

Finance in IAMs: How models can inform policymaking

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PRISMA Summer School, Utrecht, 10 Jul 2025



Agenda

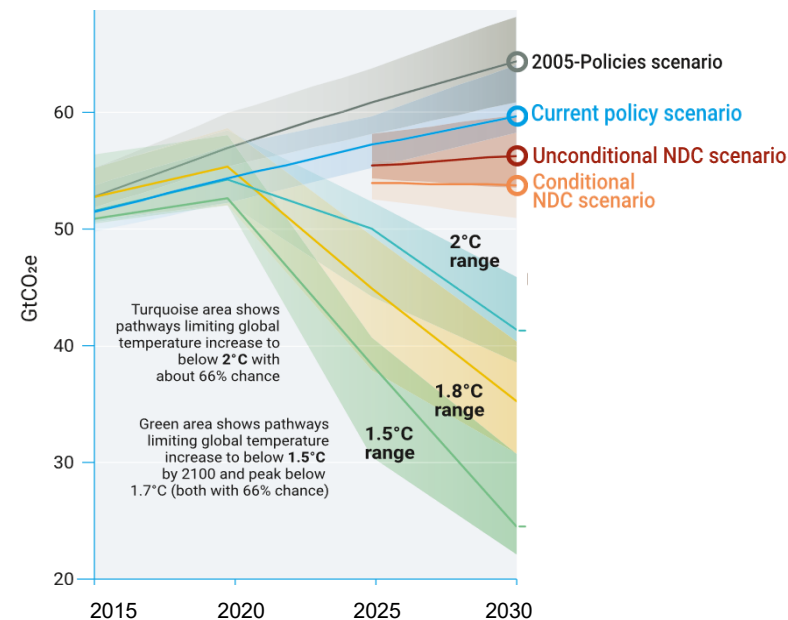
1. Why **finance** matters for the low-carbon transition
2. How the **cost of capital** determines model outcomes
3. Not just a parameter, but a lever: The role of **policymaking**

Why finance matters for the low-carbon transition

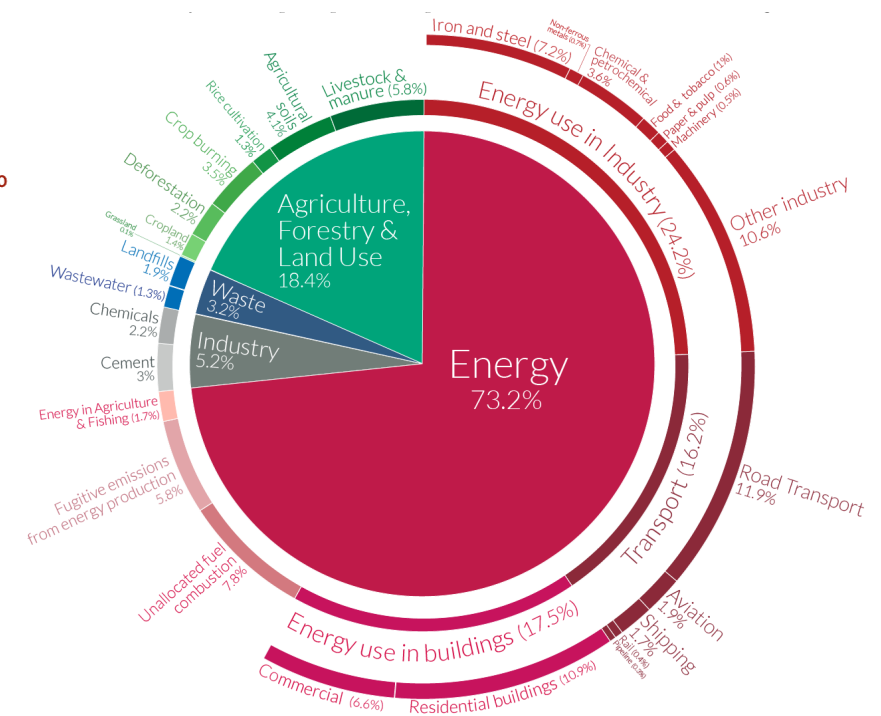
Slowing down climate change requires a totally different energy system



CO₂ emission reductions required to reach global warming targets



Global GHG emissions by sector (2016)



