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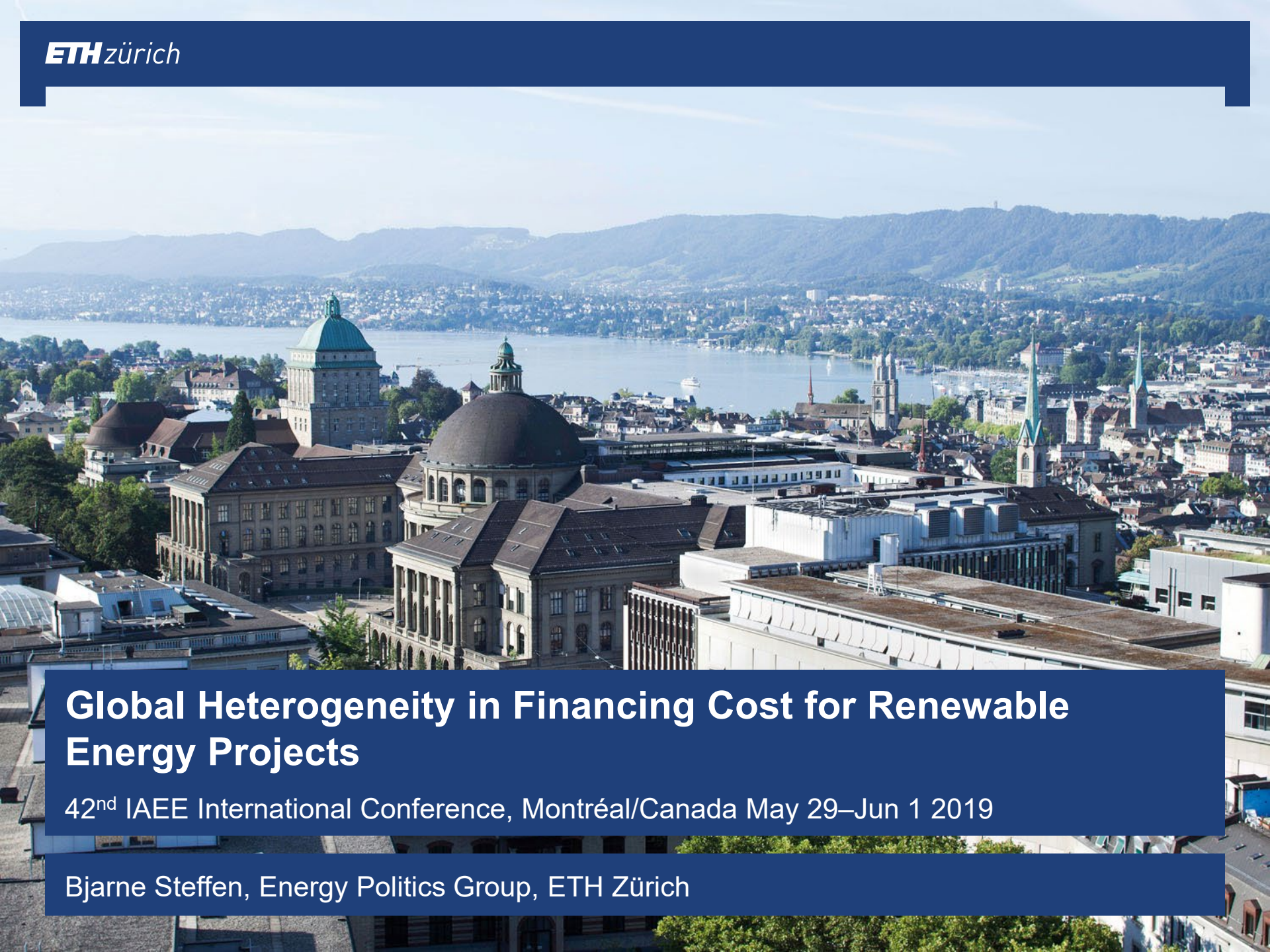

