Renewable energy financing by state investment banks: Evidence from OECD countries

Journal Article

Author(s):
Waidelich, Paul Dietmar; Steffen, Bjarne

Publication date:
2024-04

Permanent link:
https://doi.org/10.3929/ethz-b-000666196

Originally published in:
Energy Economics 132, https://doi.org/10.1016/j.eneco.2024.107455

Funding acknowledgement:
948220 - Effective green financial policies for the low-carbon transition (EC)

Energy Economics 132 (2024) 107455

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneeco

Renewable energy financing by state investment banks: Evidence from OECD countries

Paul Waidelich [a,*], Bjarne Steffen [a,b,c]

[a] Climate Finance and Policy Group, ETH Zurich, Clausiussstrasse 37, 8092 Zurich, Switzerland
[b] Institute of Science, Technology, and Policy, ETH Zurich, Universitätsstrasse 41, 8092 Zurich, Switzerland
[c] Center for Energy and Environmental Policy Research, Massachusetts Institute of Technology, 77 Massachusetts Avenue, E19-411, Cambridge, MA 02139-4307, United States of America

ARTICLE INFO

JEL classification:
G21
H81
Q48
Q55

Keywords:
Clean energy
Derisking
Public finance
Energy policy
Power generation

ABSTRACT

While governments increasingly employ state investment banks (SIBs) to finance renewable energy projects, whether these institutions' actual behavior aligns with expectations remains uncertain. Here, we assess the predictors of SIB involvement in renewable energy deals in OECD countries using a fixed-effects logit model. Our results show greater SIB involvement in higher-risk technologies such as offshore wind and biomass but decreased activity once domestic markets for solar photovoltaics mature. Contrary to what the literature suggests, however, SIBs show no increased involvement in first projects using novel technology, unlike other public-sector lenders, and less involvement in smaller renewable energy deals. The evidence on whether SIBs mobilize private sector lenders or crowd them out favors the former but remains equivocal. We conclude by discussing the implications for policymakers regarding the mandates and guidelines for SIBs.

1. Introduction

Achieving the Paris Agreement targets will require renewable energy (RE) investments of magnitudes that substantially exceed current levels (McCollum et al., 2018; IEA, 2023; Klaaßen and Steffen, 2023). Given the scale of investment needs, mobilizing finance from the private sector is necessary (IPCC, 2022). While economists typically consider a combination of carbon pricing and research subsidies to be the optimal policy strategy to achieve this aim (Acemoglu et al., 2012), governments use a wide variety of RE support policies such as feed-in tariffs (FiTs) and portfolio standards (Polzin et al., 2019; Abrell et al., 2019b). In many OECD countries, policy makers have also increasingly used state investment banks (SIBs), i.e., publicly capitalized financial institutions with independent day-to-day operations and a domestic focus, as part of their policy strategy to finance RE projects and the low-carbon transition in general (Campiglio, 2016; Cochran et al., 2014).[1] Public investment banks with "green" lending mandates exist in numerous countries (Whitney et al., 2020), including jurisdictions that traditionally lean toward less government intervention such as the United Kingdom (UK) and Australia (Geddes and Schmidt, 2020). Most recently, the United States set up a USD 14 billion fund to capitalize national clean finance institutions under the Inflation Reduction Act (US EPA, 2023), while the European Investment Bank will raise an additional EUR 45 billion for clean energy financing (EIB, 2023). However, while the theoretical and empirical understanding of other RE support policies has greatly advanced in recent years (Schmalensee, 2012; Reguant, 2019; Abrell et al., 2019a,b; Kalkuhl et al., 2013), states' prevalent use of SIBs to foster the clean energy transition has received little attention.

Conceptual studies suggest that SIBs can finance projects unable to source funds from the private sector, thus facilitating additional transactions (OECD, 2016, 2017). Furthermore, they can mobilize private financiers through signaling and derisking, allowing commercial banks to gain experience with novel technologies (Waidelich et al., 2023; Mazzucato and Penna, 2016; Mazzucato and Semieniuk, 2018; Geddes et al., 2018). However, the potential deficiencies of state-owned banks, such as lower performance and politically distorted decision making, are well known (La Porta et al., 2002; Berger et al., 2005; Carvalho, 2014; Sapienza, 2004). As a result, the *actual* financing behavior of SIBs regarding the energy transition might deviate considerably from the

---

* Corresponding author.
E-mail addresses: paul.waidelich@gess.ethz.ch (P. Waidelich), bjarne.steffen@gess.ethz.ch (B. Steffen).

[1] While this paper uses the term state investment bank, other studies also refer to such institutions as national development banks (Zhang, 2020; Torres and Zeidan, 2016).

https://doi.org/10.1016/j.eneco.2024.107455
Received 6 November 2023; Received in revised form 21 February 2024; Accepted 1 March 2024

literature's recommendations, but whether this is the case remains understudied (Polzin et al., 2019). Existing studies either investigate how public financing in general affects RE investments (Polzin et al., 2015; Cárdenas Rodríguez et al., 2015; Deleidi et al., 2020) or assess how the involvement of public financial institutions affects bank syndicates, without considering energy technologies or SIBs in particular (Gurara et al., 2020; Broccolini et al., 2021; Degl'Innocenti et al., 2022).

Quantitative evidence on whether SIBs' financing activities align with theoretical rationales can guide policy makers who are considering designing a new, green SIB or adding RE financing to the mandates of existing institutions. Furthermore, such evidence can support future research on the causal impacts of public financial institutions for the clean energy transition and for technological change more generally. Therefore, this paper addresses the following research question:

RQ. *How does the financing behavior of SIBs with respect to RE technologies differ from that of private banks, and is SIBs' actual behavior consistent with their intended role?*

To answer this question, we derive hypotheses regarding the optimal behavior of SIBs from the literature and test them by assessing the predictors of SIB involvement in debt-financing new RE projects in OECD countries using a fixed-effects logit model. We focus on debt provision because it accounts for the majority of SIB financing (Mazzucato and Macfarlane, 2017; Geddes et al., 2018). Furthermore, we limit our sample to OECD countries because, in developing countries, the primary role of public financial institutions like SIBs is to compensate for the absence of deep and well-developed credit markets, which is very different from their narrower role in countries with developed financial sectors (Torres and Zeidan, 2016).

Our paper bridges previous empirical studies on public financing for RE technologies and sector-agnostic econometric assessments of public financial institutions in general. As part of the first strand, Polzin et al. (2015) regress the newly installed RE capacity in OECD countries on RE support policies in a fixed-effects model, reporting positive impacts for FiTs, emission trading systems, and other policies but inconclusive findings for public direct investment. Studying over 5000 deals in 87 countries, Cárdenas Rodríguez et al. (2015) regress private RE investment on deal-, project-, and organization-level characteristics and public policies in a simultaneous equation Tobit model and find mixed effects of public on private investment. By contrast, Deleidi et al. (2020) report a positive impact of public direct investment on country-level private RE investment that exceeds the effect of other support policies, including FiTs. However, none of these papers analyze the role of public financial institutions or SIBs in particular.

Regarding the second strand of literature, Broccolini et al. (2021) investigate the mobilization effects of multilateral development banks on syndicated loans in developing countries using fixed-effects regressions, reporting increases in private financing inflows, syndicate sizes, and loan maturity. Similarly, Gurara et al. (2020) regress syndicated loan characteristics in developing countries on the presence of multilateral development banks in a fixed-effects model and report a positive association with loan pricing, maturity, and the propensity to service borrowers in high-risk countries. Degl'Innocenti et al. (2022) regress loan syndicate structure on the presence of development banks and report a lower syndicate concentration, particularly in times of financial turmoil, for financially constrained borrowers, and for green industries. These papers make important contributions regarding the role of public financial institutions but do not consider the energy sector or the technology risks involved. In addition, they either focus on developing countries or group SIBs together with distinctive public financial institutions such as public export credit agencies.

By combining these two strands, we make a twofold contribution to the literature. First, we provide what is – to the best of our knowledge – the first econometric assessment of SIBs' role in RE financing and the underlying drivers, thus advancing the understanding of SIBs as RE support policies. Second, we introduce the consideration of technology-specific risks and non-syndicated loans, which account for an important share of SIB lending (see Section 5), into empirical assessments of public financial institutions.

The remainder of the paper is structured as follows. Section 2 derives our research hypotheses, while Sections 3–4 summarize the data and methodology, respectively. In Section 5, we present and discuss our findings and conclude with the overall implications for policy making and research in Section 6.

2. Hypothesis development

We develop hypotheses on how SIBs *should* behave by taking into account that SIBs are actors in the banking market and, when used to induce RE investments, energy policy instruments at the same time. Therefore, we build on theoretical insights and suggestions from financial and environmental economics and, more specifically, the literature on clean energy policies to derive four hypotheses on desirable financing behavior of SIBs.

2.1. Risk-bearing ability of SIBs

Compared to private-sector actors, governments can distribute risks among large pools of taxpayers and hence incur lower costs of risk bearing (Arrow and Lind, 1970). SIBs are state-backed enterprises operating on a soft budget without hard constraints in case of financial distress (Kornai et al., 2003). Therefore, they inherit the government's risk-bearing abilities and access to capital, whether they are directly capitalized by the state or raise funds on the capital markets at government-like credit ratings (Cochran et al., 2014). In high-income countries, SIBs' investments overwhelmingly take the form of loans, whereas bonds, guarantees and equity investments account for minor portfolio shares (Macfarlane and Mazzucato, 2018). Unlike commercial banks, however, SIBs do not face the risk of deposit withdrawals (Diamond and Dybvig, 1983) and face lower return expectations than privately owned investment banks. This allows them to provide financing to high-risk undertakings that provide societal benefits but may not be financially viable at the market rate, such as small and medium-sized enterprises (SMEs) or infrastructure projects (Stiglitz, 1993; Eslava and Freixas, 2021; Hainz and Kleimeier, 2012).

In RE financing, a key determinant of risk is technology, which is mirrored by substantial cost-of-capital differences between RE technologies (Steffen, 2020). These differences are partially driven by technology-inherent characteristics. For instance, offshore wind requires large upfront investments with high risks around construction and grid access (Dukan et al., 2023), whereas biomass projects involve high feedstock risks since supply contract lengths are typically limited (Geddes et al., 2018). However, a key determinant of a power generation technology's risk–return profile is its position in the technology life cycle ranging from pilot and demonstration projects to large-scale diffusion (Wüstenhagen and Menichetti, 2012). In this life cycle, debt financing typically occurs at the deployment stage and facilitates a wide ramp-up by reducing financing costs (Grubb et al., 2021). This is because relatively immature technologies with a limited track record are less attractive for loan providers for various reasons.

First, technological developments, as well as the evolution of contract and regulatory structures, can significantly improve the risk–return structure as market shares increase (Grubb et al., 2021; Egli, 2020). Second, financiers need to build up competencies to carry out credit screening and due diligence at low transaction costs for novel technologies with low deployment (Polzin, 2017; Waidelich et al., 2023) and beliefs about risk–return profiles can be sticky (Masini and Menichetti, 2012). As a result, increases in deployment typically reduce risk premiums and raise loan tenors through financial learning (Egli et al., 2018; Egli, 2020).