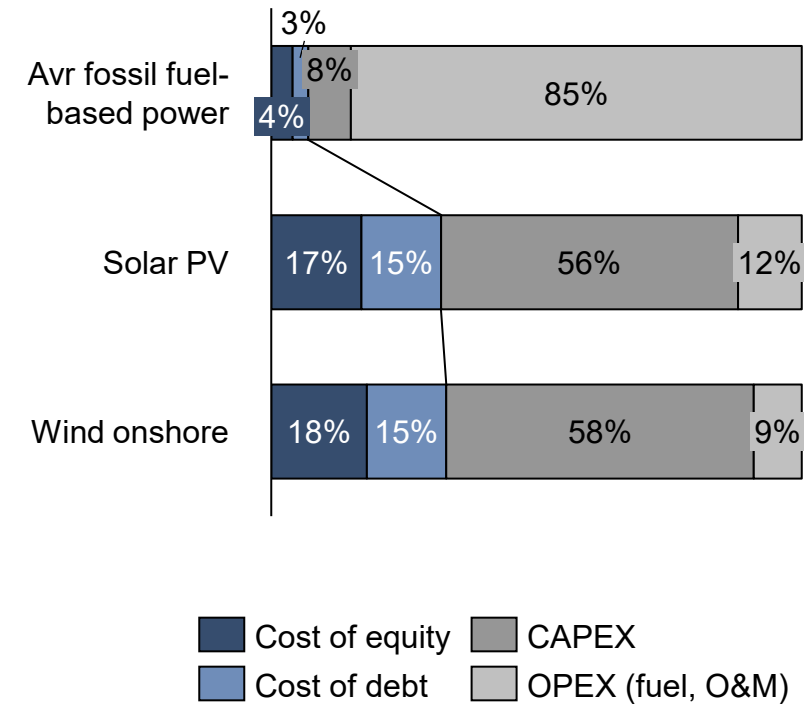
Source (center): UNEP (2020), Emissions Gap Report; (right): Hannah Ritchie, Max Roser and Pablo Rosado (2020) - "CO₂ and Greenhouse Gas Emissions". Published online at OurWorldInData.org

1. Most clean energy technologies are very capital-intensive



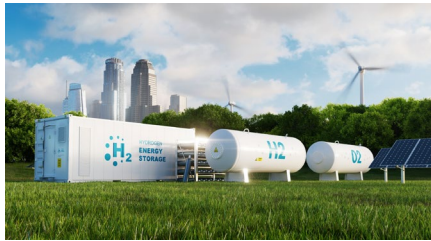
Typical cost split of power gen technologies

Percentage of LCOE¹

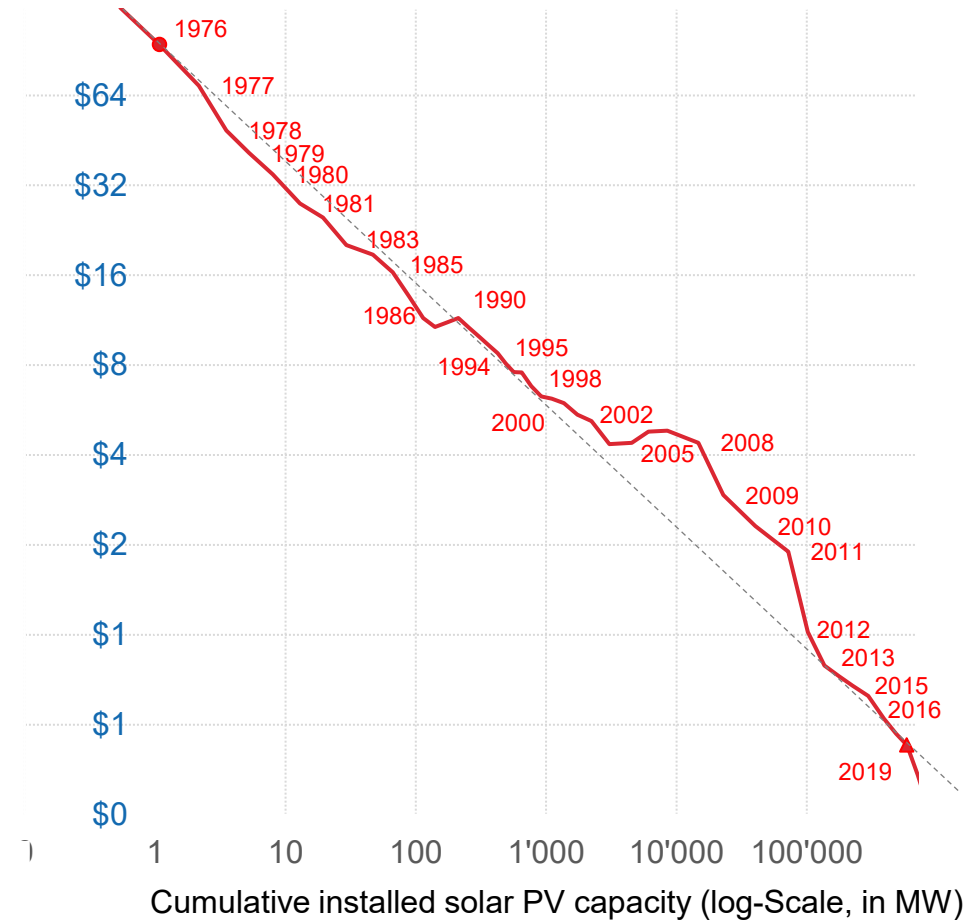


Note: LCOE = Levelized cost of electricity; Fossil fuel based power is the average of hard coal, natural gas, and diesel plants. Source: Steffen, B., Egli, F., Schmidt, T.S. (2020). The Role of Public Banks in Catalyzing Private Renewable Energy Finance. In: Donovan, C.W. (ed.). Renewable Energy Finance- Funding the Future of Energy. World Scientific, 197–215;

