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SUPPLEMENTARY INFORMATION

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A dynamic analysis of financing conditions for renewable energy technologies

Florian Egli*, Bjarne Steffen* and Tobias S. Schmidt*

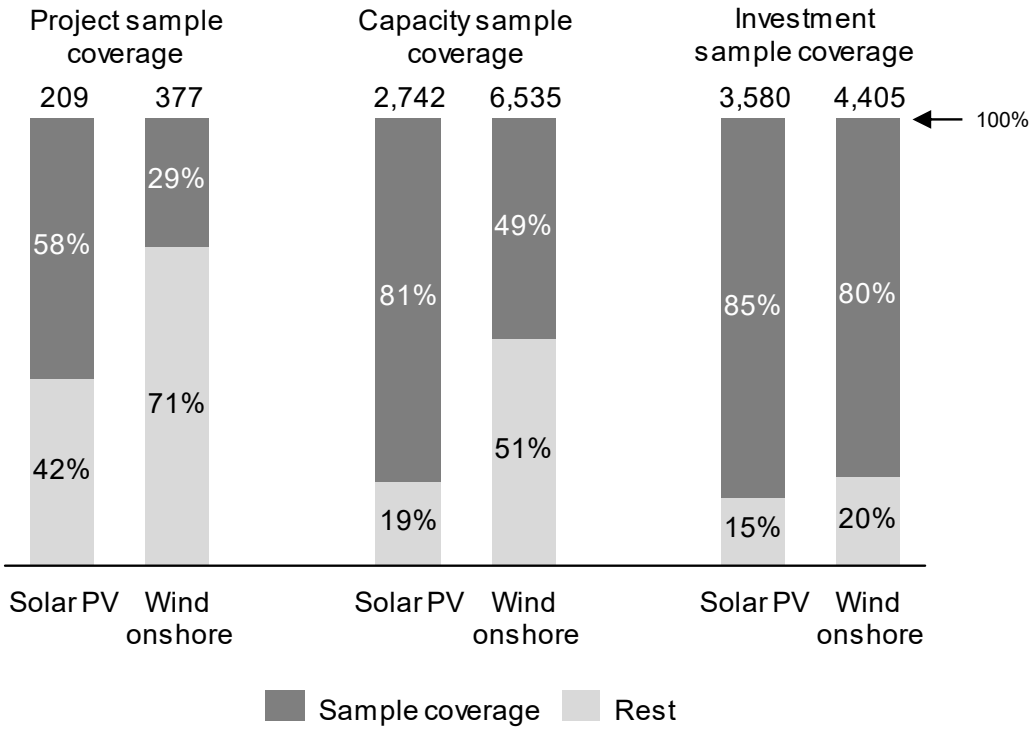
Energy Politics Group, Department of Humanities, Social and Political Sciences, ETH Zurich, Zürich, Switzerland. *e-mail: florian.egli@gess.ethz.ch; bjarne.steffen@gess.ethz.ch; tobiasschmidt@ethz.ch