Against this background, there is a case for tailoring RE support policies to technology maturity. Several studies suggest that SIBs can leverage their risk-bearing ability to be *first movers* that build a track record for novel technologies and signal commercial viability to other lenders (OECD, 2016, 2017; Geddes et al., 2018; Geddes and Schmidt, 2020; Zhang, 2020). By absorbing high initial risks, SIBs have been described as "creating markets" and fostering financial and technological innovation (Mazzucato and Penna, 2016; Mazzucato and Semieniuk, 2017). From an economic perspective, a publicly capitalized first mover can resolve the coordination failure between financiers to create a track record that spills over across the financial sector (Waidelich et al., 2023). Indeed, there is anecdotal evidence of SIBs financing lighthouse projects,[2] and the extant literature suggests that state-owned banks in general have been key for financing growth in high-risk technologies (Mazzucato and Semieniuk, 2017, 2018). Therefore, we propose the following hypothesis:

Hypothesis 1. *SIBs are more likely to provide debt financing for projects that use a higher-risk technology than for those that use a lower-risk technology.*

However, that SIBs have a greater risk-bearing ability does not imply that they leverage this ability efficiently. Undue political influence and rent-seeking behavior can distort the decision-making of all state-owned banks (Carvalho, 2014; Sapienza, 2004), which have been found to slow down financial development (La Porta et al., 2002) and be less profitable than their private-sector counterparts (Berger et al., 2005). Although these findings are often less pronounced in high-income countries (Micco et al., 2007), they suggest that state-owned banks' taking on of higher credit risks could also be explained by mere inefficiencies rather than by welfare-enhancing behavior. Moreover, as state-owned enterprises, SIBs are subject to principal–agent problems that might lead to deviations from societal objectives (Shleifer and Vishny, 1994). Through their mandates, SIBs typically have multiple objectives that are difficult to measure and weigh against each other, diffusing incentives for officials (Tirole, 1994). In particular, public employees can have weaker incentives to invest in innovative but unproven solutions because their personal upside in the case of success is lower than that of private sector employees (Hart et al., 1997; Steffen et al., 2022), leading to more risk-averse decisions. Therefore, the state ownership literature paints a more pessimistic picture regarding Hypothesis 1 and highlights the importance of assessing this question empirically.

Importantly, whether a technology is high or low risk is not static over time. Since deployment increases the financial sector's experience with a technology, risk profiles can evolve significantly over time (Egli et al., 2018), particularly given the dynamic capacity growth for wind and solar PV in many jurisdictions (IRENA, 2022). Indeed, the private sector's willingness to finance these technologies has increased, albeit not homogeneously across countries. In the case of offshore wind, markets like the UK or Germany have matured to the extent that the necessity for SIB support has been questioned (Geddes et al., 2018)—whereas, in other countries, the technology's bankability remains limited without concessional finance. Therefore, unlike technological maturity, financial maturity is driven by *time-variant, country-specific factors*, such as the existence of credible support policies and experienced financiers (Polzin, 2017; Polzin et al., 2019). However, SIBs are typically required to provide only additional financing that cannot be sourced from the private sector (or only at prohibitive costs). If access to sufficiently cheap financing is provided for mature markets, then SIBs should move on to novel, less mature technologies (OECD, 2016; Geddes et al., 2018). More generally, Torres and Zeidan (2016) argue that once domestic credit markets mature, SIBs either should turn toward indirect instruments, such as credit guarantees, and newly targeted borrowers or should be privatized.[3] Therefore, the literature suggests that it is socially beneficial for SIBs to move counter to a technology's maturity cycle, leading to the following hypothesis:

Hypothesis 2. *For the same RE technology, SIBs are more likely to provide debt financing at an early stage of low deployment levels and are less likely to provide financing at higher levels of deployment.*

Of course, technology risk and maturity are only one determinant of renewable energy finance. Project- or deal-specific characteristics can have an equal impact on financing conditions, with the size of companies and projects being an important factor (Steffen and Waidelich, 2022). Hence, SIBs and other public finance institutions are usually mandated to provide SME financing (Eslava and Freixas, 2021; Hainz and Kleimeier, 2012). This is justified by the fact that such enterprises face constrained access to finance (Beck and Demirguc-Kunt, 2006; Beck et al., 2005) and are more vulnerable to credit crunches (Iyer et al., 2014). In general, smaller entities typically face higher financing costs (Fama and French, 1992), potentially due to less favorable risk profiles and higher transaction costs (van Dijk, 2011). Indeed, SIBs themselves report that their higher-risk loans, on average, feature smaller ticket sizes, which come with lower profitability (EIB, 2022a). Such a transaction cost argument applies particularly to RE financing, where projects are often realized as special purpose vehicles with smaller ticket sizes (Steffen, 2018). Therefore, studies suggests that SIBs should pool transactions deemed too small by commercial banks (Geddes and Schmidt, 2020) or finance them via on-lending through local financial institutions (Hall et al., 2016), leading us to the following hypothesis:

Hypothesis 3. *SIBs are more likely to be involved in deals with smaller than in deals with larger ticket sizes.*

2.2. Mobilization and crowding-out of private banks

Most SIBs have a mandate to induce private capital, and many institutions report how much external funding they mobilize (Macfarlane and Mazzucato, 2018; OECD, 2016, 2017). Aside from creating a track record as first movers, SIBs can vet projects and attract other financiers by signaling the project's commercial viability (Geddes et al., 2018). This enables the private sector to learn by co-investing through syndication (Degl'Innocenti et al., 2022; Geddes and Schmidt, 2020). As borrower and technology monitoring has public-good properties (Stiglitz, 1993), SIBs can deliberately maximize opportunities for financial learning by attracting more lenders and increasing knowledge spillovers (Waidelich et al., 2023). Indeed, previous empirical studies on multilateral development banks and public financial institutions have found that their involvement correlates with larger and less concentrated syndicates (Broccolini et al., 2021; Degl'Innocenti et al., 2022). To determine whether these findings hold for SIB financing of RE projects, we propose the following hypothesis:

Hypothesis 4. *SIBs are more likely to engage in RE transactions with a higher than in those with a lower number of private-sector lenders.*

However, the extant literature also discusses the possibility that public financial institutions could have a "crowding-out" effect on private-sector finance, whereby "*public intervention directly displaces private investment by undertaking projects the private sector would have*

---

[2] For instance, the Australian Clean Energy Finance Corporation set up the Clean Energy Innovation Fund (OECD, 2017), and the German Kreditanstalt fuer Wiederaufbau (KfW) financed the country's first offshore wind park (Geddes et al., 2018).

[3] An empirical example of such a step is the UK Green Investment Bank, which started operation as a state investment bank in 2012 and was privatized in 2017.

otherwise financed” (OECD, 2016). As SIB financing is provided below the market rate, commercial banks cannot compete with SIBs’ loan terms and therefore run the risk of their lending being replaced by that of SIBs, which can ultimately hamper the long-term development of domestic credit markets (Torres and Zeidan, 2016). *Ceteris paribus*, such a replacement of lenders would imply the same number of overall lenders and a *lower* number of non-SIB lenders on a transaction. Notably, many SIBs address these risks through on-lending via private-sector financial institutions, through so-called additionality checks (Mazzucato and Macfarlane, 2017), or by limiting their financing provisions—for example, to 50% of overall project costs in the case of the European Investment Bank (EIB, 2022b). However, how effective these countermeasures are remains an open question (OECD, 2016), with some studies suggesting a substitution relationship between private and public financing provision (Cárdenas Rodríguez et al., 2015).

3. Data

To assess our hypotheses, we combine project-, transaction- and organization-level data from Bloomberg New Energy Finance (BNEF), the most comprehensive database for transaction-level information on RE asset finance (BNEF, 2022a,b,c). It features information on a wide range of variables such as project technology and capacity and the different organizations involved as sponsors, debt providers, or developers. Notably, the BNEF database only captures *utility-scale* projects (Mazzucato and Semieniuk, 2018), such that household-scale RE power generation (i.e., small rooftop solar PV) is not included in our sample. We consider all transactions that finance new-build power generation projects in OECD countries and that reached financial closing from 2004–2021.[4] As we aim to investigate the role of SIB *lending*, we exclude transactions financed purely through equity or for which the lender column in BNEF is empty.[5]

For all transactions, we merge the respective project information from BNEF using matching files provided by Bloomberg and match organization information on the basis of company names. For the 9% of transactions financing multiple RE projects, we merge the transaction with the project of the highest value or, if project values are missing, with the project with the highest power generation capacity.[6] Following these steps, we arrive at an overall sample size of $N = 4,999$ transactions for onshore and offshore wind, solar PV, concentrated solar power (CSP), geothermal, biomass and waste, and small hydro over the period 2004–2021 in OECD countries. As our interest is in studying the financing decisions of SIBs, we do not exclude deals for projects that were canceled after a financial close (0.6% of our sample). We combine these data with country-level information, such as GDP, technology shares in the national installed capacity, and technology-specific FiTs.

To identify SIBs in our sample, we start with the Global Database on Public Development Banks and Development Financing Institutions (Xu and Marodon, 2021).[7] Specifically, we include all institutions (i) based in an OECD country, (ii) with a subnational or national scope of operation, and (iii) with a mandate that either is flexible or focuses on infrastructure, local government, or microenterprises/SMEs.[8] Furthermore, we add the OECD-based state investment banks discussed in Macfarlane and Mazzucato (2018) and Geddes et al. (2018) including the European Investment Bank (EIB) because, while it is not a *national* investment bank, the EIB’s loans are made predominantly within the EU—that is, domestically (EIB, 2022c). For the same reasons, we also include the North American Development Bank, capitalized by the US and Mexico (NADB, 2022), and the Nordic Investment Bank, capitalized by the Nordic and Baltic countries—in line with research treating these multilateral institutions as SIBs rather than development finance institutions (Humphrey, 2023). Furthermore, we include other OECD-based state investment banks that meet the criteria specified above from Degl’Innocenti et al. (2022) and OECD (2017) if they are not covered by the previous sources.[9] Last, we add all subsidiaries of the identified SIBs in the BNEF Organizations database that (i) show up on any RE transactions within our sample and (ii) can be clearly identified as a financial-sector company on the basis of company classification and abstracts in BNEF.

By collapsing the subsidiary activity to the SIB parent, we arrive at a list of 32 SIBs that provide debt financing for 572 RE transactions in our sample (11.4% of all transactions). A list of the individual institutions is displayed in Table 1.[10] In addition, Table 2 provides summary statistics on the key variables in our data set, which are explained in more detail in Appendix A.

4. Methodology

To assess different predictors of SIB financing for RE projects, we estimate the following fixed-effects (FE) logit model at the transaction level:

$$
\begin{aligned}
ln\left(\frac{Pr(Y_{icta}=1|X)}{1-Pr(Y_{icta}=1|X)}\right) = {} & \beta_0\text{Tech}_a + \beta_1\text{I(Tech matured)}_{cta} + \\
& \beta_2\text{I(First-3 deal)}_{ica} + \beta_3\text{ln(Capacity}_i) + \\
& \beta_4\text{I(Cap. in 1st decile)}_{ita} + \\
& \beta_5\text{NonSIBLenders}_i + X'_{icta}\gamma + \\
& \alpha_c + \delta_t + \epsilon_{icta}
\end{aligned}
\tag{1}
$$

where Y_{icta} is a dummy variable indicating whether a transaction i in country c that closed in year t involved SIB lending. a denotes the RE technology financed by transaction i, with $Tech_a$ being the respective technology dummy. $I(Tech\ matured)_{cta}$ is a dummy indicating whether the technology had reached financial maturity in country c and year t, while $I(First\text{-}3\ deal)_{ica}$ indicates whether deal i featured among the first three transactions in country c to provide debt for projects featuring technology a (for more detailed definitions, see below). $Capacity_i$ and $NonSIBLenders_i$ account for the total generation capacity financed by transaction i and the number of non-SIB lenders involved, respectively, while $I(Cap.\ in\ 1st\ decile)_{ita}$ is a dummy indicating whether $Capacity_i$ falls within the first decile of all deals for

---

[4] For years prior to 2004, BNEF does not offer information with the same level of detail, particularly on loan syndicate members.