2. Novel techs need large investments to buy down the learning curve

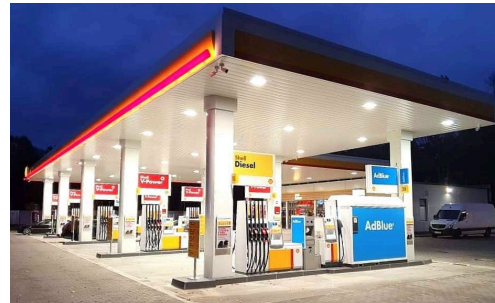


Price per Watt of solar photovoltaics (PV) modules
(log-scale, in 2022 USD)



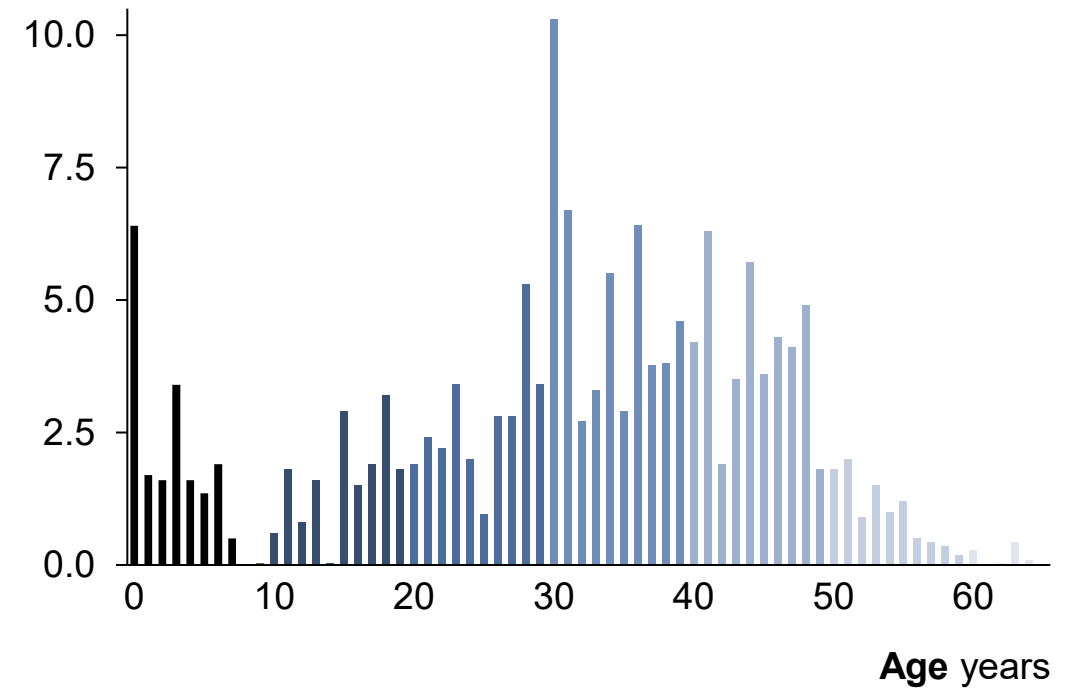
Source: Chart based on Our World in Data, which uses data from International Renewable Energy Agency (2023); Nemet (2009); Farmer and Lafond (2016)