Global Heterogeneity in Financing Cost for Renewable Energy Projects

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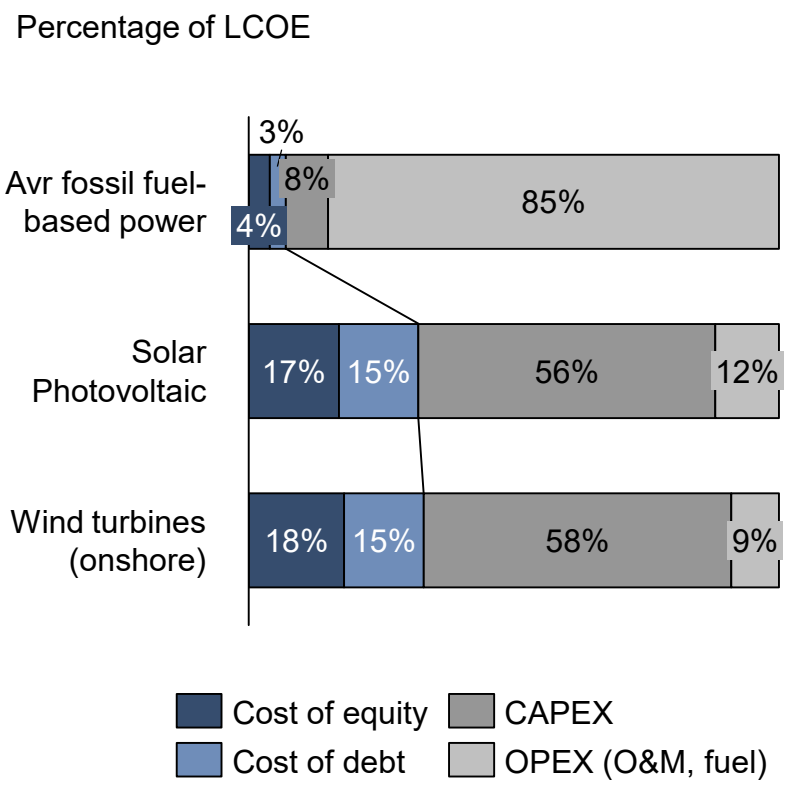
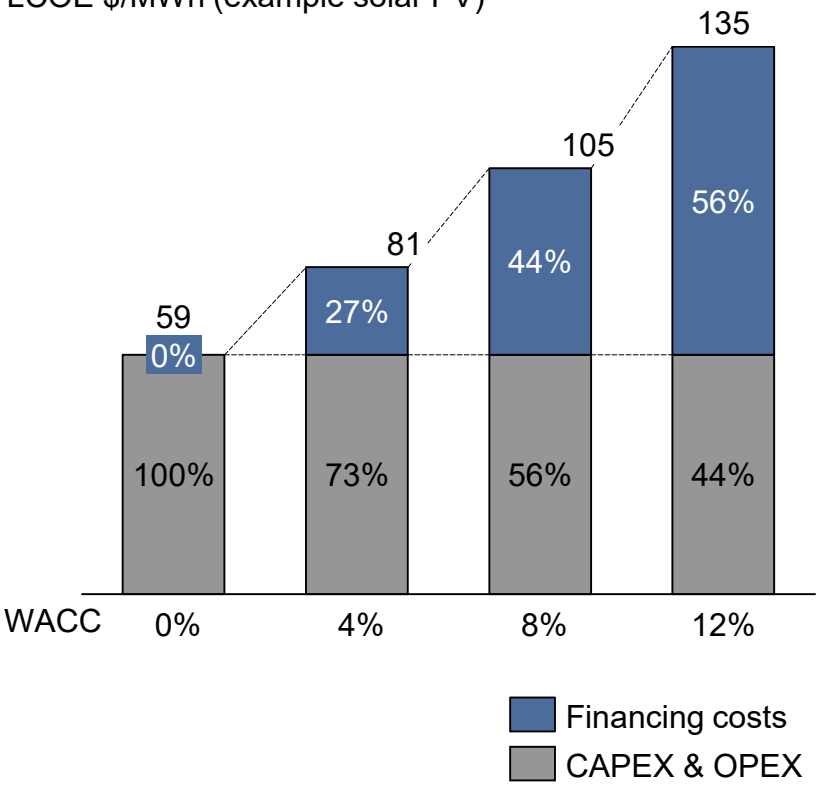
Agenda

For renewables, cost of capital a key driver of levelized cost

Renewables w/ high upfront investment…



…hence LCOE are sensitive to WACC



Note: Assumes 5% cost of debt, 10% cost of equity, European fuel costs. Fossil fuel based is the average of hard coal, natural gas and diesel. Based on Schmidt, T.S. (2014). Low-carbon investment risks and de-risking. *Nat. Clim. Chang.* 4, 237–239; Steffen, B., 2018. The importance of project finance for renewable energy projects. *Energy Economics* 69, 280–294.

Meta-analysis taking stock of estimation methods and results

- Many wind & solar PV plants are project-financed, so WACC is project-specific
- Hence, technology choices are highly sensitive to WACC (or discount rates)
- Great differences in private cost of capital are empirically observed
- Issue: Suitable data on WACC cost is hardly available for researchers
- Recently, research emerged estimating WACC – but great variety of measures and methodologies, consistent picture of state of the knowledge is missing

Here, systematic meta-analysis, answering two questions:

1. Which methods are appropriate for estimating cost of capital for RE projects?
2. What is the state of the empirical knowledge?