[5] There are an additional 138 transactions (2.8% of the sample) for which the lender is simply stated as “Not Reported”. In our main results, we code these transactions as not involving SIB lending since BNEF analysts should be able to identify lender information if SIBs feature in the syndicate, as the institutions report on their activities. However, we display the results obtained when these transactions are instead excluded in Table B4 in Appendix B.

[6] Only 10 transactions in the sample finance projects that either are based in multiple countries or cover multiple RE technologies, which mitigates potential concerns about our matching strategy.

[7] To be included in the database, an institution must (i) be a stand-alone entity without a short-term specific goal, (ii) use financial instruments as its primary product/service, (iii) finance itself through means beyond regular budget transfers, (iv) have a public policy-oriented mandate, and (v) have corporate strategies steered by the government (Xu and Marodon, 2021).

[8] These criteria lead to the exclusion of institutions with mandates in database categories not relevant to our research question (social housing, rural and agricultural development) and of export credit agencies and development finance institutions whose financing activities occur primarily abroad (exports and foreign trade promotion, international financing of private-sector development).

[9] This step effectively adds the Japanese Green Finance Organisation and the Italian Mediocredito Centrale, which account for four RE transactions in our sample.

[10] Since the UK Green Investment Bank was privatized in August 2017, we consider only its activities up to July 2017 to be SIB lending. For our reasons to not include other German Landesbanken not featured in the Xu and Marodon (2021) database, we refer the reader to Appendix B.2.

Table 1
List of SIBs including in-sample lending activity.

	Organization	Country	BNEF IDs	No. of transactions
1	Kreditanstalt fuer Wiederaufbau	Germany	3352, 31950, 503082, 53425	135
2	European Investment Bank	Luxembourg	538	133
3	BPIFrance SA	France	147133, 41599, 146361, 6700	47
4	Instituto de Credito Oficial	Spain	4259, 147751	39
5	Clean Energy Finance Corp	Australia	70222	37
6	Korea Development Bank/The	Korea (Republic)	38923, 539175, 593715, 601477	32
7	North American Development Bank	United States	1451	28
8	Nordic Investment Bank	Finland	20802	24
9	Development Bank of Japan Inc	Japan	724	21
10	UK Green Investment Bank Ltd	United Kingdom	569520, 36386	18
11	Nacional Financiera SNC	Mexico	16251	16
12	Turkiye Sinai Kalkinma Bankasi AS	Turkey	22365, 40512	15
13	Banobras	Mexico	11408	14
14	BNG Bank NV	Netherlands	151067	14
15	Japan Finance Corp	Japan	41811	10
16	NY Green Bank	United States	147083	9
17	Corp de Fomento de la Produccion	Chile	8474	8
18	Caisse des Depots et Consignations	France	3071, 45754, 795283	6
19	Banca del Mezzogiorno	Italy	11149, 628739	6
20	Nederlandse Waterschapsbank NV	Netherlands	81042	5
21	Cassa Depositi e Prestiti SpA	Italy	10748, 91142	4
22	Bank Gospodarstwa Krajowego	Poland	47021	2
23	Financiera de Desarrollo Nacional SA	Colombia	778777	2
24	Green Finance Organization	Japan	85954	2
25	MFB Magyar Fejlesztesi Bank Zrt	Hungary	147803	2
26	Scottish Investment Bank/The	United Kingdom	71610	2
27	Connecticut Green Bank	United States	16013	1
28	Development Bank of Wales Plc	United Kingdom	4310	1
29	Finnvera Oyj	Finland	569251	1
30	Korea Finance Corp	Korea (Republic)	41562	1
31	Landesbank Saar	Germany	365495	1
32	NO Burgschaften und Beteiligungen GmbH	Austria	802619	1

Table 2
Summary statistics.

Statistic	N	Mean	St. Dev.	Min	Median	Max
I(SIB lending)	4999	0.114	0.318	0	0	1
Closing year	4999	2014.803	4.430	2004	2015	2021
Capacity (MW)	4987	51.275	102.341	0.2	14.0	1467.0
I(Cap. in 1st decile — onshore & PV only)	4999	0.094	0.292	0	0	1
# of non-SIB lenders	4999	1.746	1.937	0	1	29
# of sponsors	4999	1.217	0.598	1	1	8
I(First-3 deal)	4999	0.052	0.223	0	0	1
I(Term loan)	4999	0.906	0.292	0	1	1
I(Any public sponsor)	4874	0.056	0.230	0	0	1
I(Tech matured — onshore & PV only)	4999	0.316	0.465	0	0	1
Feed-in tariff (2010 USD/kWh)	4977	0.109	0.164	0.000	0.011	0.812
Real GDP PPP growth (%)	4999	1.524	3.127	−14.839	2.005	25.176
CCPI Overall Score (0–100)	4873	47.540	13.068	18.596	49.470	76.620
Long-term interest rate (%)	4873	2.169	1.904	−0.511	2.064	22.497
Country Bank Z-score	4999	18.694	8.728	0.017	16.603	43.060
Gov. expenditures (% of GDP)	4999	18.774	3.445	10.336	19.412	26.732
Primary balance (% of GDP)	4999	−2.481	3.499	−29.896	−2.242	15.461
Environmental Policy Stringency Index (0–6)	4956	3.080	0.702	0.000	3.028	4.889
Climate policy density (cumulative #)	4999	143.317	103.451	0	108	411

Categorical variables denoted by I(...).

the same technology a that closed in the same year t. X is a matrix of explanatory variables at the transaction or country level, while ϵ_{icta} denotes the error term. To control for additional confounders, Equation (1) also includes FEs at the country (α_c) and year (δ_t) levels, following Cárdenas Rodríguez et al. (2015).[11]

We rely on a categorical dependent variable because, for more than half of transactions with a SIB lender, the financing volume provided by the SIB is not available (see Appendix D). As our sample involves only closed debt-financed deals, the logit model identifies predictors that distinguish deals involving SIBs from those financed by the other lenders in our sample, which are predominantly commercial banks and other private-sector financial companies (accounting for 78% and 12% of non-SIB lending activity, respectively; see Figure C1 in Appendix C).

To test whether SIBs are more or less likely to be involved in deals featuring high-risk technologies (Hypothesis 1), we use onshore wind as the baseline for our $Tech$ dummy because it has historically been viewed as relatively low risk and mature (Polzin et al., 2015, 2019; Cárdenas Rodríguez et al., 2015; Lehmann and Söderholm, 2018). On the basis of a literature review of technology risks and costs, Mazzucato and Semieniuk (2018) classify onshore wind and small hydro as low risk, biomass and waste as low-to-medium risk, geothermal as medium risk, and CSP and offshore wind as high risk. Regarding

---

[11] For the Czech Republic, Latvia, New Zealand, Slovakia, Slovenia, and Switzerland, we do not observe any RE transactions involving SIB lending; hence, we omit 53 transactions from these countries that are perfectly separated by the respective country FEs.

solar PV, the authors suggest that the technology's risk has transitioned from high to low, in line with strong capacity growth over the last two decades (IRENA, 2022). These risk differences directly affect the expected return required to attract funds to RE projects, which has been found to increase from solar PV and onshore wind to offshore wind (Steffen, 2020; IRENA, 2023). Therefore, Hypothesis 1 implies higher involvement of SIBs in offshore wind, CSP, geothermal and biomass than in onshore wind and solar PV.

To test whether greater market maturity predicts lower SIB involvement (Hypothesis 2), we set $I(Tech\ matured)_{cta}$ to take a value of 1 if the respective technology a accounts for at least 10% of the national installed capacity following the International Renewable Energy Agency IRENA (2023). The dummy is restricted to onshore wind and solar PV, which account for 91% of our sample, because the IRENA interviews informing the threshold were carried out only for solar PV and wind and because the sample size for the remaining technologies is too small to differentiate the technologies by their country-specific market maturity. To assess whether SIBs enter the market particularly early, we define $I(First\text{-}3\ deal)_{ica}$ on the basis of a country's first three deals corresponding to a specific technology, following the definition of very early market-opening projects in Steffen et al. (2018). Regarding the hypothesized link between SIB lending and smaller ticket sizes (Hypothesis 3), we use the log-transformed deal capacity (net of technology FEs) as a proxy for transaction volumes since the monetary transaction volume is missing for 62% of our sample. Moreover, we include the first-decile dummy $I(Cap.\ in\ 1st\ decile)_{ita}$ to allow for a specific effect of small deal size relative to other transactions for the same technology and closing year. The time-dependent threshold accounts for the fact that typical project sizes have evolved substantially for some technologies. Again, we define this more granular dummy variable only for onshore wind and solar PV due to sample size constraints for the remaining technologies.

Throughout our analyses, X features several control variables. The first is the annual growth in real GDP in country c and year t because SIBs often engage in countercyclical credit provision and therefore should be more likely to feature in deals during economic crises (Levy Yeyati et al., 2004; Mazzucato and Penna, 2016; D'Orazio and Popoyan, 2019; Eslava and Freixas, 2021).[12] The second, following Gurara et al. (2020), is a dummy indicating whether the sponsor of transaction i is a public-sector entity or is publicly owned since SIBs are often mandated to finance public-sector activities (Mazzucato and Macfarlane, 2017). The third, following Gurara et al. (2020) and Degl'Innocenti et al. (2022), is a dummy indicating whether transaction i involved a term loan, which is the main financing instrument of many SIBs (Mazzucato and Semieniuk, 2017). The fourth is the inflation-adjusted FiT for technology a in country c and year t, which is a key RE support policy that has been shown to correlate with public RE financing provisions (Cárdenas Rodríguez et al., 2015). Due to the potential link between SIB activity and GDP growth, which correlates strongly across OECD countries, we cluster standard errors at the year level and report results for clustering at the country level in Appendix B.

Despite our inclusion of a variety of controls and FEs, some issues of potential endogeneity remain, because of which our findings might not imply that specific deal characteristics and outcomes *cause* SIBs to engage. First, we observe lenders only for transactions that reached a financial close. If SIB involvement prevents a project from being canceled, as their de-risking role suggests, then variables that correlate positively (negatively) with cancellation risk, such as technology risk (number of non-SIB lenders), will correlate positively (negatively) with SIB involvement even if SIBs do not target these characteristics. Second, SIBs might target high-risk projects that struggle to attract commercial lenders, but once an SIB is involved, this could mobilize other debt providers.[13] Therefore, the estimated coefficient for the number of non-SIB lenders can be seen as the net effect of these aspects. While we provide a more detailed discussion of potential sources of endogeneity in Appendix E, we note, however, that the hypotheses in Section 2 are not of a causal nature. Although for some variables our findings do not necessarily speak to what *caused* SIBs to engage, they control for most potential distortions in correlational patterns and thus are informative of SIBs' financing behavior with respect to RE.

