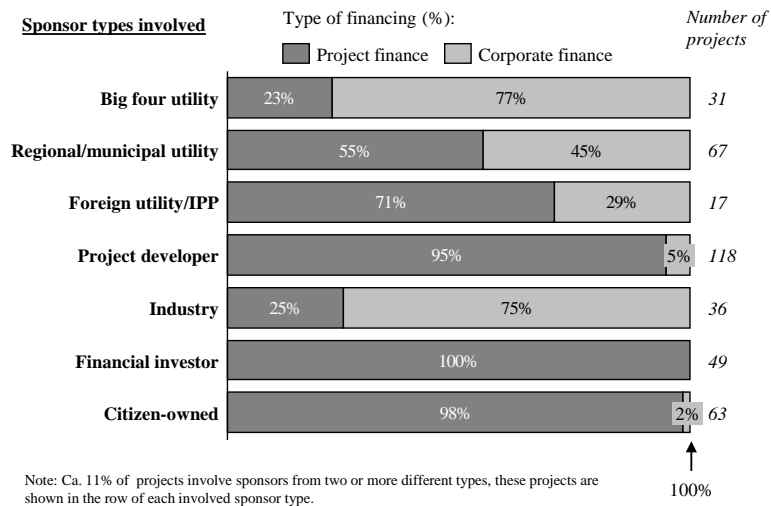**Figure 3: Use of project finance by size of project**
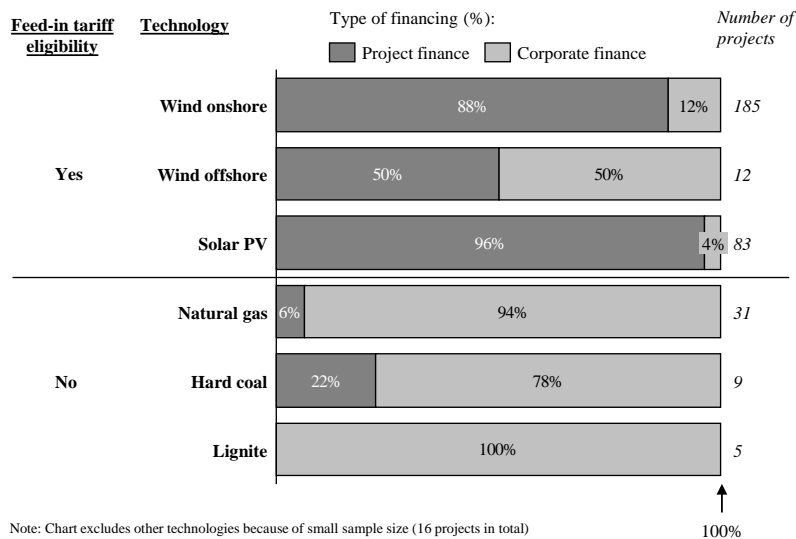
Note: Chart excludes other technologies because of small sample size (16 projects in total)
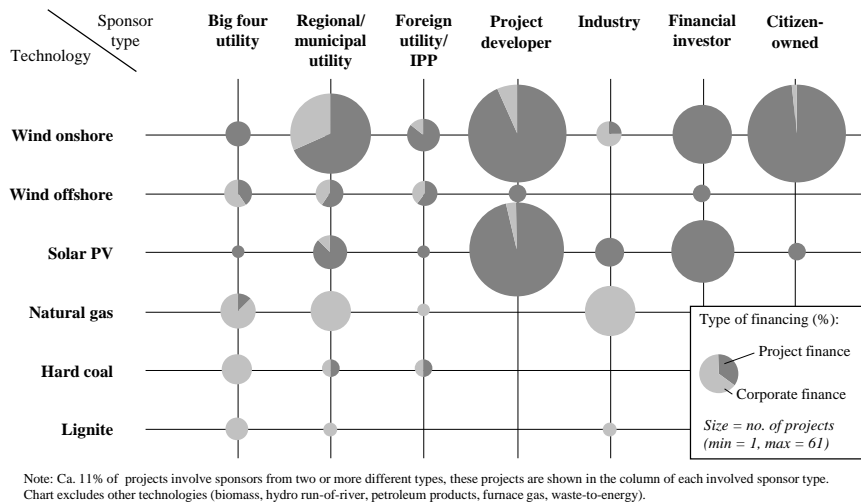
Figure 4: Use of project finance by feed-in tariff eligibility and technology