3. Fossil infrastructure needs to be replaced before the end of its lifetime



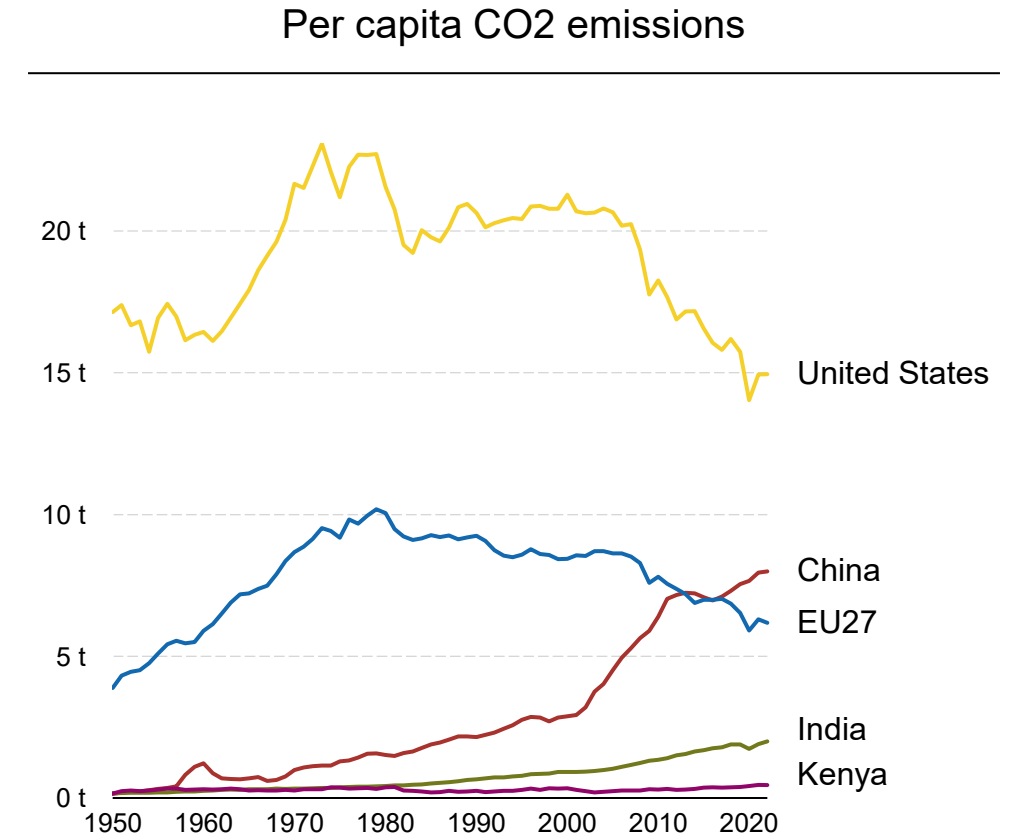
European Union coal power plant unit age

Capacity GW



Source: Own chart based on EU Coal Stress Test, Climate Analytics, www.carbonbrief.org/mapped-eu-coal-plants-should-all-close-by-2030/. Figures as of 2017

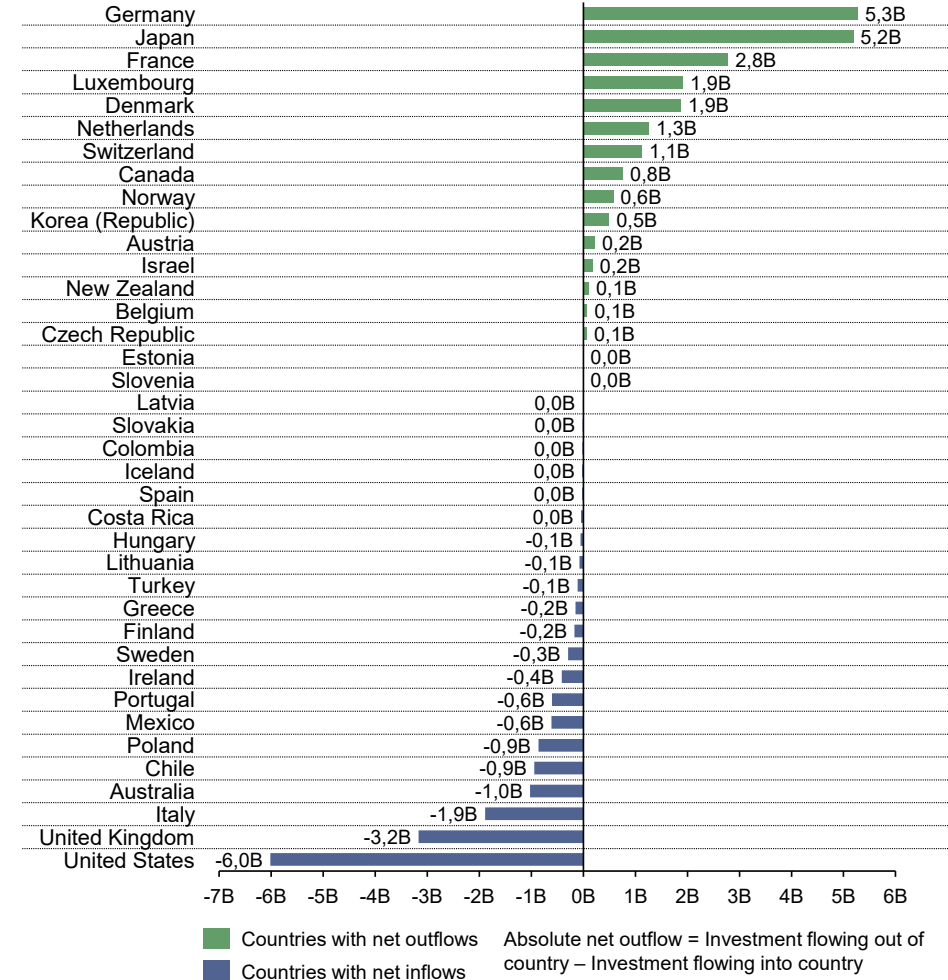
4. Major international dimensions: **global equity**, re-ordering trade