Supplementary Information

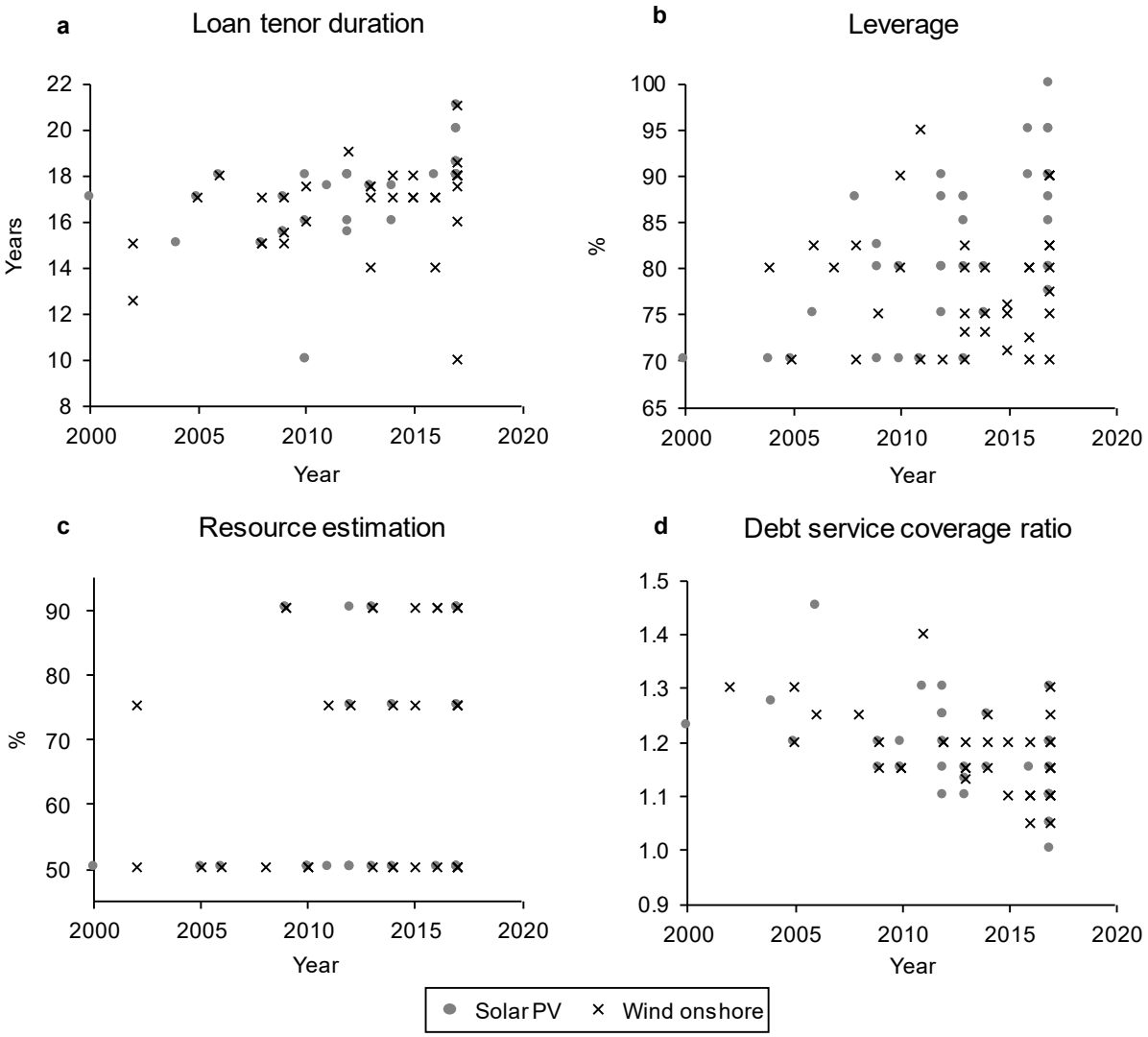
Supplementary Note 1: Key terms of project finance

In project finance, each project is a separate legal entity, set up for the project's lifetime, often called a special purpose vehicle (SPV). The project sponsors hold equity in the SPV, and banks typically provide loans (i.e., debt) to the SPV. In this paper, we call both project sponsors and banks *investors*. The expected returns to project sponsors are called *cost of equity*, and the interest to be paid on the loans is called *cost of debt*. The relative shares of debt and equity in a project define the leverage or capital structure of the SPV. Loan providers usually have no recourse beyond the project, which means the project's risk profile translates directly to the cost of debt. Consequently, the cash flows generated by the SPV must cover operating costs and the debt service (i.e., capital repayment and interest)[1]. Any remaining cash flows go to the project sponsors and constitute their return on the investment. Therefore, equity investors also are concerned about a project's ability to service outstanding debt. The common metric to assess debt service is the debt service coverage ratio (DSCR), which serves as a direct measure of project risk (see Supplementary Table 1). Moreover, the SPV's capital structure usually also is an indication of project risk because more debt increases the debt service (just as a higher cost of debt does). As per convention, we analyse the financing conditions of SPVs at the beginning of projects, i.e., the point when investors make their investment decisions. Contrary to corporate finance, project finance directly ties the cost of capital to project risk[1,2] – providing a unique setting in which to study the dynamics of renewable energy financing conditions. Because project finance conditions are not quoted publicly, it is necessary to elicit data from renewable energy investment professionals.