Differentiating by sponsor, figure 5 illustrates how differently project finance is being used by different types of sponsors. The domestic "big four" utilities, which historically used to be the main investor into power generation in Germany, use project finance in only 23% of new projects, and industrial companies (automotive, chemicals etc.) in just 25% of cases. Other energy players such as regional/municipal utilities or foreign utilities (both comparatively new players for power generation investments in Germany) rely on project finance in 55% and 71% of cases, respectively. Specialized project developers and citizen-owners mainly use project finance. Projects with a financial investor as sponsor even rely on project finance in 100% of cases – this includes both projects that are commissioned by a financial investor as sponsor alone, as well as joint ventures between financial investors and other sponsor types (mainly with project developers). The joint distribution of types of financing across sponsor types and technologies is summarized in figure 6. The chart illustrates that project developers, financial investors and citizens focus on renewables and use project finance for these projects, whereas the different types of utilities invest across all technologies, using both project and corporate finance (with project finance being more important for renewables among these sponsors also).

Sponsor types involved	Type of financing (%): Project finance ▮ Corporate finance ▯		Number of projects
Big four utility	23%	77%	*31*
Regional/municipal utility	55%	45%	*67*
Foreign utility/IPP	71%	29%	*17*
Project developer	95%	5%	*118*
Industry	25%	75%	*36*
Financial investor	100%		*49*
Citizen-owned	98%	2%	*63*

Note: Ca. 11% of projects involve sponsors from two or more different types, these projects are shown in the row of each involved sponsor type.

Figure 5: Use of project finance by type of sponsor

Note: Ca. 11% of projects involve sponsors from two or more different types, these projects are shown in the column of each involved sponsor type.
Chart excludes other technologies (biomass, hydro run-of-river, petroleum products, furnace gas, waste-to-energy).

Figure 6: Number of projects by sponsor type involved and technology

In sum, the descriptive statistics confirm that project finance has been of great importance for power projects commissioned 2010–15; especially for comparably smaller renewable energy projects that have become more frequent with Germany's efforts to move towards a low-carbon electricity system.

5.2 Drivers for use of project finance (regression analysis)

To assess the explanatory power of different motivations for project finance (research question 2), the different project- and sponsor characteristics have to be considered not only one-by-one, but jointly. Table 3 summarizes regression results following the logit specification as described in section 4.3. As figure 5 illustrated, one group of sponsors –*Financial investor* – perfectly predict the use of project finance, hence the dummy variable is dropped and the respective observations not used in specifications differentiating by sponsor type.

To test hypothesis H1, model A includes measures of project size, project risk, as well as sponsor types. If these factors are considered jointly, project size does not have a statistically significant effect on the uptake of project finance. However, the probability that project finance is used *decreases* strongly with risk exposure, as shown by the negative coefficients for the *Merchant risk* and *Renewable technology risk* variables. This results (which contradicts the hypothesis) also holds if additional technology controls are included (model B) [20]. As the contamination risk rationale predicts the use of project finance for projects that are large *and* risky at the same time, model C also explicitly accounts for this by the interaction *Installed capacity × Merchant risk* – which does not have a statistically significant effect, while the coefficient for *Merchant risk* is still strongly negative.