5. Results and discussion

5.1. Descriptive statistics

Fig. 1 displays how the transactions in our sample are distributed across different countries, years, and RE technologies, with the blue bars and value labels indicating the share of transactions that involved lending by at least one SIB. The annual number of debt-financed RE deals in OECD countries increased from less than 100 in 2004 to 300–500 over the last few years. The share of transactions with SIB lending started relatively low at 5%–8% from 2004–2008, then ramped up following the global financial crisis (14%–17% from 2009–2013) and remained at 9%–13% thereafter. Approximately 80% of transactions are located in the G7, Spain, South Korea, and the Netherlands, with SIB involvement varying significantly across countries. With respect to technology, solar PV and onshore wind dominate the sample with 60% and 31% of transactions, respectively, followed by biomass and waste (5%), whereas the remaining technologies account for no more than 1% of transactions each. Solar PV and onshore wind also feature the lowest share of SIB involvement with 6% and 14%, respectively. By contrast, SIBs lent money to 73% of all offshore wind transactions, while their involvement in other RE technologies with small project numbers – such as small hydro, geothermal, biomass and waste, or CSP – ranges from 23%–44%.

When we compare transactions with and without SIB lending through naive t-tests, the former are larger in terms of capacity (+58 MW), involve more lenders and sponsors, and are more likely to feature a term loan and a public sponsor (see Table 3). More interestingly, SIB-financed deals are less likely to fall into the first decile of deal size in a given year, feature more often among the first three debt-financed transactions in a country for the technology in question and feature less often in a mature market. In addition, the FiT for the technologies that SIBs finance is, on average, approximately 1 USD ct/kWh lower. Furthermore, countries and years in which an SIB-financed transaction takes place exhibit lower GDP growth (−0.2 pp), higher long-term interest rates (+0.6 pp), and lower banking sector stability, as evidenced by a lower banking system z-score.

5.2. Regression results

Importantly, many of the correlations discussed above are driven by the heterogeneity in SIB activity across countries and RE technologies. For example, due to the large size of offshore wind deals, which finance a mean capacity of 362 MW per deal, they feature 7.7 non-SIB lenders on average compared to only 1.7 non-SIB lenders for the remaining technologies. To control for such confounders, Table 4 displays our main specification featuring the predictors discussed in Section 4 with and without country and year FEs (columns 1 and 2, respectively), with additional technology FEs (column 3) and differentiating the IRENA-based market maturity dummy by individual technology (column 4). As discussed in Section 4, Hypothesis 1 on technology risks implies that

---

[12] In contrast to authors of previous studies (Polzin et al., 2015; Deleidi et al., 2020), we use GDP growth instead of absolute GDP to avoid spurious results resulting from the typical unit root in GDP time series (Greene, 2003).

[13] In addition, co-lending requirements in SIBs' mandates might also cause SIBs to prefer projects that already have a certain number of non-SIB lenders in place.

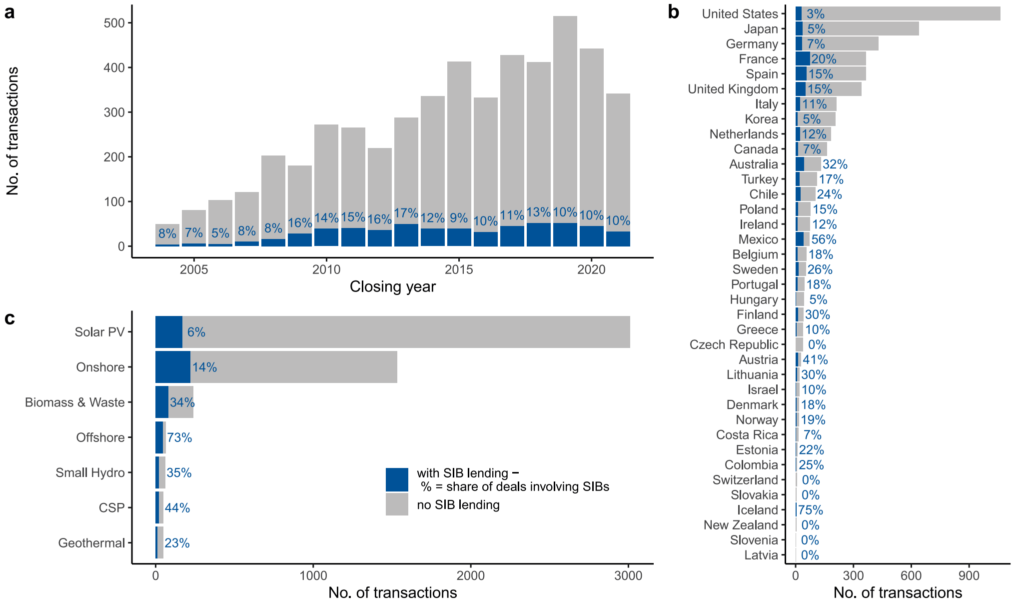

Fig. 1. Sample composition by country, technology, and year. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 3
Mean values by I(SIB lending) & t-tests.

Variables	w/ SIB lending mean (s.e.)	w/o SIB lending mean (s.e.)	Diff.	t-stat
Closing year	2014.6 (4.2)	2014.8 (4.5)	−0.184	−0.99
Capacity (MW)	102.9 (152.9)	44.6 (91.8)	58.3	8.89
I(Cap. in 1st decile — onshore & PV only)	0.033 (0.18)	0.1 (0.3)	−0.0691	−7.88
# of non-SIB lenders	2.2 (3.5)	1.7 (1.6)	0.558	3.71
# of sponsors	1.5 (0.89)	1.2 (0.54)	0.272	7.15
I(First-3 deal)	0.13 (0.33)	0.043 (0.2)	0.0849	5.94
I(Term loan)	0.96 (0.2)	0.9 (0.3)	0.0612	6.52
I(Any public sponsor)	0.13 (0.34)	0.046 (0.21)	0.0834	5.7
I(Tech matured — onshore & PV only)	0.21 (0.41)	0.33 (0.47)	−0.122	−6.64
Feed-in tariff (2010 USD/kWh)	0.1 (0.15)	0.11 (0.17)	−0.0103	−1.5
Real GDP PPP growth (%)	1.3 (3.2)	1.5 (3.1)	−0.202	−1.41
CCPI Overall Score (0–100)	52.1 (11.1)	47 (13.2)	5.15	9.95
Long-term interest rate (%)	2.7 (2.3)	2.1 (1.8)	0.571	5.52
Country Bank Z-score	16.4 (7)	19 (8.9)	−2.6	−8.1
Gov. expenditures (% of GDP)	19.4 (3.8)	18.7 (3.4)	0.745	4.43
Primary balance (% of GDP)	−2.2 (3.4)	−2.5 (3.5)	0.356	2.37
Environmental policy stringency index (0–6)	3 (0.89)	3.1 (0.67)	−0.0767	−1.98
Climate policy density (cumulative #)	111.5 (72.8)	147.4 (106.1)	−35.9	−10.4
Observations	572	4427		

SIB involvement is more likely for offshore wind, biomass and waste, CSP, and geothermal than for onshore wind and solar PV. Indeed, relative to the baseline technology (onshore wind), biomass and waste, CSP, and offshore deals are significantly more likely to involve SIB lending, whereas our coefficient with respect to geothermal is not significant at the 5% level. The effect is strongest for offshore wind, with the odds of SIB lending increasing by a factor of $e^{2.6} \approx 13.5$ for offshore relative to onshore wind, which corresponds to an average partial effect of +40 pp on the probability of SIB lending (see Figures B1–B2 in Appendix B). Although small hydro is considered a low-risk technology, the respective coefficient indicates a significantly higher likelihood of SIB involvement in such deals, as well. By contrast, solar PV deals are significantly *less* likely to involve SIB lending than onshore wind transactions. As a result, the differences of the technology FEs vis-à-vis solar PV are also positive and significant at the 5% level for all technologies, including geothermal, in the respective F-tests.

With respect to the maturity cycle (Hypothesis 2), the coefficient of the IRENA-based market maturity dummy is negative but insignificant at the 5% level if we consider solar PV and wind together (column 3). However, the effect of market maturity is highly significant for solar PV if we differentiate by individual technology in column 4, translating into a -6 pp average partial effect on the probability of SIB lending (see Figure B2 in Appendix B). By contrast, the coefficient for onshore wind is insignificant, with a t-statistic well below 1. Interestingly, the *p*-value of the solar PV FE increases considerably to almost 10% in column 4, suggesting that the significantly lower likelihood of SIB lending for PV in column 3 is driven primarily by mature markets. Indeed, if we differentiate the maturity dummy's effect by country (see Figure B5 in Appendix B), the coefficient is significantly negative at the 5% level only for Germany and Japan—which are markets where solar PV obtained capacity shares of 10% relatively early (see Figure C2 in Appendix C).

Since our dependent variable is a dummy indicating SIB involvement, this finding could stem either from SIBs reducing their activities as markets mature or from commercial banks ramping up their lending, which would also make it less likely that we observe SIB involvement for a given deal. Therefore, Fig. 2a displays the number of PV deals in the six largest markets that reached the maturity threshold in our

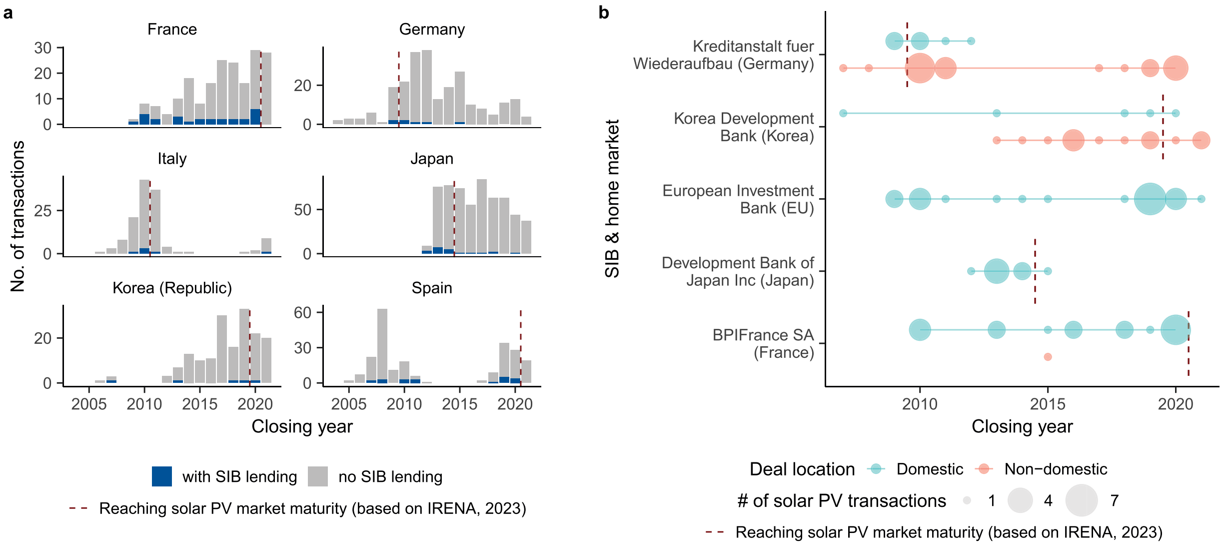

Fig. 2. Solar PV deals in main markets reaching maturity and solar PV financing of the corresponding main SIBs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

sample period, with transactions involving SIBs marked in blue. In most markets, the overall deal activity *declines* after market maturity is reached, meaning that the decrease in SIB involvement shares results from an even stronger decline in SIB activity. Italy and Spain show the strongest reductions in PV deals after 2010, when fiscal pressures caused these countries to reduce their PV support policies (Karneyeva and Wüstenhagen, 2017).