Characteristics of WACC for renewable energy

Measures of cost of capital

Vanilla WACC

$$WACC_{vanilla} = \delta\, C_d + (1-\delta) C_e$$

After-tax WACC

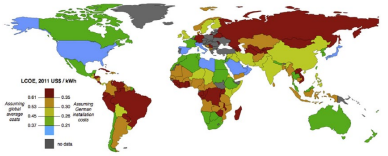
$$WACC_{after-tax} = \delta\,(1-\tau)\, C_d + (1-\delta) C_e$$

Pre-tax WACC

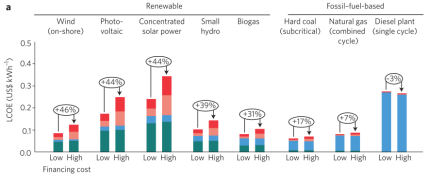
$$WACC_{pre-tax} = \delta\, C_d + (1-\delta)\frac{1}{(1-\tau)} C_e$$

Expected heterogeneity

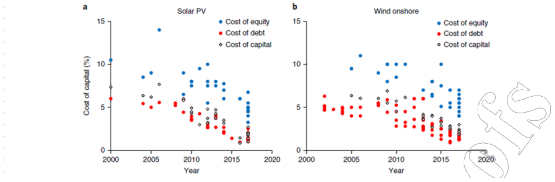
- Between countries



- Between technologies



- Over time



Sources: Schmidt, T.S. (2014). Low-carbon investment risks and de-risking. Nat. Clim. Chang. 4, 237–239; Ondraczek, J., Komendantova, N., Patt, A., 2015. WACC the dog: The effect of financing costs on the levelized cost of solar PV power. Renew. Energy 75, 888–898; Egli, F., Steffen, B., Schmidt, T.S., 2018. A dynamic analysis of financing conditions for renewable energy technologies. Nat. Energy 3, 1084–1092.