While in theory the motive to prevent "contamination" of a core business could apply for firms of all sizes, it might be particularly relevant for companies that have a large existing business. To make sure that results are not distorted by "younger" sponsors such as project developers, a supplementary analysis repeats regression models A–C for a subsample including only big four utilities, regional/municipal utilities, foreign utilities/IPP, and industry (see appendix D). Results are the same. Thus, hypothesis H1 can be rejected, meaning that "risk contamination" is not a significant driver of renewable energy project finance in Germany.

Hypothesis H2 states that if "securitization" considerations are decisive, project finance will be used more often if "high-risk" players (i.e. companies with high financing cost due to challenges in their core business) realize low-risk projects. In Germany, this characteristic applies in the period under study for the *Big four utilities* that are privately held to a significant extent, and have been hit hard by the energy transition[21] (regional/municipal utilities, in contrast, typically profit from implicit guarantees from their public owners and thus have very low refinancing costs). Model D in table 3 includes an interaction term *Big four utility × No merchant risk* that identifies low-risk projects realized by these "high risk" sponsors. The coefficient to this term is not statistically significantly different from zero, thus it seems likely that securitization by the Big four utilities in Germany is not a major driver for project finance (though H2 cannot be formally rejected for the data given).

The third hypothesis H3 refers to sponsor characteristics, predicting that project finance is used more often by *project developers* or *citizen owners*. Four model specifications (A, B, C, E) include dummy variables for sponsor types, all estimating a statistically significant increase in project finance probability if these sponsor types are involved, in a magnitude comparable to the effect of project risk. Consequently, the hypothesis cannot be rejected. Interestingly, all other sponsor types (except for *financial investor* of course) do not make a statistically significant difference for the probability of project finance, the estimated coefficients are also much smaller in magnitude. Thus it seems likely that the "debt overhang" reason is an important driver for project finance. For the projects realized by citizen owners, it could also be the case that the "independence of civic projects" motivation is applicable.

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[20] As the technology *Lignite* perfectly predicts a failure to use project finance (cf. figure 4), the corresponding observations are excluded

[21] To underline this point, note that "the yields on RWE and E.ON sticks used to track 10-year government bonds, but since 2008 the yields have climbed to around 10% while government bonds have remained relatively stable" (Tulloch et al., 2017, p. 78).

		A	**B**	**C**	**D**	**E**	**F**
		(all sponsors)	(all sponsors)	(all sponsors)	(all sponsors)	(all sponsors)	(only RegMun[a])
Project size	Installed capacity	2.271 (2.175)	2.758 (2.483)	1.944 (2.636)	2.392 (2.346)	3.611 (3.370)	0.458 (3.090)
	Installed capacity squared	-1.038 (0.854)	-1.804 (1.157)	-1.299 (0.916)	-1.150 (0.946)	-1.633 (1.322)	0.296 (1.047)
Project risk	Merchant risk (no feed-in tariff)	-2.558*** (0.771)	-2.190*** (0.803)	-2.702*** (0.886)	-2.771*** (0.783)	-0.935 (1.438)	-3.827 (3.513)
	Renew. tech. risk[b] (wind offshore)	-2.391* (1.268)	-2.596* (1.394)	-2.012 (1.898)	-2.272* (1.379)	-2.663 (1.907)	-1.607 (1.811)
Technology controls	Hard coal		2.396 (2.786)				
	Solar PV		2.673*** (1.026)				
Free CF pot.[c]	CAPEX to OPEX ratio					4.049*** (1.478)	4.724* (2.473)
Sponsor type	Big four utility	-0.810 (0.876)	-0.458 (0.903)	-0.787 (0.869)	0.055 (1.331)	-0.662 (1.016)	
	Regional/municipal utility	-0.425 (0.833)	-0.555 (0.874)	-0.393 (0.852)	-0.406 (0.811)	-0.474 (0.962)	
	Foreign utility/IPP	0.948 (1.038)	1.073 (1.039)	0.940 (1.025)	1.034 (1.066)	1.250 (1.208)	
	Project developer	2.371*** (0.812)	2.024** (0.926)	2.409*** (0.839)	2.440*** (0.784)	2.297** (0.933)	
	Industry	-0.620 (1.017)	-0.913 (0.987)	-0.573 (1.046)	-0.491 (0.964)	-1.057 (1.152)	
	Citizen-owned	3.604*** (1.259)	3.541*** (1.283)	3.623*** (1.263)	3.637*** (1.251)	3.638*** (1.348)	
	Horizontal joint venture	1.381* (0.722)	1.889** (0.803)	1.368* (0.715)	1.403* (0.737)	2.239** (0.974)	1.749 (1.264)
Interaction terms	Installed capacity × Merchant risk				0.985 (2.847)		
	Big four utility × No merchant risk				-1.216 (1.499)		
	Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
	Pseudo-R^2	0.522	0.534	0.523	0.524	0.578	0.347
	Observations	292	287	292	292	276	64