Whether this means that SIBs reduce their lending activity for the technology depends on their mandate and scope of activities. Fig. 2b displays the PV lending activities of the most active SIBs in the respective PV markets: for Germany, France, Japan, and Korea, their national SIBs, and for Spain and Italy, the supranational European Investment Bank. Dashed vertical lines denote when the respective home market for PV reaches maturity, while blue (red) points represent deals inside (outside) the SIB's home market.[14] As displayed, the German KfW, the most active national SIB in our sample, has expanded its geographic scope of activity abroad to less mature PV markets, such as Mexico, Chile, and Spain, while its domestic RE financing decreased (D'Orazio and Löwenstein, 2022). Similarly, the Korean Development Bank is increasingly financing PV deals abroad, while the in-sample lending of the European Investment Bank has shifted away from markets such as Germany and Italy, primarily toward Spain. All of these institutions have in common that their activities span a wide range of countries. Conversely, the Development Bank of Japan, which almost exclusively provides debt domestically, features in no further PV transactions after 2015.[15]

Regarding the alleged first-mover role of SIBs, Table 4 suggests that SIBs are not significantly more likely to engage in a country's first three market-opening deals providing debt to the respective technology once we control for technology differences. Our differentiating the market-opening dummy by technology does not affect this conclusion: the effect remains insignificant for all technologies except CSP (see Figure B7 in Appendix B), for which our sample includes only 13 market-opening deals. Therefore, SIBs' first-mover role does not go significantly beyond the general targeting of high-risk technologies and, in the case of solar PV, reacting to increasing market maturity. This poses the question of who else, if not SIBs, provides debt through market-opening deals in OECD countries. To answer this, we classify the lenders appearing on such deals based on their Bloomberg Industry Classification Standard (BICS) codes and calculate the shares of financial and nonfinancial private-sector lenders and of SIBs and other public-sector lenders.

Fig. 3b displays the results separately for solar PV, onshore wind, and the remaining technologies and reveals that most first-mover lenders remain commercial banks and other private-sector financial companies—although the prevalence of these lenders increases considerably in subsequent deals. In contrast, public-sector lenders account for 19%, 23%, and 33% of lender appearances in market-opening deals for solar PV, onshore wind, and other technologies, respectively—but for only approximately half of these shares in subsequent deals. Importantly, however, this difference is not primarily driven by SIBs but by other public-sector entities, such as export credit agencies and (subnational) governments. In addition, multilateral development banks are particularly important in the case of Latin American OECD new-joiners, whose financial markets are less developed. Notably, the activity of other public-sector entities drops considerably for subsequent deals, illustrating that these institutions, unlike SIBs, appear to deliberately target market-opening deals through their lending.

Regarding Hypothesis 3, the results in Table 4 show that SIBs are significantly more likely to be involved as lenders for *larger* transactions after we include technology FEs, with the odds of SIB lending increasing by 0.47% for every 1% increase in financed capacity (column 3). This finding is robust across all specifications in this paper and, for our main specification, corresponds to an average partial effect of +0.3 pp in the probability of SIB lending per 1 MW increase in capacity (see Figure B1 in Appendix B). In addition, we find no evidence that a deal capacity that falls within the 1st decile of all transactions financing the same technology and closing in the same year affects the likelihood of SIB lending significantly. To explore this relationship further, Table 5 displays additional regression results where we use a second-order polynomial of deal capacity instead of the log-transformed value (columns

---

[14] The European Investment Bank's PV lending in our sample occurs entirely within current or, in the case of the UK, former EU member countries. Therefore, all these deals are classified as domestic. Since the bank does not have a single home market, no dashed line denoting PV market maturity is displayed.

[15] The small, nonzero SIB involvement shares for Japan from 2016–2020 are due to activities by Japan Finance Corp and lending abroad by the Korea Development Bank.

Table 4
Regression results for the main specification.

	I(SIB lending)			
	(1)	(2)	(3)	(4)
(Intercept)	−5.09****			
	(0.472)			
I(First-3 deal)	1.17****	1.01****	0.128	0.111
	(0.144)	(0.171)	(0.225)	(0.223)
ln(Capacity in MW)	0.528****	0.568****	0.474****	0.481****
	(0.053)	(0.056)	(0.060)	(0.060)
I(Cap. in 1st decile — onshore & PV only)	0.084	0.216	0.221	0.220
	(0.306)	(0.337)	(0.308)	(0.306)
# of non-SIB lenders	−0.039**	−0.007	−0.104****	−0.104****
	(0.019)	(0.019)	(0.029)	(0.030)
Real GDP PPP growth (%)	−0.029	−0.040	−0.031	−0.029
	(0.021)	(0.030)	(0.035)	(0.036)
Feed-in tariff (2010 USD/kWh)	0.651**	0.036	1.43****	1.27***
	(0.302)	(0.449)	(0.435)	(0.481)
I(Any public sponsor)	0.831****	0.555**	0.427*	0.433*
	(0.200)	(0.222)	(0.258)	(0.262)
I(Term loan)	1.33****	0.693**	0.788***	0.729***
	(0.268)	(0.275)	(0.274)	(0.262)
Tech = Biomass&Waste			1.45****	1.57****
			(0.275)	(0.278)
Tech = PV			−0.686****	−0.395*
			(0.168)	(0.220)
Tech = SmallHydro			1.42**	1.49**
			(0.690)	(0.689)
Tech = CSP			1.15***	1.39***
			(0.411)	(0.443)
Tech = Offshore			2.60****	2.74****
			(0.685)	(0.692)
Tech = Geothermal			0.799	0.878*
			(0.524)	(0.530)
I(Tech matured — onshore & PV only)			−0.365*	
			(0.219)	
I(Tech matured) × Tech = Onshore				0.038
				(0.309)
I(Tech matured) × Tech = PV				−0.854****
				(0.247)
Country FEs		Yes	Yes	Yes
Closing year FEs		Yes	Yes	Yes
Observations	4841	4797	4797	4797
Pseudo R^2	0.111	0.208	0.261	0.264
BIC	3125.4	3166.1	3044.0	3043.7

Clustered (Closing year) standard-errors in parentheses
No. of observations decreases due to missing values in regressors (column 1) as well as perfect separation by country FEs (columns 2–4), see Section 4.
* Signif. Codes: 0.1.
** Signif. Codes: 0.05.
*** Signif. Codes: 0.01.
**** Signif. Codes: 0.001.

1–2) and bin dummies for all deciles relative to the 6th decile as a baseline (columns 3–4).[16]

Indeed, the coefficients for the linear and squared capacity terms suggest a positive, concave relationship between deal size and the likelihood of SIB involvement. In addition, when we use decile bins relative to the 6th decile, lower (higher) capacity deciles correlate with lower (higher) odds of SIB involvement, although the respective coefficients are statistically significant only for the 1st and the 9th–10th deciles. Therefore, we conclude that a lower transaction size is, in general, significantly and robustly associated with a *reduced* likelihood of SIB lending for the utility-scale projects in our sample. Importantly, the different specifications to capture size effects do not alter our previous conclusions regarding technology risk and maturity, as most of the technology FEs (except the FE for geothermal) and the maturity dummy for PV remain economically and statistically significant and SIB involvement shows no significant pattern for the first deals providing debt to a technology in a country.

Regarding the question of mobilizing private banks (Hypothesis 4), Table 4 seemingly suggests a significant negative correlation between the number of non-SIB lenders and SIB involvement (columns 3–4). However, this result is heavily driven by the fact that 188 deals have an SIB as the only lender. Since our sample includes only debt-financed transactions with at least one lender, having zero non-SIB lenders perfectly predicts our dependent variable, which can introduce a spurious negative correlation. To avoid this artifact, we restrict our sample to transactions with at least one non-SIB lender, such that our dependent variable indicates whether at least one SIB featured as a *co-lender*—which addresses the question of mobilization more appropriately.

The results are presented in Table 6 and show that, conditional on the presence of non-SIB lenders on a deal, a larger number of non-SIB lenders correlates positively with a higher likelihood of SIB lending, albeit not significantly at the 5% level for our main specification (columns 2–3). Our interacting the number of non-SIB lenders with the technology FEs reveals that the effect is driven primarily by solar PV

---

[16] To explore the robustness of the previous findings, Table 5 also displays the coefficients for all variables related to technology risk and maturity, but, for the sake of conciseness, omits the coefficients for all further controls.

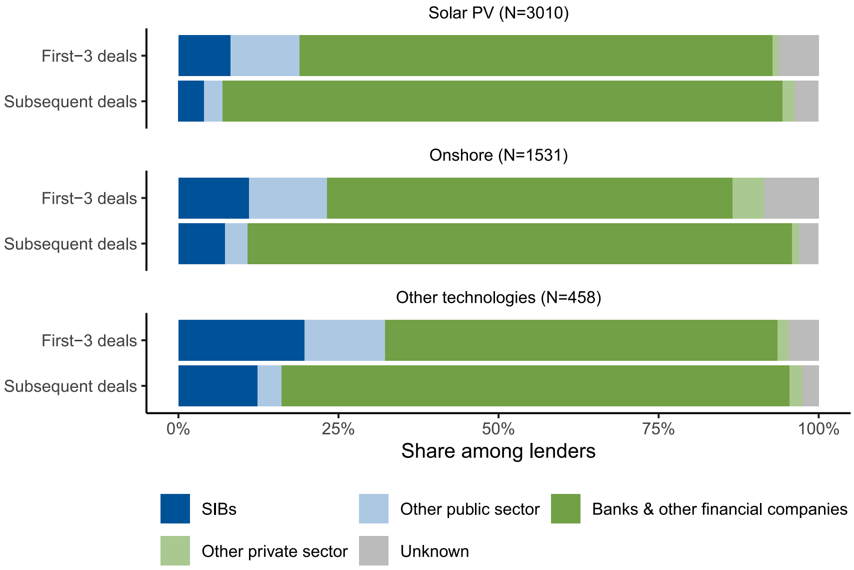

Fig. 3. Involvement of SIBs and other lenders in market-opening and subsequent deals. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and offshore wind transactions (see Figure B9 in Appendix B). Overall, these findings favor the lender mobilization hypothesis over potential crowding-out concerns. This is in line with the mobilization effect of public financial institutions and multilateral development banks reported by previous, sector-agnostic studies (Degl'Innocenti et al., 2022; Broccolini et al., 2021), which consider only syndicated loans, similar to the subsample used in Table 6. However, we note that the relationship is not statistically significant, and in addition, we cannot rule out that, for deals with SIBs as the only lender, some crowding-out has occurred.

Regarding our previous conclusions about technology risk, market maturity, and size, we note that excluding solo lending by SIBs reduces the statistical significance of several of the technology FEs with small sample sizes (offshore, CSP, small hydro). This is somewhat unsurprising since for these small-N technologies, our omitting deals with SIBs as the only lender(s) removes over a quarter of all deals involving SIBs from our sample and reduces the overall number of deals by more than 10%. However, the offshore wind FE remains significant at the 10% level, and by contrast, both the magnitude and the significance of the market maturity dummy (column 3) increase relative to the estimates from our main specification in Table 4 above. With respect to market-opening deals and size effects, our previous conclusions remain unaltered for this subsample.

Notably, the results for the control variables in our regressions are informative about other potential roles of SIBs suggested in the literature. First, our results provide no evidence that SIB lending is significantly more likely in years with lower GDP growth or higher banking sector instability (see Table B4 in Appendix B). Since business cycles correlate strongly across OECD countries (see Table C1 in Appendix C), this outcome could be driven by the country and year FEs absorbing the identifying variation. However, the year FEs for the years of the global financial crisis and those directly thereafter are not significantly larger than those for subsequent years if we estimate them explicitly (see Fig. 4). This suggests that countercyclical financing provision plays a less significant role in RE lending by SIBs, potentially because the number of RE transactions shows little reaction to the global financial crisis (see Fig. 1).