Reproducible protocol resulting in 19 peer-reviewed articles

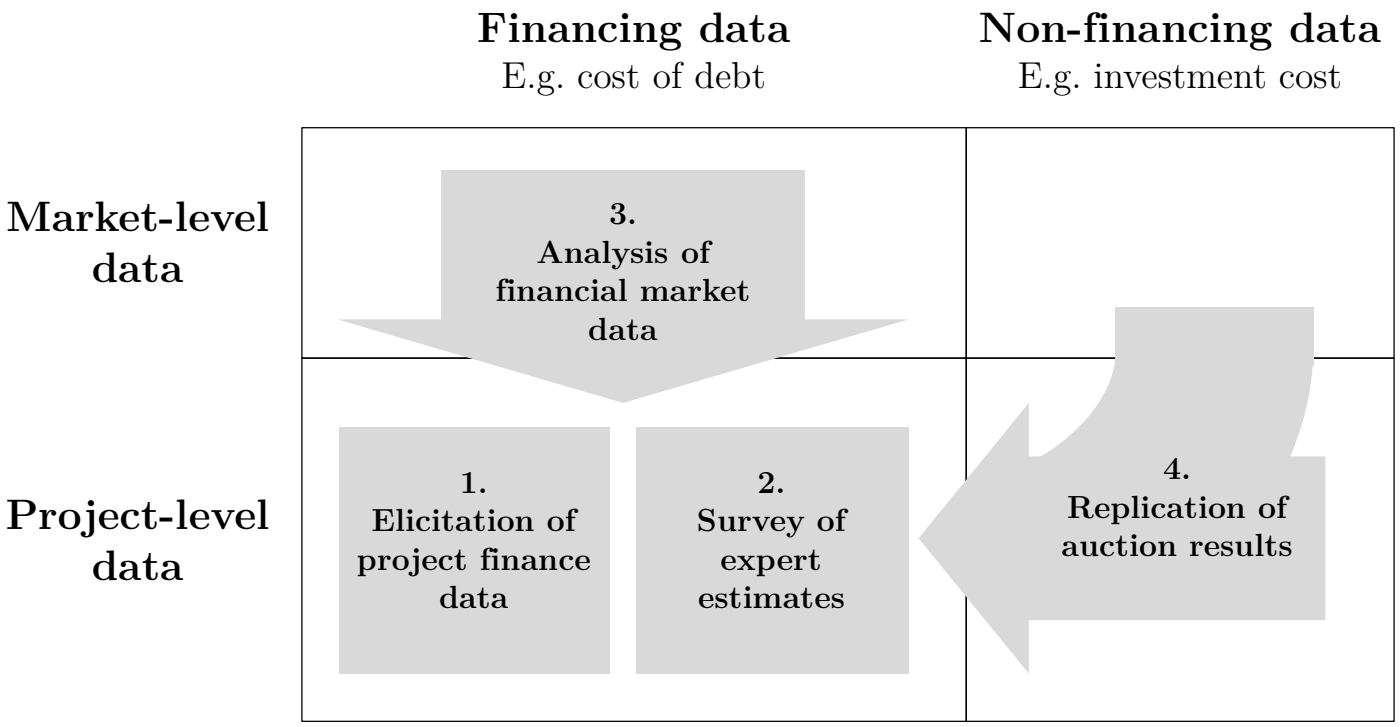
Preliminary

No	Reference	Technologies	Countries	Years	Estimated cost of capital components				Estimation method
					CoD	CoE	DS	WACC	
1	(Angelopoulos et al., 2016)	Onshore wind	26 EU member states	2014	x	x	x	x	Expert interviews, using estimates from financial market data as the starting point for discussion
2	(Angelopoulos et al., 2017)	Solar PV, onshore wind	Greece	2014–2016	x	x	x	x	Same as no. 1
3	(Apostoleris et al., 2018)	Solar PV	Saudi Arabia, United Arab Emirates	2015, 2017	x		x		Analysis/re-engineering of a financial model for winning auction bids, based on archival information
4	(Ardani et al., 2013b, 2013a)	Solar PV	United States	2012				x	Expert interviews with various market participants (including developers and financiers), and archival information
5	(Dobrotkova et al., 2018)	Solar PV	Brazil, Chile, El Salvador, Guatemala, India, Jamaica, Mexico, Peru, South Africa, Uganda, United Arab Emirates, Zambia	2013–2016				x	Analysis/re-engineering of a financial model for winning auction bids, based on archival information and expert interviews
6	(Donovan and Nuñez, 2012)	Other (mix of renewables)	Brazil, China, India	2009		x			Estimates from financial market data, using the CAPM adjusted for downside beta characteristics in emerging markets
7	(Egli et al., 2018)	Solar PV, onshore wind	Germany	2000–2017	x	x	x	x	Elicitation of cost of capital components of 133 projects from financial institutions (banks and investors)
8	(Estache and Steichen, 2015)	Solar PV, offshore wind, onshore wind, other (biomass)	Belgium	2012				x	Estimates from financial market data using the CAPM
9	(Kitzing and Weber, 2015)	Offshore wind	Germany	2014	x	x	x	x	Estimates from financial market data, and archival information
10	(Krupa and Harvey, 2017)	Other (mix of renewables)	United States	2016	x	x			Expert interviews and archival information
11	(Kumar et al., 2017)	Solar PV, onshore wind, other (biomass)	Cambodia, China, India, Malaysia, Thailand, Vietnam	2016	x		x	x	Expert interviews with one country expert for each country, and archival information
12	(Lorenzoni and Bano, 2009)	Solar PV, onshore wind, other (hydro)	Italy	2007	x	x		x	Elicitation of cost of capital components of unspecified project-financed plants from financial institutions.
13	(Partridge, 2018)	Onshore wind, other (coal, gas)	Denmark, India, United States	2015, 2017	x	x		x	Estimates from financial market data
14	(Shrimali et al., 2013)	Solar PV, onshore wind	India	2010–2011	x	x	x		Elicitation of cost of capital components from developers of specified projects, re-engineering of debt share
15	(Szabó et al., 2010)	Solar PV, onshore wind, other (bioenergy)	Generic EU/United States	unclear				x	Expert interviews to judge technology-specific risk adjustments to standard values, archival information
16	(Voormolen et al., 2016)	Offshore wind	Belgium, Denmark, Germany, Netherlands, United Kingdom	2012				x	Expert interviews to judge country-specific risk adjustments, archival information including financial modeling by BNEF
17	(Werner and Scholtens, 2017)	Onshore wind	Germany	2000–2013				x	Estimates from financial market data
18	(Wood and Ross, 2012)	Onshore wind, offshore wind	Denmark, Germany, Netherlands, Spain, Sweden, Switzerland, United States	2008	x	x	x	x	Compilation from national authorities as part of International Energy Agency (IEA) task, drawing on elicitation of financial details of specified actual projects, or expert interviews

Note: CoD = cost of debt, CoE = cost of equity, DS = debt share, WACC = weighted average cost of capital

Source: Steffen, B., 2019. Estimating the Cost of Capital for Renewable Energy Projects, SSRN . https://doi.org/10.2139/ssrn.3373905