Standard errors in parentheses

[a]RegMun = Regional/municipal utility [b]Renew. tech. risk = Renewables technology risk [c]Free CF pot. = Free cash flow potential
*statistically significant at 10%; **significant at 5%; ***significant at 1%

Table 3: Results from logit regression on use of project finance

Hypothesis H4 postulates project finance being used more often by *horizontal joint ventures* between energy utilities – the respective dummy variable indeed has a statistically significant effect in that direction as long as sponsor types are included (models A, B, C, E), such that our hypothesis cannot be rejected. However, it naturally only explains the uptake of project finance in very specific cases, and thus this motivation complements the other hypotheses tested.

Finally, hypothesis H5 postulates a higher *CAPEX to OPEX ratio* to increase the probability that project finance is used. Model E includes the ratio as an explanatory variable, alongside the size-, risk- and sponsor-type parameters.

Its coefficient is statistically significantly positive, such that the hypothesis motivated by the "agency conflicts between owners and managers"-reason cannot be rejected. For an additional perspective on H5, model F considers only projects that have been realized by a single type of sponsors, to abstract from different sponsor characteristics – focusing on regional/municipal utilities as they are active in all technologies and use both project finance and corporate finance in a relevant proportion. Also in this regression, projects with a higher CAPEX to OPEX ratio show a larger probability to use project finance. As the *CAPEX to OPEX ratio* is large especially for renewable energy technologies, the correlation with the *Merchant risk (no feed-in tariff)* variable is high (and the latter loses statistical significance if the *CAPEX to OPEX ratio* is included). Thus the positive coefficient should not be mistaken to confirm that the "agency conflicts between owners and managers" reason plays a role; it only shows that H5 cannot be rejected, and as such "agency conflicts between owners and managers" cannot be excluded as driver for project finance, possibly besides the "debt overhang" reason.

In sum, the robust rejection of hypothesis H1 suggests that the contamination risk argument as the "classical" reason to use project finance in energy does not explain it in the German context, nor do information asymmetries between sponsor and lender in the sense of Shah and Thakor (1987). Also "securitization" of renewable energy projects through Big four utilities with a risky core business does not play a role for the period under study. Instead, it seems likely that the "debt overhang" reason causes the uptake of project finance in Germany, with the prevention of "agency conflicts between owners and managers" being a possible alternative explanation.

5.3   Robustness and limitations

Our most important findings (namely rejection of H1, and non-rejection of H3) are robust across the different model specifications produced in table 3. Nevertheless, certain limitations of the empirical approach need to be discussed. First, the sample of projects under study is not fully randomly selected, but driven by the availability of data in the creation of the dataset described in section 4.2. However, with full data available for 73% of all plants commissioned during the period under study, a potential sample selection bias is likely to be small – as illustrated in figure 2, the missing information mainly concerns plants <20 MW, but data availability is still >60% here, and project size is also included as independent variables in all regression specifications.