Furthermore, we find that the FiT level for a transaction's technology shows a significant positive correlation with the likelihood of SIB lending, which is particularly driven by onshore wind and solar PV transactions (see Figure B6 in Appendix B). This finding can be interpreted in multiple ways. First, it could indicate that the use of SIBs for RE financing correlates with more stringent levels of RE support policy in general. However, the significantly positive association remains unaltered if we include measures of overall climate policy stringency such as the CCPI, the OECD's Environmental Policy Stringency Index, or the density of energy- and climate-related policies following Steffen (2021), which themselves are not significantly related to SIB lending (see Tables B4 and B8 in Appendix B). Second, the FiT variable could capture some variation related to market maturity since most OECD countries have reduced their FiT levels as RE technologies have become more cost-competitive (see Figure C3 in Appendix C). In this case, the positive association between FiT and SIB lending further corroborates our finding that, at least for solar PV, SIB lending is more likely at lower market maturity.

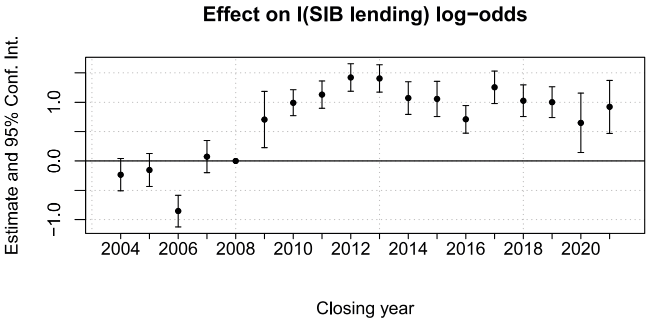

Fig. 4. Year fixed effects using the main specification (Table 4, column 3).

5.3. Robustness checks

To ensure that our results are robust, we deploy a wide battery of checks. Regarding operationalization, ticket size proxies other than the log-transformed deal capacity have already been discussed in the previous section. Furthermore, we apply the market maturity dummy to all RE technologies (instead of only onshore wind and solar PV), use the technology's share in the country's installed capacity as a continuous variable in place of the binary variable with the 10% threshold, and

Table 5
Additional specifications for size effects.

	I(SIB lending)			
	(1)	(2)	(3)	(4)
Tech = Biomass&Waste	1.38****	1.49****	1.54****	1.62****
	(0.280)	(0.287)	(0.323)	(0.324)
Tech = PV	−0.949****	−0.683***	−1.32****	−1.07****
	(0.172)	(0.231)	(0.139)	(0.204)
Tech = SmallHydro	1.19*	1.26*	1.33*	1.38**
	(0.662)	(0.665)	(0.709)	(0.704)
Tech = CSP	1.17***	1.38***	1.73****	1.93****
	(0.417)	(0.463)	(0.420)	(0.461)
Tech = Offshore	2.46****	2.59****	3.59****	3.68****
	(0.671)	(0.682)	(0.649)	(0.655)
Tech = Geothermal	0.727	0.807	0.795*	0.848*
	(0.555)	(0.562)	(0.479)	(0.484)
I(Tech matured — onshore & PV only)	−0.329		−0.352	
	(0.234)		(0.221)	
I(Tech matured) × Tech = Onshore		0.048		0.0006
		(0.331)		(0.317)
I(Tech matured) × Tech = PV		−0.775***		−0.774****
		(0.271)		(0.233)
I(First-3 deal)	0.112	0.096	0.028	0.011
	(0.227)	(0.225)	(0.242)	(0.241)
Capacity (MW)	0.008****	0.008****		
	(0.001)	(0.001)		
Capacity (MW) square	-5.88×10^{-6}****	-5.98×10^{-6}****		
	(1.39×10^{-6})	(1.42×10^{-6})		
I(Cap. in 1st decile)	−0.426*	−0.435*		
	(0.237)	(0.237)		
Capacity decile = 1			−0.688**	−0.688**
			(0.303)	(0.297)
Capacity decile = 2			−0.320	−0.309
			(0.342)	(0.346)
Capacity decile = 3			−0.495	−0.485
			(0.317)	(0.314)
Capacity decile = 4			−0.492*	−0.484*
			(0.282)	(0.280)
Capacity decile = 5			−0.266	−0.235
			(0.400)	(0.398)
Capacity decile = 7			0.195	0.193
			(0.299)	(0.289)
Capacity decile = 8			0.276	0.305
			(0.322)	(0.320)
Capacity decile = 9			0.802****	0.813****
			(0.217)	(0.216)
Capacity decile = 10			1.30****	1.31****
			(0.224)	(0.224)
Further controls of main specification	Yes	Yes	Yes	Yes
Country FEs	Yes	Yes	Yes	Yes
Closing year FEs	Yes	Yes	Yes	Yes
Observations	4797	4797	4797	4797
Pseudo R^2	0.256	0.258	0.258	0.260
BIC	3072.2	3073.1	3115.5	3117.4

Clustered (Closing year) standard-errors in parentheses
All capacity decile dummies are applied only to onshore wind and solar PV.
* Signif. Codes: 0.1.
** Signif. Codes: 0.05.
*** Signif. Codes: 0.01.
**** Signif. Codes: 0.001.

deploy separate technology FEs for early- and later-stage solar PV, following Mazzucato and Semieniuk (2018). Regarding the definition of market-opening deals, our main specification considers the first three deals associated with a given technology in a country, but we conduct robustness checks using just the first and the first 5, 10, and 25 deals. Aside from the climate policy stringency measures discussed in the previous section, we also explore the inclusion of further control variables from the literature, such as government surplus and expenditures in percentage of GDP to measure the available fiscal space (Cárdenas Rodríguez et al., 2015), the bank z-score to measure domestic banking sector distress (Degl'Innocenti et al., 2022), the long-term interest rate (Polzin et al., 2015; Deleidi et al., 2020), and the number of sponsors (Cárdenas Rodríguez et al., 2015). However, the coefficients for all these control variables are insignificant, while missing values for some countries further reduce our sample size—which is why we omit them in our main specification.

In addition, we explore more demanding specifications with technology and country–year FEs or with country and technology–year FEs, as well as standard errors clustered at the country instead of the year level. Since noise in the FEs can contaminate our coefficient estimates due to the incidental parameter problem (Neyman and Scott, 1948; Lancaster, 2000), we further present the results obtained when we drop each FE group (country/year/technology) with fewer than 25 observations and when we use the bias-corrected two-way FE estimator proposed by Fernández-Val and Weidner (2016). Moreover, we explore whether to omit observations for which the BNEF data classify the

Table 6
Regression results for lender mobilization.

	I(SIB lending)		
	(1)	(2)	(3)
(Intercept)	−6.47****		
	(0.489)		
I(First-3 deal)	0.941****	0.164	0.160
	(0.148)	(0.267)	(0.265)
ln(Capacity in MW)	0.517****	0.535****	0.537****
	(0.062)	(0.081)	(0.082)
I(Cap. in 1st decile — onshore & PV only)	0.305	0.432	0.430
	(0.377)	(0.374)	(0.375)
# of non-SIB lenders	0.102****	0.066*	0.066*
	(0.020)	(0.035)	(0.035)
Real GDP PPP growth (%)	−0.019	−0.009	−0.008
	(0.022)	(0.036)	(0.036)
Feed-in tariff (2010 USD/kWh)	1.00***	1.87****	1.80***
	(0.361)	(0.538)	(0.578)
I(Any public sponsor)	0.558****	0.142	0.148
	(0.164)	(0.253)	(0.257)
I(Term loan)	2.02****	1.32****	1.29****
	(0.301)	(0.299)	(0.284)
Tech = Biomass&Waste		1.15****	1.19****
		(0.295)	(0.304)
Tech = PV		−1.03****	−0.903***
		(0.188)	(0.278)
Tech = SmallHydro		1.06	1.10
		(0.675)	(0.678)
Tech = CSP		0.459	0.577
		(0.485)	(0.541)
Tech = Offshore		1.21*	1.26*
		(0.633)	(0.648)
Tech = Geothermal		0.680	0.706
		(0.499)	(0.510)
I(Tech matured — onshore & PV only)		−0.479**	
		(0.200)	
I(Tech matured) × Tech = Onshore			−0.314
			(0.326)
I(Tech matured) × Tech = PV			−0.704***
			(0.219)
Country FEs		Yes	Yes
Closing year FEs		Yes	Yes
Observations	4664	4600	4600
Pseudo R^2	0.138	0.284	0.284
BIC	2321.9	2354.8	2362.1

Clustered (Closing year) standard-errors in parentheses.
* Signif. Codes: 0.1.
** Signif. Codes: 0.05.
*** Signif. Codes: 0.01.
**** Signif. Codes: 0.001.

lenders as "Not Reported", instead of coding them as not involving SIB debt-financing. To ensure that our using a binary dependent variable does not drive our findings, we also extract SIB loan volumes from unstructured text information in BNEF and use the share of SIBs in a deal's total debt financing as an alternative fractional dependent variable with a suitable estimator (Papke and Wooldridge, 1996). However, this requires assumption-based imputation for almost 170 of our 572 deals involving an SIB. Therefore, we deem this approach inferior to our logit model.

The results are displayed in Tables B1–B8 in Appendix B and, for the alternative dependent variable, in Tables D1–D2 in Appendix D. Regarding the effects of size and market maturity, our main findings – namely, of a significant and positive (negative) effect of deal size (PV market maturity) – are robust across all the models under consideration. The same holds true for our main results on the FEs for biomass and waste (significantly positive), offshore wind (significantly positive at the 5% level or, if deals with an SIB as the only lender are discarded, at the 10% level), and geothermal (insignificant). By contrast, the difference between solar PV, CSP, and small hydro vis-à-vis onshore wind is not consistently significant, and neither is the weak positive association between SIB lending and the number of non-SIB lenders (if deals financed by SIBs alone are discarded). Therefore, we conclude that our main findings regarding size, PV market maturity, and technology risks for offshore wind as well as those on biomass and waste constitute strong evidence. By contrast, the findings on lender mobilization and on the differences in SIB lending between onshore wind and the remaining technologies are less conclusive.

6. Conclusion

This paper examines the financing behavior of SIBs with respect to RE technologies relative to that of commercial banks and whether this behavior coincides with the role of these institutions suggested by the academic literature. By considering debt-financed RE transactions in OECD countries, we provide strong evidence that SIB financing activities are significantly more likely than financing activities by other lenders to involve higher-risk technologies, which could be explained either by deliberate targeting or by SIBs' reduction of cancellation risks through their (technology-agnostic) involvement. In the case of solar PV, the likelihood of SIB financing decreases for markets reaching maturity, as SIBs reduce their lending activities or shift them toward foreign markets if their mandates allow for it. By contrast, we find no evidence of similar maturity-related patterns for onshore wind. Potential reasons for this difference are the less dynamic market growth for onshore wind over our sample period (see Figure C2 in Appendix C), which could limit both the identifying variation net of FEs and the likelihood that either SIBs or private-sector lenders proactively revise their financing behavior, or the lower social acceptability of onshore wind projects compared to solar PV, which might warrant continued SIB activity (Schumacher et al., 2019).