Methods for WACC estimation follow 4 distinct approaches



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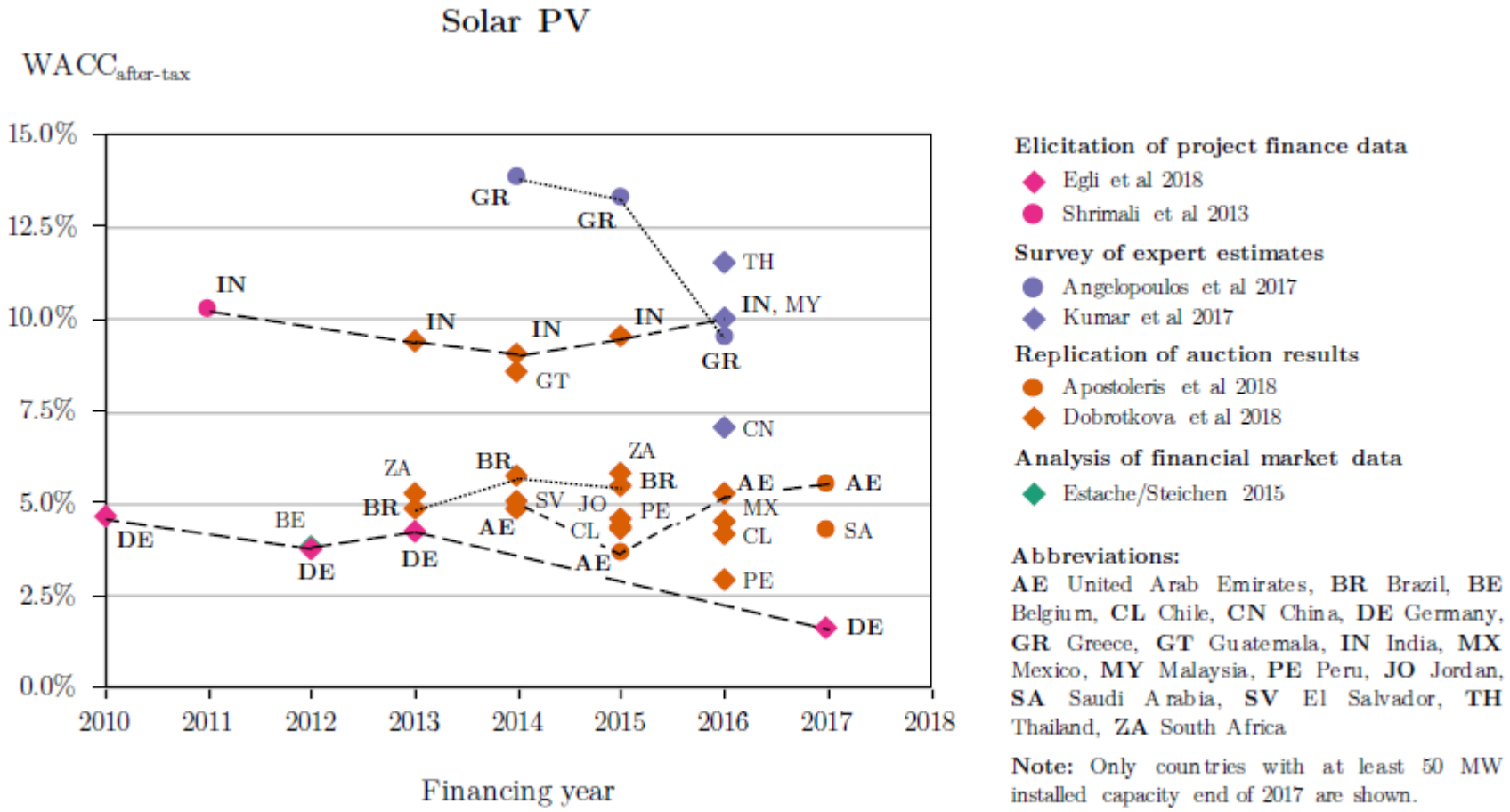
Overview estimates of the WACC for solar PV projects

Preliminary



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Overview estimates of the WACC for onshore wind projects

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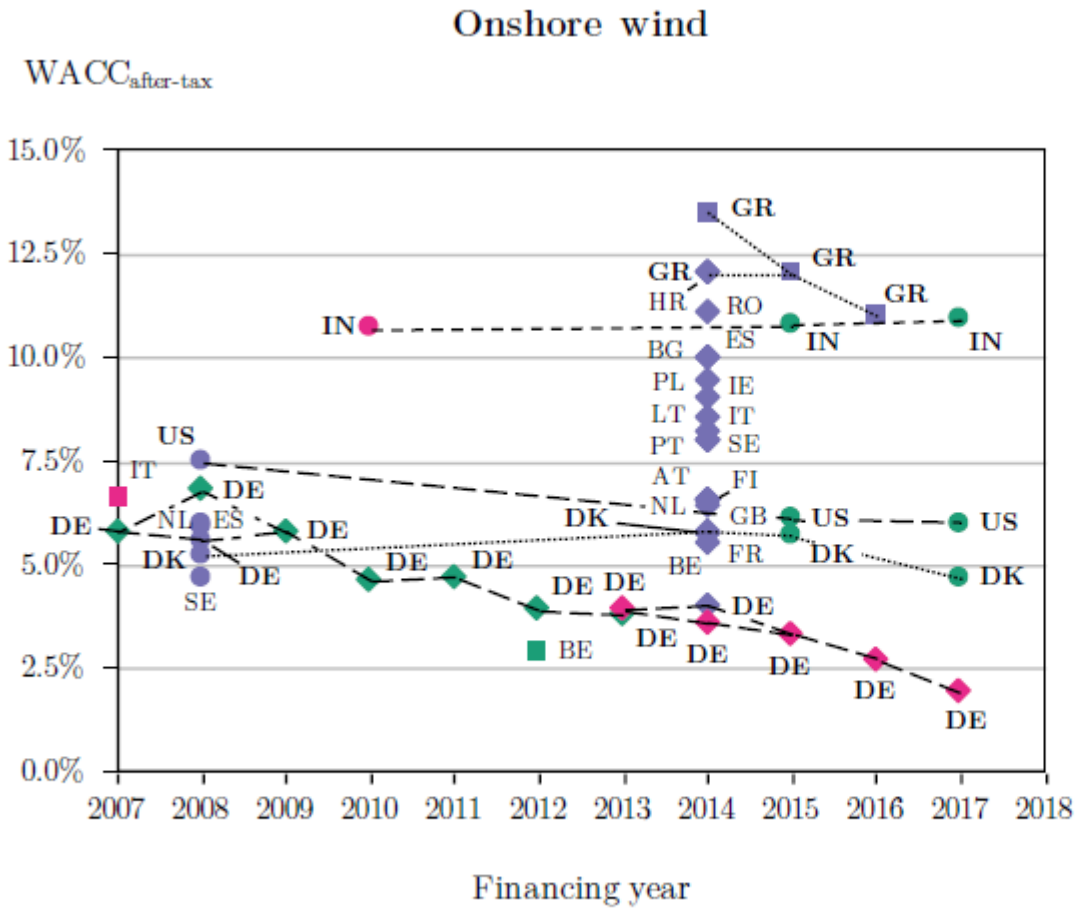