Second, the grid regulator's plant list is comprehensive only for projects starting at a size of 10 MW and we limit the analysis accordingly, so the results do not make any statements for smaller plants. While project finance is not relevant for small setups such as roof-top solar PV in Germany, it might play a role for wind and solar parks slightly below 10 MW. Yet the presented results apply to a large part of the market (including overall installations of 25 GW during 2010–15, cf. table 2), and are not affected by the segment of small installations being out of scope.

Finally, by focusing on project- and sponsor-characteristics, the present analysis does not scrutinize the regulatory framework regarding power generation, investment in general, or taxation regimes, which can make project finance more or less attractive. This is justified as all projects have been realized in the same country, and regulatory changes over time are broadly captures by year-fixed effects. The results from Germany have important implications that apply to other developed countries as well, which will be discussed in the next section.

6 Implications

The results highlight that project finance plays an important role in the energy sector – not only in the risky environments of a developing country, but also in stable, low-risk countries such as Germany. As it is not used for "contamination risk" considerations, but rather to address capital constraints of new power generation players or to discipline managers of "high CAPEX/low OPEX" businesses, project finance is highly relevant especially for smaller projects in renewable energy technologies such as wind and solar.

These findings matter for policy makers: The broad use of project finance in Germany implies that in order to foster investment in (also comparably small) renewable energy projects, it is helpful to create a regulatory and financial market environment which enables project finance at low transaction costs. Not because project finance is preferable to corporate finance per se, but because it is the financing structure which allows a large group of sponsors (developers, financial investors, and citizen owners) to realize projects despite a small own balance sheet. This can be of particular importance in transition times, where large incumbent players have high cost of capital, and small entrants have not (yet) the size of balance sheets required for major investments. A crucial prerequisite for project finance is a high certainty on revenue streams, which is currently achieved through feed-in tariffs or long-term power purchase agreements in many countries. As scholars and policy makers consider to increasingly "re-risk" mature renewable energies by making them bear merchant risk again (cf. Pahle and Schweizerhof, 2016), carefully-designed policies are needed in order to keep projects viable for project finance.

Furthermore, additional factors contribute to conditions favorable for project finance, including the availability of appropriate legal entities, a well-functioning insurance market providing coverage at low cost, as well as banks willing to provide project finance for comparably small projects. In Germany, municipally-owned saving banks and local co-operative banks often took that role, in contrast for instance to the UK where a more centralized banking system was less willing to fund especially civic-owned projects (Hall et al., 2016). Within the financial sector, the actors need to develop tools that allow for project structuring and appraisals at a cost appropriate for smaller plants, e.g. by standardizing deal structures and due diligence criteria. In sum, a conducive "project finance ecosystem" is necessary to allow new players such as the German wind project developers to build a large pipeline of new projects, without being restricted by a debt overhang. From a policy maker point of view, the financial framework can complement renewable support policies such as feed-in tariffs and related schemes.

On the flipside, the broad use of project finance by comparably new power generation players also shows that the currently weak balance sheets of large incumbent utilities (e.g. the German "Big four") are less an issue regarding investment in renewables.[22] For instance, Tulloch et al. (2017) express a common concern by noting that "If EU policies significantly impact the returns of European utilities this can, in turn, affect utilities' cost of capital and capital-raising ability... Put differently, the shift towards liberalization appears to conflict with the policy objectives of enhancing security of supply and encouraging investment in low-emission generating technology, as it does not provide a sound basis for investment in the sector" (p. 78). At least for the case of Germany, our results show that the lion's share of low-emission generating technology was realized using project finance, and thereby largely independent of large utilities' cost of capital. Project finance actually allowed a broad variety of players – ranging from municipalities over financial investors to foreign IPPs – to act as sponsor of renewable energy projects.[23]