While the flip side of the maturity-related patterns is that SIBs are more likely to act as debt providers in immature PV markets, we find no clear evidence that SIBs are significantly more involved in a country's *very first* debt financing deals for a novel technology. Such first-mover roles are instead played by other public-sector entities, with a particular role for export credit agencies and multilateral development banks in less-developed OECD countries. However, the maturity-related patterns of SIB financing seem to be very jurisdiction dependent, which might reconcile our findings with previous, qualitative studies on selected SIBs acting as first movers for RE financing. Beyond technology risk and maturity, in contrast to the literature's suggestions, SIBs are more likely to finance *larger* utility-scale RE transactions, which could result from politically influenced decision making with respect to more prominent deals or from misalignment of SIB managers' and staff's incentives with the policy objective of enabling smaller-scale (but more laborious and potentially less profitable) RE projects.

Regarding the question of mobilizing private banks, we find that SIBs often operate as sole lenders. In a co-lending role, however, the presence of an SIB in a transaction correlates with higher syndicate sizes—a finding that aligns with previous studies on public financial institutions but that is not consistent across all our robustness checks. Therefore, the question of whether and to what extent SIBs mobilize other lenders in RE financing remains an important avenue for future research with more causality-focused research designs. Last, stringent RE policy support in the form of feed-in tariffs robustly predicts SIB involvement, hinting either at a complementary use of policy measures or at further maturity-related financing patterns. Conversely, the general countercyclical financing behavior of SIBs seems to play a limited role in RE financing.

Taken together, our results reveal that SIBs do indeed leverage their risk-bearing abilities to foster riskier RE technologies in immature markets but do not seem to prioritize first-mover roles or the financing of smaller utility-scale assets. These findings are immediately relevant for policy makers who are considering establishing a new institution or revising an SIB's mandate. Given our results, decision makers in such situations should place particular emphasis on deliberately targeting smaller-scale deals, ensuring that the SIB's mandate and guidelines are effective in this regard if enabling smaller RE projects is a policy objective. Furthermore, policy makers should mandate that SIBs withdraw from sufficiently mature technologies or incentivize them to do so—for example, by setting clear guidelines for additionality. Moreover, our results illustrate that empirical relationships in RE financing are strongly moderated by technology differences. This highlights the importance of researchers' use of a high technological resolution in assessing energy financing and can inform future empirical research to avoid spurious findings.

However, there are several limitations to the findings presented here that lend themselves to exploration in further research. First, our results might speak to correlational rather than causal patterns of SIB financing activities for some variables, primarily the number of non-SIB lenders. While our empirical method allows us to identify significant and important effects across SIBs, it should not be seen as a substitute for causal analysis of individual banks' project patterns in their precise context. Second, although this paper disentangles SIBs' financing patterns from those of other public financial institutions, we treat SIBs as a homogeneous group of institutions and do not explore or compare the mandates of different SIBs in more detail. Third, our sample is limited to *utility-scale* RE projects, and therefore, our findings do not speak to SIBs' financing of household-scale projects and investments, which, for some countries, can be extensive. Last, while our research design implicitly compares SIBs to non-SIB lenders, we do not carry out comprehensive comparisons with other types of public financial institutions to explore how SIBs' financing patterns and roles differ from those of other state-owned institutions.

To advance our understanding of SIBs as RE support policies, future research should leverage the specifics of SIB mandates and available information on governing parties to explore how different legal stipulations and political orientations of policymakers translate into financing patterns and, ultimately, deployment outcomes. Another avenue for research would be to empirically assess the RE financing behavior of state-owned export credit agencies or development finance institutions to highlight similarities and differences with public financial institutions whose focus lies abroad. This would not only provide additional context for the findings presented here but also could guide policy makers further on how to channel SIB and public financing in general to foster the clean energy transition.

Funding

This work was supported by an ERC Starting Grant awarded by the European Research Council (ERC) (Grant Agreement No. 948220, Project No. GREENFIN).

CRediT authorship contribution statement

Paul Waidelich: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Bjarne Steffen:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

For valuable comments, the authors thank Joscha Krug and participants at the EAERE 2023 Annual Conference, the 18th IAEE European Conference (2023), the 11th Mannheim Conference on Energy and the Environment (2023), the APPAM 2022 Fall Research Conference, and the IEWT 2023, as well as two anonymous reviewers.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.eneco.2024.107455.

References

Abrell, J., Kosch, M., Rausch, S., 2019a. Carbon abatement with renewables: Evaluating wind and solar subsidies in Germany and Spain. J. Public Econ. 169, 172–202. http://dx.doi.org/10.1016/j.jpubeco.2018.11.007.

Abrell, J., Rausch, S., Streitberger, C., 2019b. The economics of renewable energy support. J. Public Econ. 176, 94–117. http://dx.doi.org/10.1016/j.jpubeco.2019.06.002.

Acemoglu, D., Aghion, P., Bursztyn, L., Hemous, D., 2012. The environment and directed technical change. Amer. Econ. Rev. 102 (1), 131–166. http://dx.doi.org/10.1257/aer.102.1.131.

Arrow, K.J., Lind, R.C., 1970. Uncertainty and the evaluation of public investment decisions. Amer. Econ. Rev. 60 (3), 364–378.

Beck, T., Demirguc-Kunt, A., 2006. Small and medium-size enterprises: Access to finance as a growth constraint. J. Bank. Financ. 30 (11), 2931–2943. http://dx.doi.org/10.1016/j.jbankfin.2006.05.009.

Beck, T., Demirguc-Kunt, A., Maksimovic, V., 2005. Financial and legal constraints to growth: Does firm size matter? J. Finance 60 (1), 137–177. http://dx.doi.org/10.1111/j.1540-6261.2005.00727.x.

Berger, A.N., Clarke, G.R., Cull, R., Klapper, L., Udell, G.F., 2005. Corporate governance and bank performance: A joint analysis of the static, selection, and dynamic effects of domestic, foreign, and state ownership. J. Bank. Financ. 29 (8–9), 2179–2221. http://dx.doi.org/10.1016/j.jbankfin.2005.03.013.

BNEF, 2022a. Asset finance database. URL https://www.bnef.com/asset-financing.

BNEF, 2022b. Organizations database. URL https://www.bnef.com/organizations.

BNEF, 2022c. Renewable energy projects database. URL https://www.bnef.com/projects.

Broccolini, C., Lotti, G., Maffioli, A., Presbitero, A.F., Stucchi, R., 2021. Mobilization effects of multilateral development banks. World Bank Econ. Rev. 35 (2), 521–543. http://dx.doi.org/10.1093/wber/lhz049.

Campiglio, E., 2016. Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy. Ecol. Econom. 121, 220–230. http://dx.doi.org/10.1016/j.ecolecon.2015.03.020.

Cárdenas Rodríguez, M., Haščič, I., Johnstone, N., Silva, J., Ferey, A., 2015. Renewable energy policies and private sector investment: Evidence from financial microdata. Environ. Resour. Econ. 62 (1), 163–188. http://dx.doi.org/10.1007/s10640-014-9820-x.

Carvalho, D., 2014. The real effects of government-owned banks: Evidence from an emerging market. J. Finance 69 (2), 577–609. http://dx.doi.org/10.1111/jofi.12130.

Cochran, I., Hubert, R., Marchal, V., Youngman, R., 2014. Public financial institutions and the low-carbon transition: Five case studies on low-carbon infrastructure and project investment. OECD Environ. Policy Pap. 72, http://dx.doi.org/10.1787/5jxt3rhpgn9t-en.

Degl'Innocenti, M., Frigerio, M., Zhou, S., 2022. Development banks and the syndicate structure: Evidence from a world sample. J. Empir. Financ. 66, 99–120. http://dx.doi.org/10.1016/j.jempfin.2022.01.002.

Deleidi, M., Mazzucato, M., Semieniuk, G., 2020. Neither crowding in nor out: Public direct investment mobilising private investment into renewable electricity projects. Energy Policy 140, 111195. http://dx.doi.org/10.1016/j.enpol.2019.111195.

Diamond, D.W., Dybvig, P.H., 1983. Bank runs, deposit insurance, and liquidity. J. Polit. Econ. 91 (3), 401–419.

D'Orazio, P., Löwenstein, P., 2022. Mobilising investments in renewable energy in Germany: which role for public investment banks? J. Sustain. Finance Invest. 12 (2), 451–474. http://dx.doi.org/10.1080/20430795.2020.1777062.

D'Orazio, P., Popoyan, L., 2019. Fostering green investments and tackling climate-related financial risks: Which role for macroprudential policies? Ecol. Econom. 160, 25–37. http://dx.doi.org/10.1016/j.ecolecon.2019.01.029.

Dukan, M., Gumber, A., Egli, F., Steffen, B., 2023. The role of policies in reducing the cost of capital for offshore wind. iScience 26 (6), 106945. http://dx.doi.org/10.1016/j.isci.2023.106945.

Egli, F., 2020. Renewable energy investment risk: An investigation of changes over time and the underlying drivers. Energy Policy 140 (111428), http://dx.doi.org/10.1016/j.enpol.2020.111428.

Egli, F., Steffen, B., Schmidt, T.S., 2018. A dynamic analysis of financing conditions for renewable energy technologies. Nat. Energy 3 (12), 1084–1092. http://dx.doi.org/10.1038/s41560-018-0277-y.

EIB, 2022a. Evaluation of the EIB's special activities. http://dx.doi.org/10.2867/683589.

EIB, 2022b. The innovation response: 2021 activity report. http://dx.doi.org/10.2867/978447.

EIB, 2022c. Loans. URL https://www.eib.org/en/products/loans/index.htm.

EIB, 2023. EIB to support green deal industrial plan with €45 billion in additional financing. URL https://www.eib.org/en/press/all/2023-270-eib-to-support-green-deal-industrial-plan-with-eur45-billion-in-additional-financing.

Eslava, M., Freixas, X., 2021. Public development banks and credit market imperfections. J. Money Credit Bank. 53 (5), 1121–1149. http://dx.doi.org/10.1111/jmcb.12807.

Fama, E.F., French, K.R., 1992. The cross-section of expected stock returns. J. Finance 47 (2), 427–465.

Fernández-Val, I., Weidner, M., 2016. Individual and time effects in nonlinear panel models with large n , t. J. Econometrics 192 (1), 291–312. http://dx.doi.org/10.1016/j.jeconom.2015.12.014.

Geddes, A., Schmidt, T.S., 2020. Integrating finance into the multi-level perspective: Technology niche-finance regime interactions and financial policy interventions. Res. Policy 49 (6), 103985. http://dx.doi.org/10.1016/j.respol.2020.103985.

Geddes, A., Schmidt, T.S., Steffen, B., 2018. The multiple roles of state investment banks in low-carbon energy finance: An analysis of Australia, the UK and Germany. Energy Policy 115, 158–170. http://dx.doi.org/10.1016/j.enpol.2018.01.009.

Greene, W.H., 2003. Econometric Analysis, fifth ed. Prentice Hall, Upper Saddle River, N.J..

Grubb, M., Drummond, P., Poncia, A., McDowall, W., Popp, D., Samadi, S., Penasco, C., Gillingham, K.T., Smulders, S., Glachant, M., Hassall, G., Mizuno, E., Rubin, E.S., Dechezleprêtre, A., Pavan, G., 2021. Induced innovation in energy technologies and systems: a review of evidence and potential implications for CO2 mitigation. Environ. Res. Lett. 16 (4), 043007. http://dx.doi.org/10.1088/1748-9326/abde07.

Gurara, D., Presbitero, A., Sarmiento, M., 2020. Borrowing costs and the role of multilateral development banks: Evidence from cross-border syndicated bank lending. J. Int. Money Finance 100, 102090. http://dx.doi.org/10.1016/j.jimonfin.2019.102090.