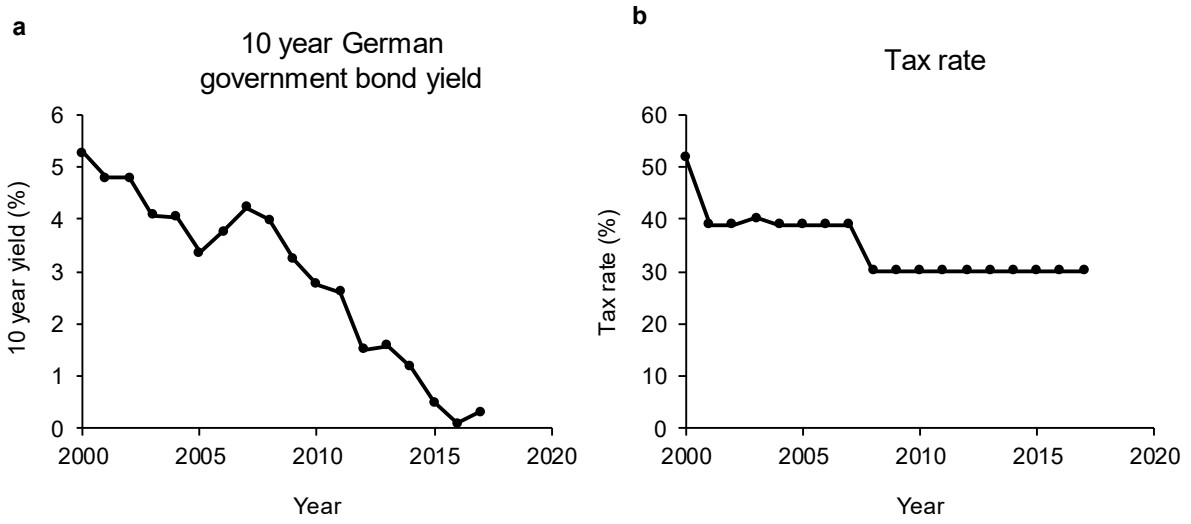
Supplementary Figures



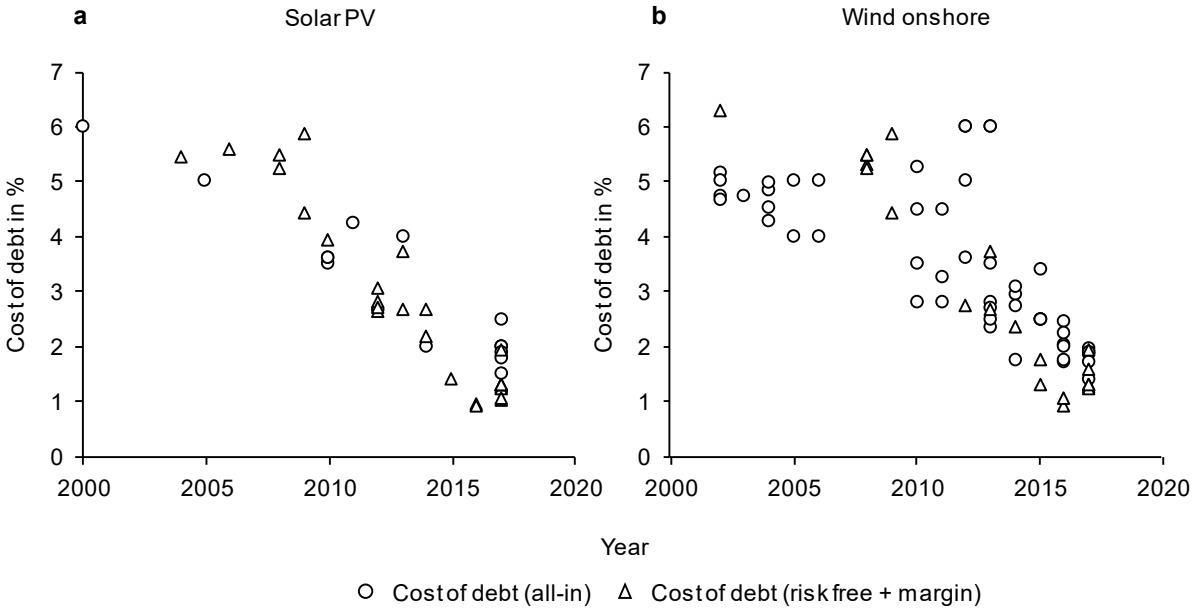
Supplementary Figure 1: Market share of our data providers. Sample coverage is shown with regards to all deals recorded in the BNEF asset database between 2000 and 2017. We calculate the sample coverage over the total of deals, where a lead debt arranger is specified. BNEF provides at least one lead debt arranger for 45% of solar PV investments and 42% of wind onshore investments.