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[22] Incumbent utilities of course can have roles other than investment in power generation that are crucial for a successful transition to low-carbon power systems, such as investment in grid extension, energy storage, etc.
[23] Our results showed that during 2010–15, the German Big Four utilities did not use project finance as a securitization instrument to a significant extent. Recently, however, a related route has been chosen by RWE who created a spin-off

Finally, the prevalence of project finance needs to be taken into account by scholars analyzing or modelling energy investment decisions. As we highlight, especially the financing of renewable energy projects is typically structured without recourse to the sponsor. Consequently, profitability assessments and investment decisions (e.g. in techno-economic models, and system models with capacity extension) should take project-specific cost of capital into account, as compared to the established practice to use a standard weighted average cost of capital (WACC) for power utilities.

7 Conclusion

This article aimed at understanding the importance and drivers of project finance in the energy sector – especially in investment-grade, "low risk" countries that strive towards a low-carbon power system. Drawing on economic, financial, and management theory, eight potential reasons to use non-recourse project finance have been distilled and assessed empirically for the case of in Germany, an extreme case of a very low-risk investment environments.

Using a newly created database which combines the grid regulator's asset information with data from the German trade register, it is shown that the classical "contamination risk" explanation does not hold – project finance is not used for large and risky projects, but instead mainly for small, low-risk renewable energy projects. The key factor is the type of project sponsor, with especially independent project developers and citizen owners using project finance to grow their wind and solar project pipeline, beyond what the strength of their corporate balance sheet would allow for. A number of alternative reasons for project finance have been assessed, and implications for policy makers, the financial sector, as well as energy scholars derived.

From a global point of view, Germany is not only an important market for renewable energy investment, but understanding the role of project finance there also helps to assess its importance in other low-risk countries. The way in which different regulatory-, legal- and market-conditions affect the role that project finance can take for renewable energy projects could be an interesting avenue for future research. In principle, though, this article underlines the importance that project finance can have in a low-risk, investment-grade country, and also for comparably small projects. Which are very unlike the "large and complex installations" (BCBS, 2006, p. 53) that typically come to mind when talking about project finance in energy. The article thus sheds light on an important and previously unstudied aspect of financial structures for power plants, and thereby adds to the emerging literature on renewable energy finance.

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including the entire renewable energy business and other stable branches such as grid operation, reaching lower re-financing costs. Also E.ON split their business, however by carving out the risky "core" business to a separate company instead (cf. "German power companies - Braking Bad," 2016).

Acknowledgements

Appendix

A   Calculation of CAPEX to OPEX ratios

We calculate the ratio of capital expenditure (per annual MWh electricity produced) and operating expenditure (per annual MWh electricity produced) drawing on data from VGB Powertech (2015), the European technical association of power generating companies. Their estimates are based on a compilation of 11 different data sources focusing on Europe, and well in line with the Germany-specific cost estimates for conventional plants as summarized in Steffen and Weber (2013). We use the "real case" which reflects actual full-load hours in European power market (as compared to a general optimal range), and take the average between the maximum and minimum provided in VGB Powertech (2015) to calculate technology-specific values (see table A1). Finally, the ratios are scaled to ensure regression coefficients are comparable to those of the binary variables (dividing by two standard deviations following the standard approach proposed by Gelman (2008)).

		Hard coal	Lignite	Gas (CCGT)	Wind onshore	Wind offshore	Solar PV
Investment cost	€/kW	1450	1575	675	1400	3650	1250
Annual full-load hours	h	3250	5000	1625	2500	3600	1450
CAPEX	**€/MWh$_{el}$**	**446**	**315**	**415**	**560**	**1014**	**862**
O&M cost	€/kW/a	35.5	39	21	40	110	19
Fuel cost	€/MWh	9	5	23.5			
Carbon price	€/tCO$_2$	7.5	7.5	7.5			
Electrical efficiency	%	0.45	0.42	0.6			
Carbon factor	tCO$_2$/MWh	0.339	0.404	0.202			
OPEX	**€/MWh$_{el}$**	**35**	**26**	**53**	**12**	**28**	**9**
CAPEX/OPEX		13	12	8	47	37	96
CAPEX/OPEX scaled		0.19	0.18	0.12	0.69	0.54	1.43