Source: Based on Ritchie, Rosado and Roser (2023), <https://ourworldindata.org/co2-and-greenhouse-gas-emissions>. Carbon dioxide (CO2) emissions from fossil fuels and industry. Land-use change is not included.

4. Major international dimensions: global equity, re-ordering trade

Annual RE investment flows per OECD country (2004-22)



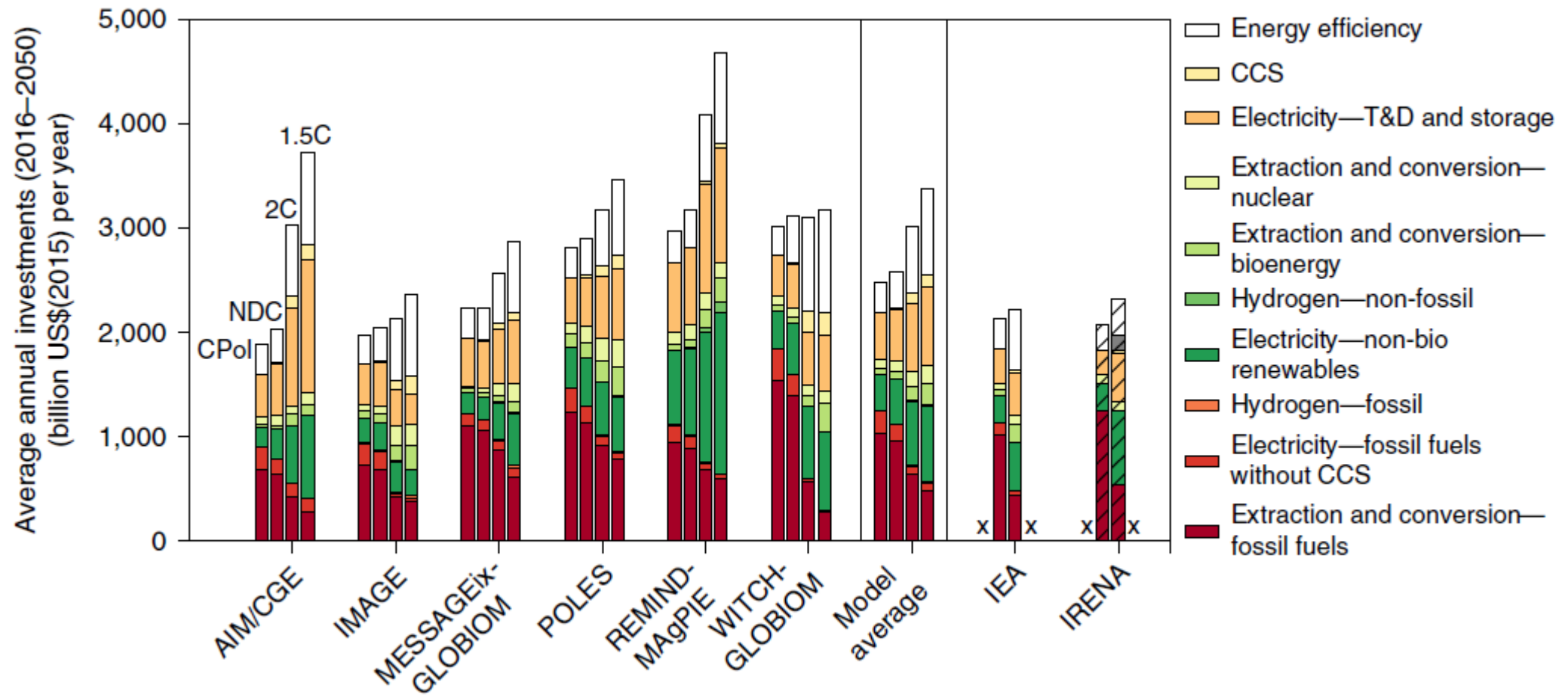
Source: Eberhart S, Schmidt TS, Steffen B, Egli F (2025), The internationalization of global renewable energy finance, *iScience* 28, 5112367.

Implication I: Financing needs are immense – how big exactly?