Elicitation of project finance data
- Egli et al 2018
- Lorenzoni/Bano 2009
- Shrimali et al 2013

Survey of expert estimates
- Angelopoulos et al 2016
- Angelopoulos et al 2017
- Wood/Ross 2012

Analysis of financial market data
- Estache/Steichen 2015
- Partridge 2018
- Werner/Scholtens 2016

Abbreviations:
AT Austria, **BG** Bulgaria, **BR** Brazil, **BE** Belgium, **DE** Germany, **DK** Denmark, **ES** Spain, **FI** Finland, **FR** France, **GB** United Kingdom, **GR** Greece, **HR** Croatia, **IE** Ireland, **IN** India, **IT** Italy, **LT** Lithuania, **NL** Netherlands, **PL** Poland, **PT** Portugal, **RO** Romania, **SE** Sweden, **US** United States

Note: Only countries with at least 50 MW installed capacity end of 2017 are shown.

Source: Steffen, B., 2019. Estimating the Cost of Capital for Renewable Energy Projects, SSRN . https://doi.org/10.2139/ssrn.3373905

Overview estimates of the WACC for offshore wind projects

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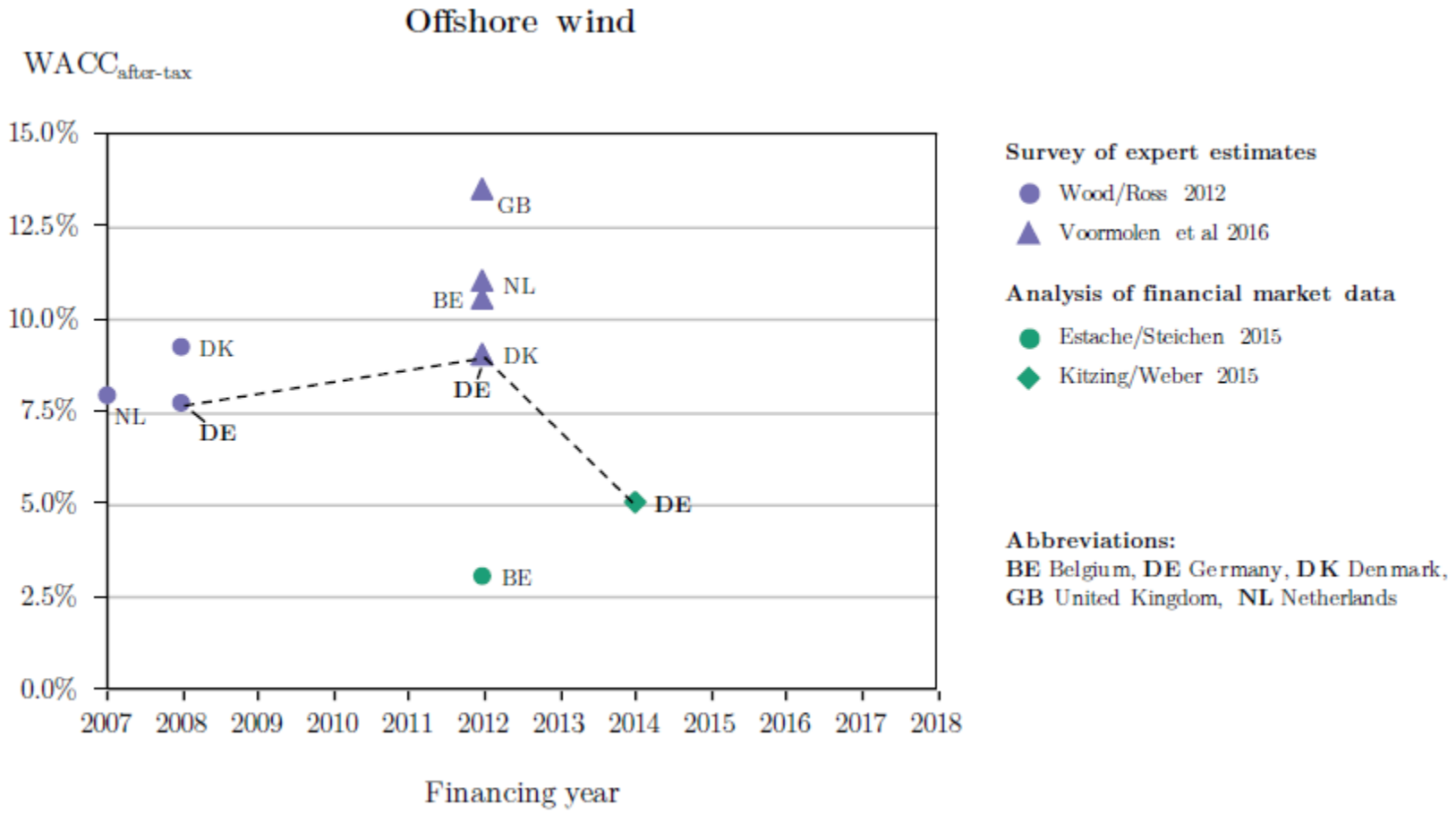