Table A.1: Calculation of CAPEX to OPEX ratio by technology
(source: VGB Powertech (2015), Steffen and Weber (2013), own calculation)

B. Definition of sponsor types

The sponsor type has been coded along the definitions summarized in table A.2. Note: For the purpose of this article, the sponsor type considers the company that owns the power plant at time of commissioning. Projects that have been prepared and realized by a project developer, for instance, and are sold to a financial investor once online are consequently shown under "project developer", not under "financial investor".

Sponsor type	Definition	Examples
Big four utility	The four largest incumbent national utilities	EnBW, E.ON, RWE, Vattenfall
Regional/municipal utility	Regional or local utilities that are (1) owned by the municipality or other regional authorities, and (2) provide public infrastructure services including electricity sales and/or grid operation. Also includes co-operations of regional utilities.	Stadtwerke München, Stadtwerke Schwäbisch Hall
Foreign utility/IPP	Utilities with their home market outside Germany, and independent power producers	Axpo (Switzerland), Dong (Denmark)
Project developer	Companies focusing on the development, construction and commissioning of renewable energy plants (often for sale soon after commissioning)	Energiekontor, Juwi
Industry	Non-energy industrial company that produces electricity only as side business, typically for own consumption. Also includes OEM of power plant equipment	Daimler (automotive), Dow (chemicals)
Financial investor	Financial services company that manages investments into asset classes such as renewables power plants (institutional investors, specialized funds, etc.). Unlike *Project developers*, financial investors have a clear focus on financing, investment management, and sales of investment products, even though other project development steps can also be part of activities	Capital Stage, Commerz Real
Citizen-owned	Group of (typically local) citizens owning one or a portfolio of several renewable energy plants, and individuals (often farmers) controlling family-owned power plant	So-called Bürger-Windparks (citizens' wind farms), Mainzer Energiegenossenschaft

Table B.1: Definition of sponsor types

C. Descriptive statistics and correlation coefficients

	Mean	S.D.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
(1) Project finance	0.778	0.416	1.000																		
(2) Capacity	0.200	0.512	-0.385	1.000																	
(3) Capacity squared	0.301	1.277	-0.348	0.968	1.000																
(4) Merchant risk (no feed-in tariff)	0.138	0.346	-0.666	0.565	0.528	1.000															
(5) Renew. tech. risk (wind offshore)	0.037	0.189	-0.131	0.205	0.052	-0.079	1.000														
(6) Hard coal	0.028	0.164	-0.226	0.692	0.658	0.421	-0.033	1.000													
(7) Solar PV	0.255	0.437	0.261	-0.173	-0.137	-0.235	-0.115	-0.099	1.000												
(8) Lignite	0.015	0.123	-0.234	0.362	0.423	0.312	-0.025	-0.021	-0.073	1.000											
(9) CAPEX to OPEX ratio	0.799	0.414	0.522	-0.394	-0.338	-0.642	-0.121	-0.250	0.893	-0.187	1.000										
(10) Big four utility	0.089	0.286	-0.431	0.600	0.565	0.406	0.225	0.342	-0.159	0.224	-0.321	1.000									
(11) Regional/municipal utility	0.197	0.398	-0.239	0.051	0.026	0.093	0.108	0.011	-0.148	0.001	-0.167	0.035	1.000								
(12) Foreign utility/IPP	0.046	0.210	-0.024	0.172	0.108	0.039	0.268	0.142	-0.095	-0.028	-0.108	-0.069	-0.035	1.000							
(13) Project developer	0.363	0.482	0.310	-0.192	-0.168	-0.303	-0.080	-0.127	0.365	-0.094	0.429	-0.191	-0.293	-0.105	1.000						
(14) Financial investor	0.151	0.358	0.225	-0.093	-0.088	-0.169	0.009	-0.071	0.227	-0.053	0.254	-0.102	-0.187	-0.052	-0.175	1.000					
(15) Industry	0.077	0.267	-0.374	-0.057	-0.063	0.419	-0.057	-0.049	-0.037	0.058	-0.227	-0.050	-0.114	-0.064	-0.194	-0.057	1.000				
(16) Citizen-owned	0.194	0.396	0.243	-0.134	-0.114	-0.197	-0.096	-0.083	-0.252	-0.061	-0.097	-0.154	-0.204	-0.108	-0.306	-0.207	-0.142	1.000			
(17) Horizontal joint venture	0.071	0.257	-0.084	0.248	0.195	0.063	0.264	0.173	-0.162	-0.035	-0.170	0.166	0.527	0.111	-0.183	-0.116	-0.080	-0.135	1.000		
(18) Installed capacity × Merchant risk	0.127	0.509	-0.384	0.958	0.974	0.626	-0.049	0.720	-0.147	0.382	-0.385	0.562	0.034	0.106	-0.189	-0.106	-0.027	-0.123	0.191	1.000	
(19) Big four utility × No merchant risk	0.037	0.189	-0.171	0.053	-0.007	-0.079	0.394	-0.033	-0.077	-0.025	-0.051	0.626	0.067	-0.043	-0.080	-0.037	-0.057	-0.096	0.137	-0.049	1.000