Picture generated with Dall-E

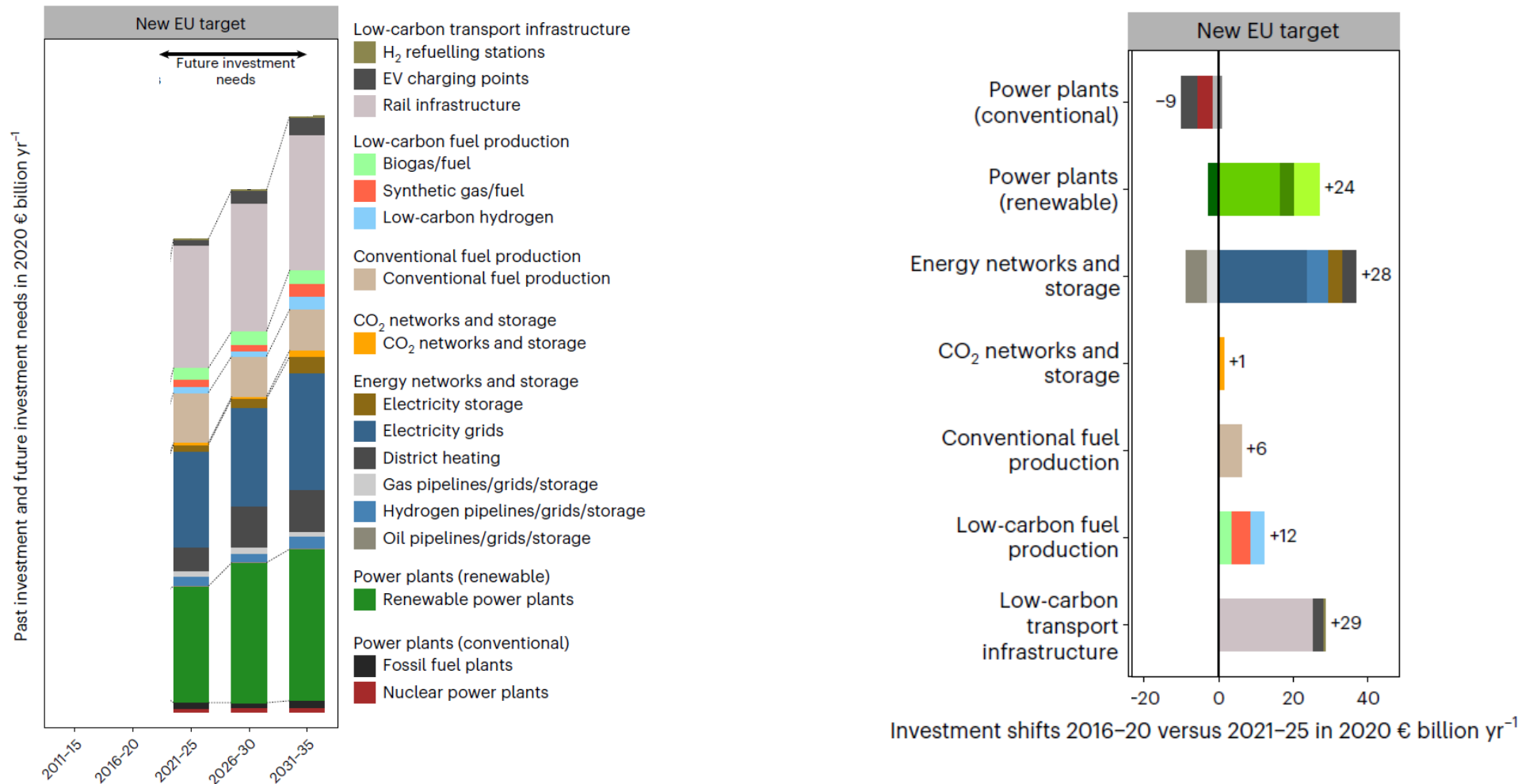
Model-based analysis allows to compare scenarios



Source: McCollum, David L., et al. "Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals." Nature Energy 3.7 (2018): 589-599.

To answer policymakers' questions, sometimes further steps needed

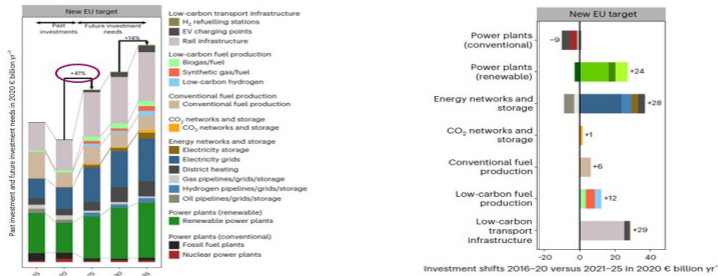
Putting into context: What *changes* are needed



Source: Klaaßen, L., & Steffen, B. (2023). Meta-analysis on necessary investment shifts to reach net zero pathways in Europe. *Nature Climate Change*, 1-9.