Hainz, C., Kleimeier, S., 2012. Political risk, project finance, and the participation of development banks in syndicated lending. J. Financial Intermediat. 21 (2), 287–314. http://dx.doi.org/10.1016/j.jfi.2011.10.002.

Hall, S., Foxon, T.J., Bolton, R., 2016. Financing the civic energy sector: How financial institutions affect ownership models in Germany and the United Kingdom. Energy Res. Soc. Sci. 12, 5–15. http://dx.doi.org/10.1016/j.erss.2015.11.004.

Hart, O., Shleifer, A., Vishny, R.W., 1997. The proper scope of government: Theory and an application to prisons. Q. J. Econ. 112 (4), 1127–1161.

Humphrey, C., 2023. Financing the Future: Multilateral Development Banks in the Changing World Order of the 21st Century, first ed. Oxford University Press, Oxford.

IEA, 2023. World Energy Outlook 2023. https://www.iea.org/reports/world-energy-outlook-2023.

IPCC, 2022. Climate Change 2022: Mitigation of Climate Change. Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, http://dx.doi.org/10.1017/9781009157926,

IRENA, 2022. Renewable energy statistics 2022. URL https://www.irena.org/publications/2022/Jul/Renewable-Energy-Statistics-2022.

IRENA, 2023. The cost of financing for renewable power. URL https://www.irena.org/Publications/2023/May/The-cost-of-financing-for-renewable-power.

Iyer, R., Peydró, J.-L., da Rocha-Lopes, S., Schoar, A., 2014. Interbank liquidity crunch and the firm credit crunch: Evidence from the 2007–2009 crisis. Rev. Financ. Stud. 27 (1), 347–372. http://dx.doi.org/10.1093/rfs/hht056.

Kalkuhl, M., Edenhofer, O., Lessmann, K., 2013. Renewable energy subsidies: Second-best policy or fatal aberration for mitigation? Resour. Energy Econ. 35 (3), 217–234. http://dx.doi.org/10.1016/j.reseneeco.2013.01.002.

Karneyeva, Y., Wüstenhagen, R., 2017. Solar feed-in tariffs in a post-grid parity world: The role of risk, investor diversity and business models. Energy Policy 106, 445–456. http://dx.doi.org/10.1016/j.enpol.2017.04.005.

Klaaßen, L., Steffen, B., 2023. Meta-analysis on necessary investment shifts to reach net zero pathways in Europe. Nature Clim. Change 13, 58–66. http://dx.doi.org/10.1038/s41558-022-01549-5.

Kornai, J., Maskin, E., Roland, G., 2003. Understanding the soft budget constraint. J. Econ. Lit. 41 (4), 1095–1136.

La Porta, R., Lopez-de Silanes, F., Shleifer, A., 2002. Government ownership of banks. J. Finance 57 (1), 265–301.

Lancaster, T., 2000. The incidental parameter problem since 1948. J. Econometrics 95 (2), 391–413.

Lehmann, P., Söderholm, P., 2018. Can technology-specific deployment policies be cost-effective? The case of renewable energy support schemes. Environ. Resour. Econ. 71 (2), 475–505. http://dx.doi.org/10.1007/s10640-017-0169-9.

Levy Yeyati, E., Micco, A., Panizza, U., 2004. Should the government be in the banking business? The role of state-owned and development banks. IADB Res. Dep. Work. Pap. 517, URL https://publications.iadb.org/publications/english/document/Should-the-Government-Be-in-the-Banking-Business-The-Role-of-State-Owned-and-Development-Banks.pdf.

Macfarlane, L., Mazzucato, M., 2018. State investment banks and patient finance: An international comparison: Policy report. URL https://www.ucl.ac.uk/bartlett/public-purpose/publications/2018/feb/state-investment-banks-and-patient-finance-international-comparison-0.

Masini, A., Menichetti, E., 2012. The impact of behavioural factors in the renewable energy investment decision making process: Conceptual framework and empirical findings. Energy Policy 40, 28–38. http://dx.doi.org/10.1016/j.enpol.2010.06.062.

Mazzucato, M., Macfarlane, L., 2017. Patient strategic finance: opportunities for state investment banks in the UK: Policy report. URL https://www.ucl.ac.uk/bartlett/public-purpose/publications/2017/dec/patient-strategic-finance-opportunities-state-investment-banks-uk.

Mazzucato, M., Penna, C.C., 2016. Beyond market failures: the market creating and shaping roles of state investment banks. J. Econ. Policy Reform. 19 (4), 305–326. http://dx.doi.org/10.1080/17487870.2016.1216416.

Mazzucato, M., Semieniuk, G., 2017. Public financing of innovation: new questions. Oxf. Rev. Econ. Policy 33 (1), 24–48. http://dx.doi.org/10.1093/oxrep/grw036.

Mazzucato, M., Semieniuk, G., 2018. Financing renewable energy: Who is financing what and why it matters. Technol. Forecast. Soc. Change 127, 8–22. http://dx.doi.org/10.1016/j.techfore.2017.05.021.

McCollum, D.L., Zhou, W., Bertram, C., de Boer, H.-S., Bosetti, V., Busch, S., Després, J., Drouet, L., Emmerling, J., Fay, M., Fricko, O., Fujimori, S., Gidden, M., Harmsen, M., Huppmann, D., Iyer, G., Krey, V., Kriegler, E., Nicolas, C., Pachauri, S., Parkinson, S., Poblete-Cazenave, M., Rafaj, P., Rao, N., Rozenberg, J., Schmitz, A., Schoepp, W., van Vuuren, D., Riahi, K., 2018. Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals. Nat. Energy 3 (7), 589–599. http://dx.doi.org/10.1038/s41560-018-0179-z.

Micco, A., Panizza, U., Yañez, M., 2007. Bank ownership and performance: Does politics matter? J. Bank. Financ. 31 (1), 219–241. http://dx.doi.org/10.1016/j.jbankfin.2006.02.007.

NADB, 2022. 2021 Annual report. URL https://www.nadb.org/uploads/files/2021_annual_report_eng_final.pdf.

Neyman, J., Scott, E.L., 1948. Consistent estimates based on partially consistent observations. Econometrica 16 (1), 1–32.

OECD, 2016. Green Investment Banks: Scaling up Private Investment in Low-Carbon, Climate-Resilient Infrastructure. Green Finance and Investment, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264245129-en.

OECD, 2017. Green investment banks: Innovative public financial institutions scaling-up private, low-carbon investment policy reform. OECD Environ. Policy Pap. 6, http://dx.doi.org/10.1787/e3c2526c-en.

Papke, L.E., Wooldridge, J.M., 1996. Econometric methods for fractional response variables with an application to 401 (K) plan participation rates. J. Appl. Econometrics 11 (6), 619–632.

Polzin, F., 2017. Mobilizing private finance for low-carbon innovation – A systematic review of barriers and solutions. Renew. Sustain. Energy Rev. 77, 525–535. http://dx.doi.org/10.1016/j.rser.2017.04.007.

Polzin, F., Egli, F., Steffen, B., Schmidt, T.S., 2019. How do policies mobilize private finance for renewable energy? A systematic review with an investor perspective. Appl. Energy 236, 1249–1268. http://dx.doi.org/10.1016/j.apenergy.2018.11.098.

Polzin, F., Migendt, M., Täube, F.A., von Flotow, P., 2015. Public policy influence on renewable energy investments—A panel data study across OECD countries. Energy Policy 80, 98–111. http://dx.doi.org/10.1016/j.enpol.2015.01.026.

Reguant, M., 2019. The efficiency and sectoral distributional impacts of large-scale renewable energy policies. J. Assoc. Environ. Resour. Econ. 6 (S1), S129–S168. http://dx.doi.org/10.1086/701190.

Sapienza, P., 2004. The effects of government ownership on bank lending. J. Financ. Econ. 72, 357–384. http://dx.doi.org/10.1016/j.jfineco.2002.10.002.

Schmalensee, R., 2012. Evaluating policies to increase electricity generation from renewable energy. Rev. Environ. Econ. Policy 6 (1), 45–64. http://dx.doi.org/10.1093/reep/rer020.

Schumacher, K., Krones, F., McKenna, R., Schultmann, F., 2019. Public acceptance of renewable energies and energy autonomy: A comparative study in the french, german and swiss upper rhine region. Energy Policy 126, 315–332. http://dx.doi.org/10.1016/j.enpol.2018.11.032.

Shleifer, A., Vishny, R.W., 1994. Politicians and firms. Q. J. Econ. 109 (4), 995–1025.

Steffen, B., 2018. The importance of project finance for renewable energy projects. Energy Econ. 69, 280–294. http://dx.doi.org/10.1016/j.eneco.2017.11.006.

Steffen, B., 2020. Estimating the cost of capital for renewable energy projects. Energy Econ. 88, 104783. http://dx.doi.org/10.1016/j.eneco.2020.104783.

Steffen, B., 2021. A comparative analysis of green financial policy output in OECD countries. Environ. Res. Lett. 16 (7), 074031. http://dx.doi.org/10.1088/1748-9326/ac0c43.

Steffen, B., Karplus, V., Schmidt, T.S., 2022. State ownership and technology adoption: The case of electric utilities and renewable energy. Res. Policy 51 (6), 104534. http://dx.doi.org/10.1016/j.respol.2022.104534.

Steffen, B., Matsuo, T., Steinemann, D., Schmidt, T.S., 2018. Opening new markets for clean energy: The role of project developers in the global diffusion of renewable energy technologies. Bus. Politics 20 (4), 553–587. http://dx.doi.org/10.1017/bap.2018.17.

Steffen, B., Waidelich, P., 2022. Determinants of cost of capital in the electricity sector. Progr. Energy 4 (3), 033001. http://dx.doi.org/10.1088/2516-1083/ac7936.

Stiglitz, J., 1993. The role of the state in financial markets. World Bank Econ. Rev. 7 (1), 19–52.

Tirole, J., 1994. The internal organization of government. Oxf. Econ. Pap. 46 (1), 1–29.

Torres, E., Zeidan, R., 2016. The life-cycle of national development banks: The experience of Brazil's BNDES. Q. Rev. Econ. Finance 62, 97–104. http://dx.doi.org/10.1016/j.qref.2016.07.006.

US EPA, 2023. National clean investment fund. URL https://www.epa.gov/greenhouse-gas-reduction-fund/national-clean-investment-fund.

van Dijk, M.A., 2011. Is size dead? A review of the size effect in equity returns. J. Bank. Financ. 35 (12), 3263–3274. http://dx.doi.org/10.1016/j.jbankfin.2011.05.009.

Waidelich, P., Krug, J., Steffen, B., 2023. Mobilizing credit for clean energy: De-risking and public loan provision under learning spillovers. ZEW Discuss. Pap. Ser. 23–040, URL https://www.zew.de/PU84341.

Whitney, A., Grbusic, T., Meisel, J., Becerra Cid, A., Sims, D., Bodnar, P., 2020. State of green banks 2020. URL https://rmi.org/insight/state-of-.

Wüstenhagen, R., Menichetti, E., 2012. Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research. Energy Policy 40, 1–10. http://dx.doi.org/10.1016/j.enpol.2011.06.050.

Xu, J., Marodon, R., 2021. The public development banks and development financing institutions database. URL http://www.dfidatabase.pku.edu.cn/.

Zhang, F., 2020. Leaders and followers in finance mobilization for renewable energy in Germany and China. Environ. Innov. Soc. Transit. 37, 203–224. http://dx.doi.org/10.1016/j.eist.2020.08.005.