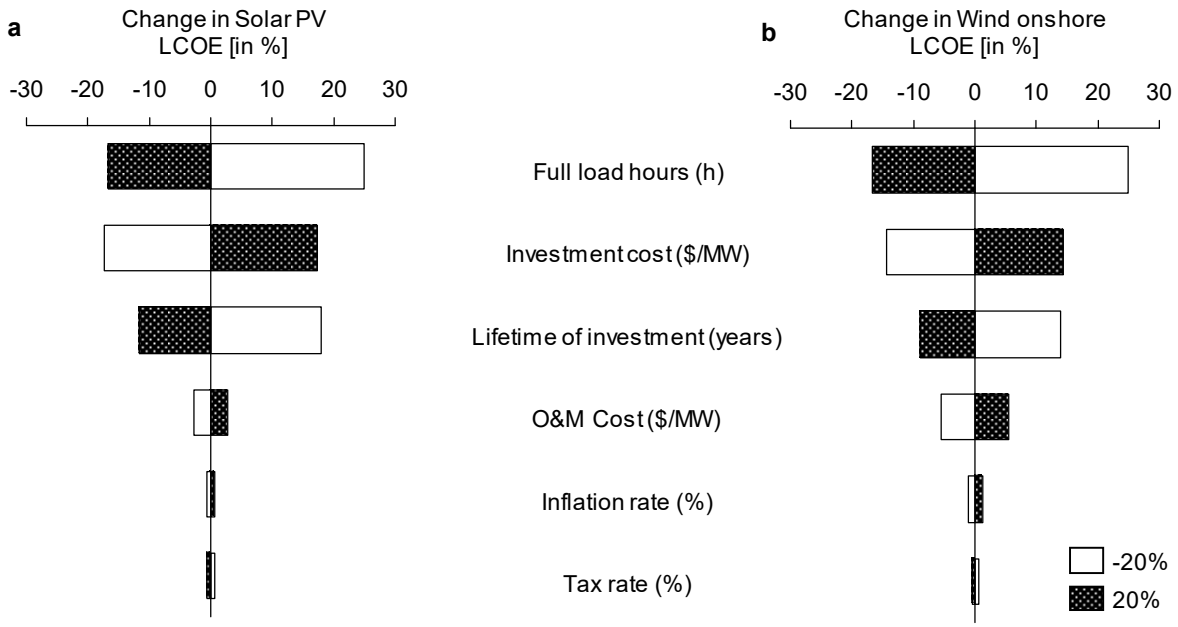
Supplementary Figure 2: Financial deal characteristics. **a**, Loan tenors (N = 70) increased over time. **b**, Leverage (N = 74) increased for solar PV and remained relatively constant for wind onshore. **c,** the resource estimation (percentile of the estimated distribution) has remained split between p50 (median) and p90 (risk-averse) for both technologies (N = 61). **d**, The debt service coverage ratio (N = 71) decreased for both technologies.



Supplementary Figure 3: Economic variables. Government bond yields decreased from over 5% to 0.31% over the period of our sample (**a**)[3]. The corporate tax rate has fallen from 52% to 30%, making debt comparatively more expensive (**b**)[4].



Supplementary Figure 4: Data validity check comparing the reported all-in cost of debt vs. 'synthetic' cost of debt resulting from reported debt margins adding the yield of a 10 year German government bond (risk free). **a**, Solar PV projects (N = 42), of which 15 all-in and 27 'synthetic'. **b**, Wind onshore projects (N = 73), of which 51 all-in and 22 'synthetic'.



Supplementary Figure 5: LCOE sensitivity analysis for solar PV (**a**) and wind onshore (**b**). The figure depicts percent changes in the LCOE for both technologies given a +/- 20% change in one of the LCOE variables (all other variables stay remain constant). See Table 4 in the Supplementary Information for the values.