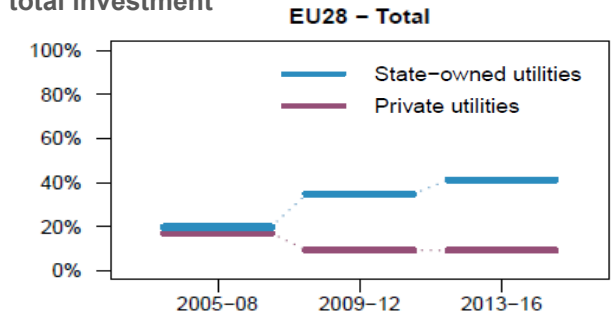
To answer policymakers' questions, sometimes further steps needed

Putting into context: What *changes* are needed?

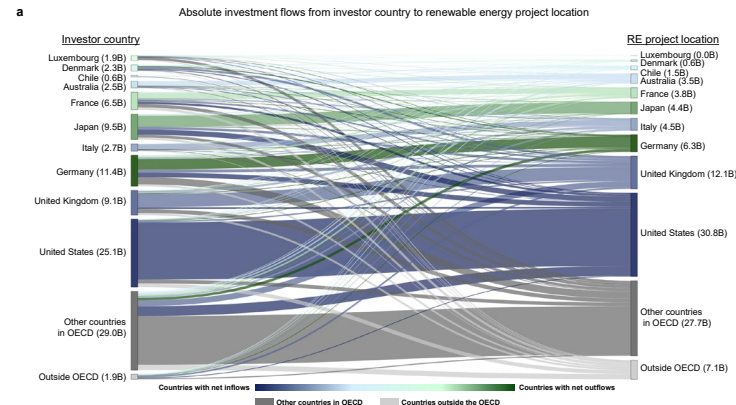


Public or private finance needed?

Share of renewables
in total investment

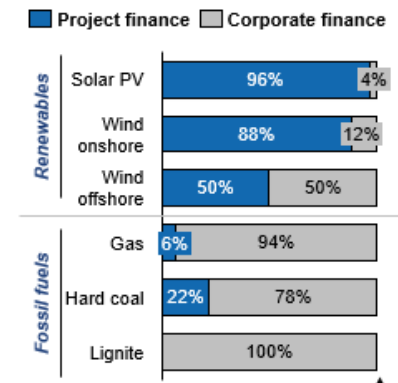


Changes to international capital flows?



Which type of private finance?

Financing structures of power plants
Germany, 2010–2015



Sources : Klaaßen, L., & Steffen, B. (2023). Meta-analysis on necessary investment shifts to reach net zero pathways in Europe. *Nature Climate Change*, 1-9. Steffen, B., Karplus, V., & Schmidt, T. S. (2022). State ownership and technology adoption: The case of electric utilities and renewable energy. *Research Policy*, 51(6), 104534. Eberhart S, Schmidt TS, Steffen B, Egli F (2025), The internationalization of global renewable energy finance, *iScience* 28, 5112367. Steffen, B. (2018), The importance of project finance for renewable energy projects, *Energy Economics* (69), 280–294.