Table C.1: Descriptive statistics and correlation coefficients

D.   Supplemental analysis: Regressions for sub-sample of sponsors

As additional sensitivity analysis regarding the assessment of hypothesis H1, the following table repeats regression models A, B, C from table 3 in the main text, but only including observations from four sponsor types: *Big four utilities*, *Regional/municipal utilities*, *Foreign utilities/IPP*, and *Industry*. The results from table 3 do hold for this sub-sample in terms of direction and statistical significance of coefficients; also the magnitude of coefficients is comparable.

		G (only selected sponsors)	H (only selected sponsors)	I (only selected sponsors)
Project size	Installed capacity	2.610 (2.028)	2.978 (2.659)	2.567 (2.460)
	Installed capacity squared	-1.094 (0.831)	-1.895 (1.521)	-1.126 (0.885)
Project risk	Merchant risk (no feed-in tariff)	-3.283*** (0.743)	-2.623*** (0.849)	-3.299*** (0.818)
	Renew. tech. risk[a] (wind offshore)	-2.760** (1.160)	-2.771** (1.241)	-2.711 (1.722)
Technology controls	Hard coal		2.577 (3.496)	
	Solar PV		4.098** (1.774)	
Free CF pot.[b]	CAPEX to OPEX ratio			
Sponsor type	Big four utility	-1.604 (1.031)	-1.325 (1.046)	-1.601 (1.038)
	Regional/municipal utility	-1.174 (1.119)	-1.314 (1.093)	-1.171 (1.135)
	Foreign utility/IPP	0.384 (1.305)	0.656 (1.250)	0.382 (1.300)
	Industry	-1.205 (1.282)	-1.731 (1.292)	-1.200 (1.306)
	Horizontal joint venture	1.320* (0.763)	1.963** (0.835)	1.317* (0.766)
Interaction terms	Installed capacity × Merchant risk			0.124 (2.611)
	Big four utility × No merchant risk			
	Year fixed effects	Yes	Yes	Yes
	Pseudo-R^2	0.344	0.384	0.344
	Observations	138	133	138
		Standard errors in parentheses		

[a]Renew. tech. risk = Renewables technology risk   [b]Free CF pot. = Free cash flow potential
*statistically significant at 10%; **significant at 5%; ***significant at 1%

Table D.1: Results from logit regression on use of project finance (sensitivity analysis)

Supplementary data

Supplementary data is available in the online version of the paper.

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