Supplementary Tables

Supplementary Table 1: Definitions of financial terms.

Term	Definition
Capital expenditure (CAPEX)	The initial expenditure (i.e. investment) into the RET generation asset.
Cost of capital (CoC)	The weighted average cost of capital (often denoted WACC) of a project, calculated according to Equation (2).
Cost of debt	Interest payments on the debt raised to finance a project.
Cost of equity	Dividends payments (i.e. return) to project shareholders.
Debt margin	The project specific margin on top of the refinancing rate of the debt provider (e.g., bank).
Debt service coverage ratio (DSCR)	A measure of project cash flows available to pay debt obligations, namely the principal repayment and interest rate payments.
Financing conditions	The wider financial conditions of a project including among others CoC, DSCR, and loan tenor.
Financing cost	The total cost of capital service, including debt service (i.e. principal repayment and interest rate payments) and returns to equity.
Investment cost	The initial investment cost of a RET generation. Used interchangeably with capital expenditure.
Leverage	The project capital structure, i.e. the share of debt of the total investment sum.
Loan tenor	The time period for repayment of the loan.
Operating expenditure (OPEX)	Expenditures to operate the RET generation assets, occurring throughout the asset lifetime (if operated).
P value	The percentile value of the distribution of solar irradiation or wind speed predictions used for project assessment. Calculating project returns on a p90 value means to take the 90^{th} percentile of the predicted distribution and represents a more conservative approach than for example p50 (median).

Supplementary Table 2: Summary statistics. Counting all project where we have a value for at least one of the following variables: Cost of debt, cost of equity, leverage, cost of capital, loan tenor, and DSCR, our sample covers 48 solar PV and 85 wind onshore projects between 2000 and 2017 (N = 133). If we limit the sample to projects for which we have data on the cost of capital only (cost of debt, cost of equity or cost of capital), our sample includes 43 solar PV and 78 wind onshore projects (N = 121).

	N	Mean	Std. Dev.	Min	Max
K_D	112	3.18	1.57	0.89	6.28
K_E	66	7.07	2.13	3.25	14
Leverage (debt share)	74	80	7.75	70	100
Debt margin	49	1.25	0.43	0.7	2.65
Cost of capital	57	3.20	1.59	0.59	9.50
Loan tenor	70	16.89	2.11	10	21
DSCR	71	1.18	0.08	1	1.45

Supplementary Table 3: Full interview sample (N = 41)

ID	Interview type	Current organisation	Current position	Based in	RET investment experience (years)	Sex	Age range
1	Structured	Debt provider	Head of Division Energy & Utilities	Germany	12	M	25-45
2	Structured	Debt provider	Vice President	Germany	28	M	45-65
3	Structured	Debt provider	Associate Director Project Finance & Capital Advisory	Germany	7	M	25-45
4	Structured	Debt provider	Associate Director Infrastructure & Power Project Finance	Germany	9	M	25-45
5	Structured	Debt provider	Executive Director Project Finance Renewable Energies	Germany	21	M	45-65
6	Structured	Debt provider	Associate Director Global Infrastructure Debt	United Kingdom	5	F	25-45
7	Structured	Debt provider	Head Renewable Energies	Germany	27	M	45-65
8	Structured	Debt provider	Project Finance Analyst	Germany	11	M	25-45
9	Structured	Debt provider	Vice President Corporates & Small Business Project Finance	Germany	11	M	45-65
10	Structured	Debt provider	Director Structured Finance Power & Renewables	The Netherlands	11	M	45-65
11	Structured	Debt provider	Director Structured Finance Utilities, Power & Renewables	The Netherlands	11	M	25-45
12	Structured	Debt provider	Senior Manager Structured Finance Renewable Energy	Germany	19	M	45-65
13	Structured	Debt provider	Director Project & Structured Finance Utilities, Power and Renewables	Italy	11	F	25-45
14	Structured	Debt provider	Director Corporate Strategy	The Netherlands	19	M	40-65
15	Structured	Debt provider	Head of Renewable Energies	Germany	23	M	40-65
16	Structured	Debt provider	Head of Project Finance Origination Renewable Energies	Germany	8	M	45-65
17	Structured	Debt provider	Managing Director Project & Acquisition Finance	United Kingdom	12	M	25-45
18	Structured	Equity provider*	Head Risk Advisory	Germany	13	M	45-65
19	Structured	Equity provider*	CEO	Germany	10	M	45-65
20	Structured	Equity provider*	Founder and CEO	Germany	5	M	25-45
21	Structured	Equity provider	Principal	Switzerland	5	M	25-45
22	Structured	Equity provider	Partner	Switzerland	9	M	45-65
23	Structured	Equity provider	Director Infrastructure Equity Investment Team	Germany	12	M	45-65
24	Structured	Equity provider	Vice President Renewables	Switzerland	3	M	25-45
25	Structured	Equity provider	CIO	Germany	2	M	25-45
26	Structured	Equity provider	CEO	Germany	2	M	25-45
27	Structured	Equity provider	Associate Director Energy & Cleantech	France	12	M	25-45
28	Structured	Equity provider	Associate	United Kingdom	18	M	25-45
29	Structured	Public actor	Head Energy Services	Switzerland	12	M	25-45
30	Structured	Public actor	Deputy Head Energy Management	Switzerland	3	M	25-45
31	Structured	Public actor	CEO	Switzerland	7	M	45-65