Source: Steffen, B., 2019. Estimating the Cost of Capital for Renewable Energy Projects, SSRN . https://doi.org/10.2139/ssrn.3373905

Patterns over time corrected for general interest rate changes

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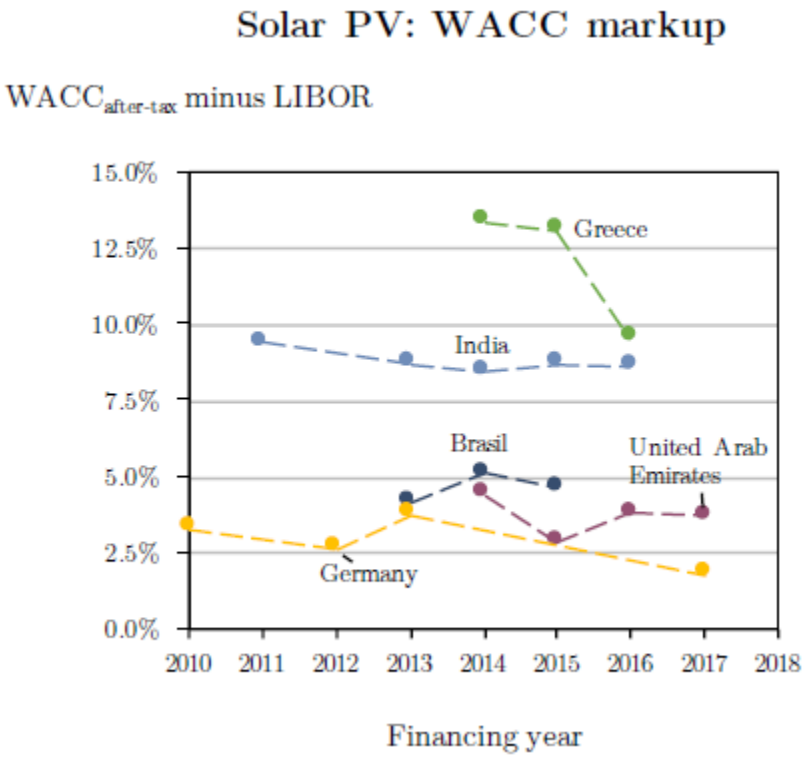

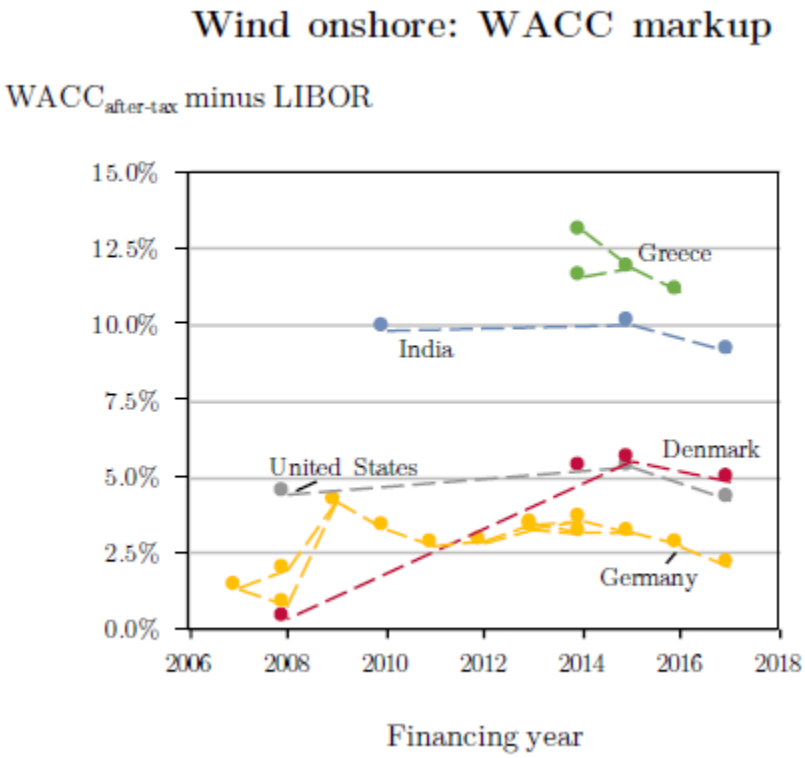

Source: Steffen, B., 2019. Estimating the Cost of Capital for Renewable Energy Projects, SSRN . https://doi.org/10.2139/ssrn.3373905