32	Structured	Public actor	Head Portfolio and Asset Management Renewable Energies	Switzerland	8	M	25-45
33	Structured	Public actor	Vice President Origination and Structuring	Germany	6	M	25-45
34	Exploratory	Equity provider	Founding Partner	Switzerland	18	F	45-65
35	Exploratory	Equity provider	Investments Director	United Kingdom	12	M	25-45
36	Exploratory	Equity provider*	Head Risk Advisory	Germany	13	M	45-65
37	Exploratory	Equity provider	Partner	Switzerland	9	M	45-65
38	Exploratory	Equity provider	Principal	Switzerland	5	M	25-45
39	Exploratory	Other (former researcher)	Head Hybrid Power Solutions	Germany	12	M	25-45
40	Exploratory	Public actor	Senior Investment Manager	Norway	11	M	45-65
41	Exploratory	Public actor	Economist	Luxemburg	15	M	25-45

* = Acts as advisor for equity investors

Note: For age, only ranges given to protect anonymity of interviewees

Supplementary Table 4: LCOE model parameters

	Solar PV		**Wind onshore**	
Parameters	2000-05	2017	2000-05	2017
Inflation	2%	2%	2%	2%
Full load hours p.a.[5,6]	1051	1051	1500	2716
Investment cost US$ MW^{-1} (CAPEX)[7]	6.37m	1.05m	1.60m	2.00m
Operation and maintenance cost US$ MW^{-1} $year^{-1}$ (OPEX)[6,8]	8’000	8’000	38’000	38’000
Asset lifetime	20	20	20	20
Cost of capital	5.1%	1.6%	4.5%	1.9%

Supplementary Table 5: Solar PV experience rate estimation and robustness checks. All regressions are calculated using OLS with robust standard errors and all variables are in log. For each specification, we show a version without and a version with investor fixed effects. InvUNEP denotes the cumulative global investment data from UN Environment (columns 1 and 2), InvEU denotes cumulative European investment (columns 3 and 4), InvBNEFxIRENA denotes the alternative measure for cumulative global investment using data from BNEF on investment cost per MW and data from IRENA on capacity (columns 5 and 6). The resulting minimum and maximum experience rates are shown in Supplementary Table 7. For details on the variables, see Methods.

	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Log(debt margin)						Log(dscr-1)						Log(loan tenor)					
Log(InvUNEP)	-0.162***	-0.149***					-0.209***	-0.257***					0.0376**	0.0585**				
	(0.0532)	(0.0362)					(0.0744)	(0.0638)					(0.0170)	(0.0224)				
Log(InvEU)			-0.155**	-0.147***					-0.186**	-0.215***					0.0276*	0.0479**		
			(0.0567)	(0.0451)					(0.0699)	(0.0543)					(0.0152)	(0.0200)		
Log(InvBNEFxIRENA)					-0.164***	-0.151***					-0.226***	-0.273***					0.0403**	0.0623**
					(0.0511)	(0.0356)					(0.0759)	(0.0609)					(0.0171)	(0.0226)
Constant	1.194***	1.693***	2.042***	2.532***	1.162***	1.662***	-0.588	-0.206	0.335	0.746	-0.539	-0.163	2.598***	2.434***	2.501***	2.231***	2.591***	2.423***
	(0.350)	(0.239)	(0.690)	(0.556)	(0.322)	(0.227)	(0.429)	(0.497)	(0.804)	(0.749)	(0.416)	(0.468)	(0.117)	(0.157)	(0.187)	(0.256)	(0.114)	(0.152)
Investor fixed effects	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
Observations	27	27	27	27	27	27	35	35	35	35	35	35	36	36	36	36	36	36
R-squared	0.287	0.850	0.204	0.801	0.284	0.847	0.162	0.696	0.115	0.634	0.167	0.697	0.104	0.398	0.050	0.319	0.107	0.402

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Supplementary Table 6: Wind onshore experience rate estimation and robustness checks. All regressions are calculated using OLS with robust standard errors and all variables are in log. For each specification, we show a version without and a version with investor fixed effects. InvUNEP denotes the cumulative global investment data from UN Environment (columns 1 and 2), InvEU denotes cumulative European investment (columns 3 and 4), InvBNEFxIRENA denotes the alternative measure for cumulative global investment using data from BNEF on investment cost per MW and data from IRENA on capacity (columns 5 and 6). The resulting minimum and maximum experience rates are shown in Supplementary Table 7. For details on the variables, see Methods.

	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Log(debt margin)						Log(dscr-1)						Log(loan tenor)					
Log(lnvUNEP)	-0.164**	-0.162***					-0.261***	-0.283***					0.0430*	0.0532**				
	(0.0633)	(0.0472)					(0.0594)	(0.0936)					(0.0253)	(0.0254)				
Log(lnvEU)			-0.254**	-0.254***					-0.423***	-0.459**					0.0688*	0.0866**		
			(0.0982)	(0.0750)					(0.0992)	(0.161)					(0.0401)	(0.0377)		
Log(lnvBNEFxIRENA)					-0.182***	-0.178***					-0.280***	-0.310***					0.0449	0.0567*
					(0.0638)	(0.0423)					(0.0646)	(0.0964)					(0.0280)	(0.0288)
Constant	1.250***	1.789***	3.272**	3.819***	1.292***	1.816***	-0.123	-0.0273	3.315***	3.703*	-0.118	0.0186	2.531***	2.472***	1.976***	1.769***	2.538***	2.473***
	(0.416)	(0.317)	(1.196)	(0.910)	(0.392)	(0.264)	(0.344)	(0.651)	(1.161)	(1.974)	(0.350)	(0.628)	(0.154)	(0.172)	(0.474)	(0.464)	(0.159)	(0.183)
Investor fixed effects	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
Observations	22	22	22	22	22	22	36	36	36	36	36	36	34	34	34	34	34	34
R-squared	0.212	0.913	0.209	0.915	0.235	0.925	0.218	0.636	0.224	0.645	0.222	0.648	0.089	0.746	0.091	0.753	0.083	0.743

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Supplementary Table 7: Experience rate robustness checks. The table indicates minimum and maximum values for the experience rates across all model specifications shown in Supplementary Tables 5 and 6.

	Solar PV		**Wind onshore**	
	Min	Max	Min	Max
Debt margin	10%	11%	11%	16%
DSCR	12%	17%	17%	27%
Loan tenor	-2%	-4%	-3%	-6%

Supplementary References

1. Gatti, S. *Project finance in theory and practice : designing, structuring, and financing private and public projects*. (Academic Press, 2013).
2. Steffen, B. The importance of project finance for renewable energy projects. *Energy Econ.* **69,** 280–294 (2018).
3. European Central Bank. *Long-term interest rate statistics for EU Member States*. (2018).
4. OECD. *Statutory corporate income tax rate*. (2018).
5. Wirth, H. *Aktuelle Fakten zur Photovoltaik in Deutschland*. (2018).
6. Durstewitz, M. *et al. Windenergie Report Deutschland 2016*. (Fraunhofer Verlag, 2017).
7. BNEF. *Asset database*. *Bloomberg* (2017).
8. Bächler, M. *Technical Risk Management during O & M of PV Plants*. (2016).