Average WACC for 2017 interest rate levels

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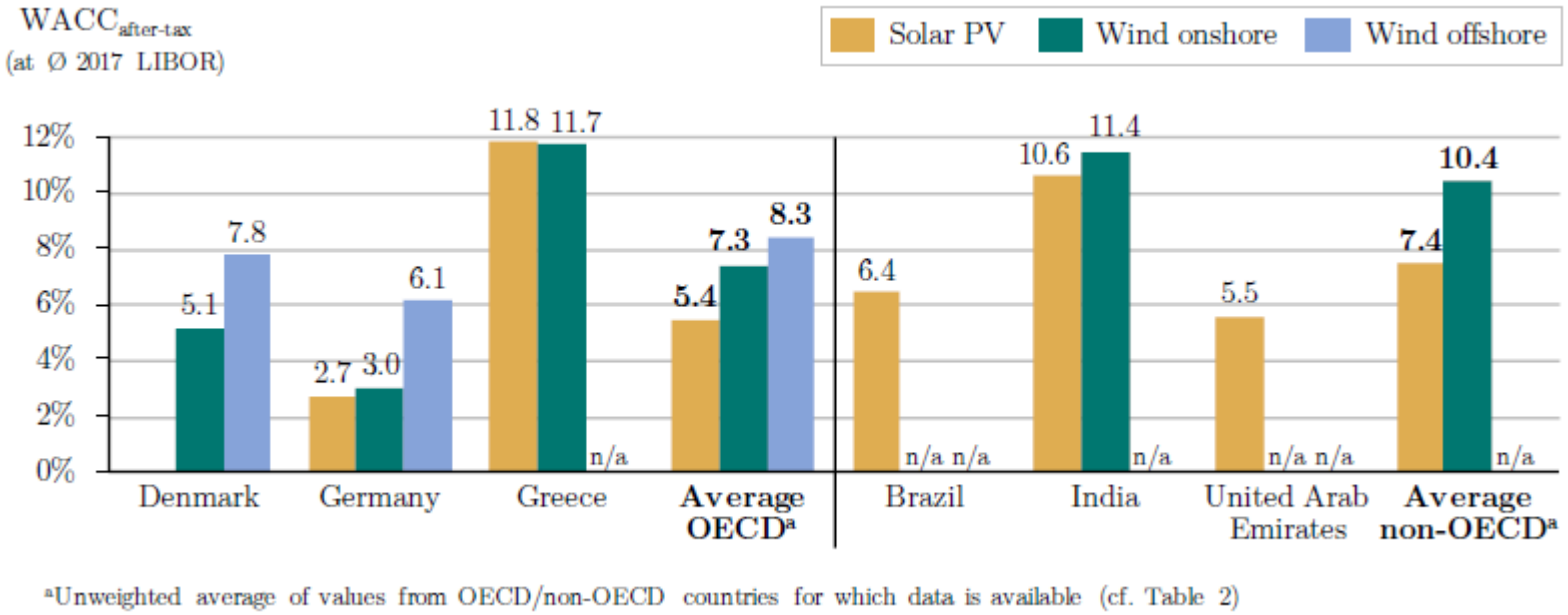

[a]Unweighted average of values from OECD/non-OECD countries for which data is available (cf. Table 2)

Source: Steffen, B., 2019. Estimating the Cost of Capital for Renewable Energy Projects, SSRN . https://doi.org/10.2139/ssrn.3373905

Conclusion

WACC estimates for solar PV and wind in 46 countries available

Large heterogeneity emphasizes necessity to use different WACC assumptions in different contexts

Future research could improve accuracy of estimates, by including all refinements proposed in literature, and by combining different methods

Empirical scope should address new countries (e.g. France, Italy, United States), and also well-studied ones to further assess precision of methods

For policymakers, country differences suggests considering to explicitly address financing costs as part of a renewable energy policy mix

Thank you for your attention!

@BjarneSteffen | @ETH_EPG

Working paper:

Steffen, B., 2019. Estimating the Cost of Capital for Renewable Energy Projects, SSRN . https://doi.org/10.2139/ssrn.3373905

See also:

Egli, F., Steffen, B., Schmidt, T.S., 2018. A dynamic analysis of financing conditions for renewable energy technologies. Nature Energy 3, 1084–1092. https://www.nature.com/articles/s41560-018-0277-y

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

Schmidt, T.S. (2014). Low-carbon investment risks and de-risking. Nature Climate Change 4, 237–239. https://doi.org/10.1038/nclimate2112

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