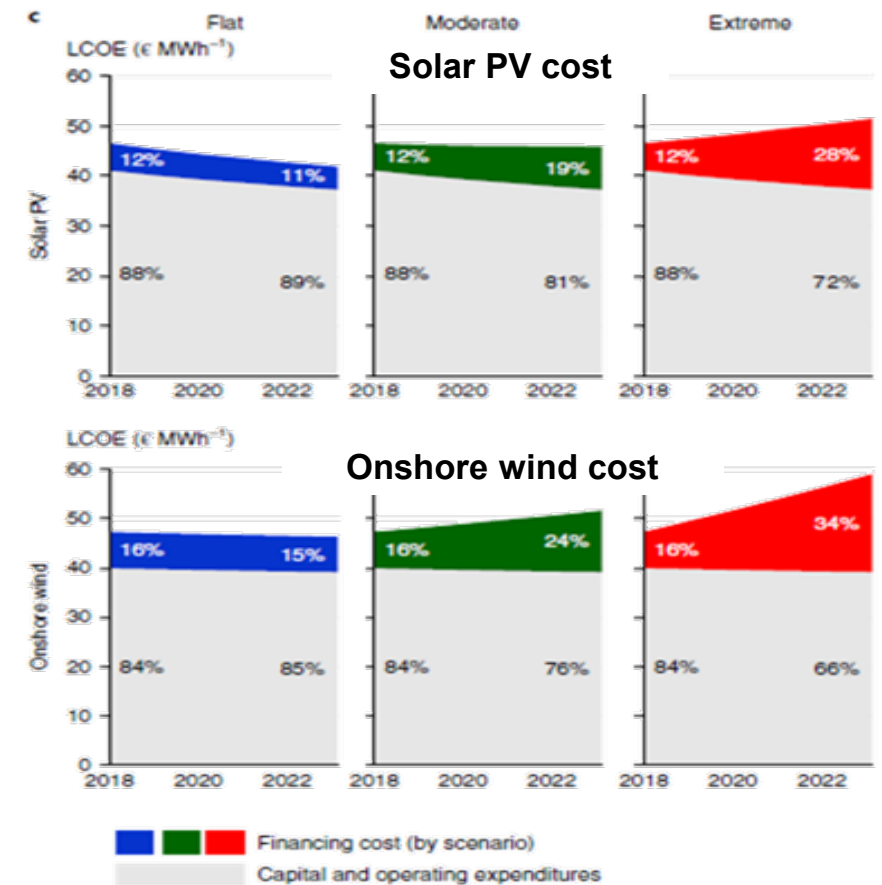
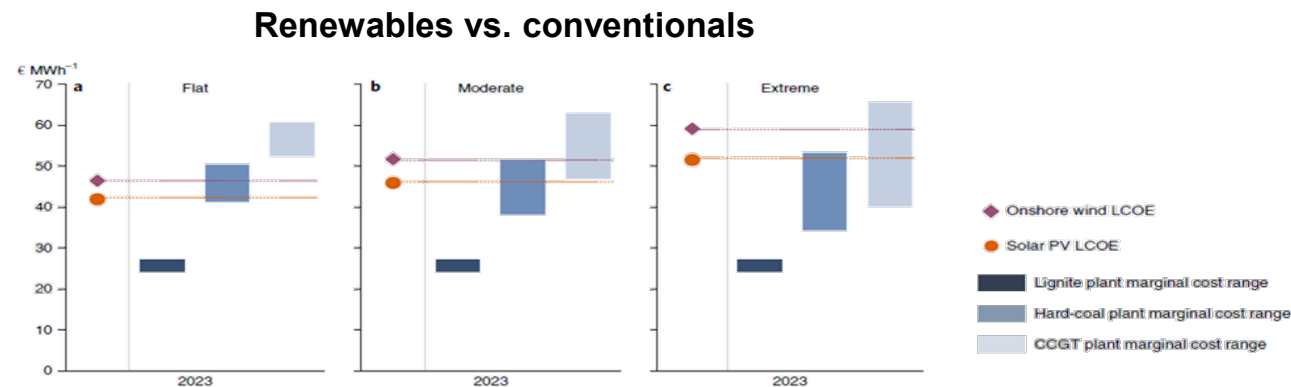
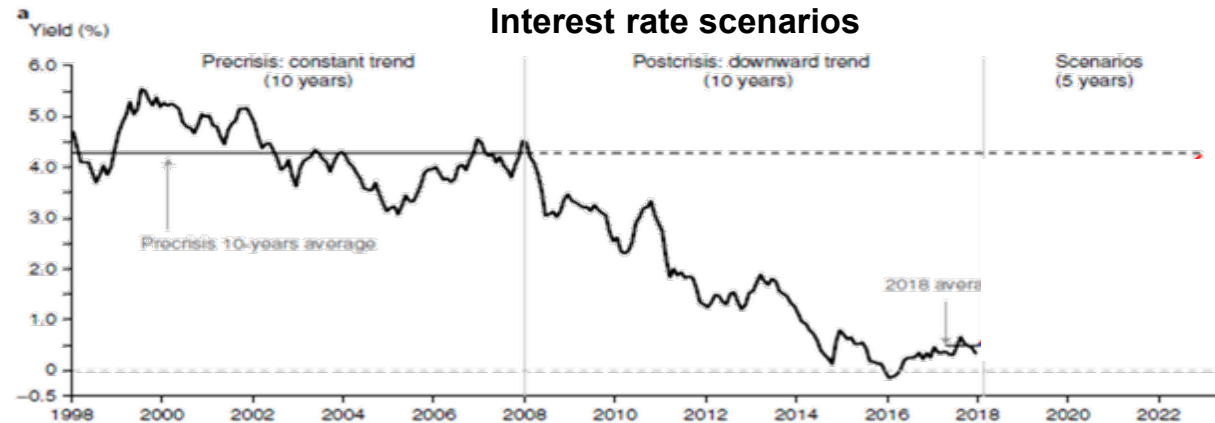
Implication II: The cost of capital is crucial – how?



Picture generated with Dall-E

How the cost of capital determines model outcomes

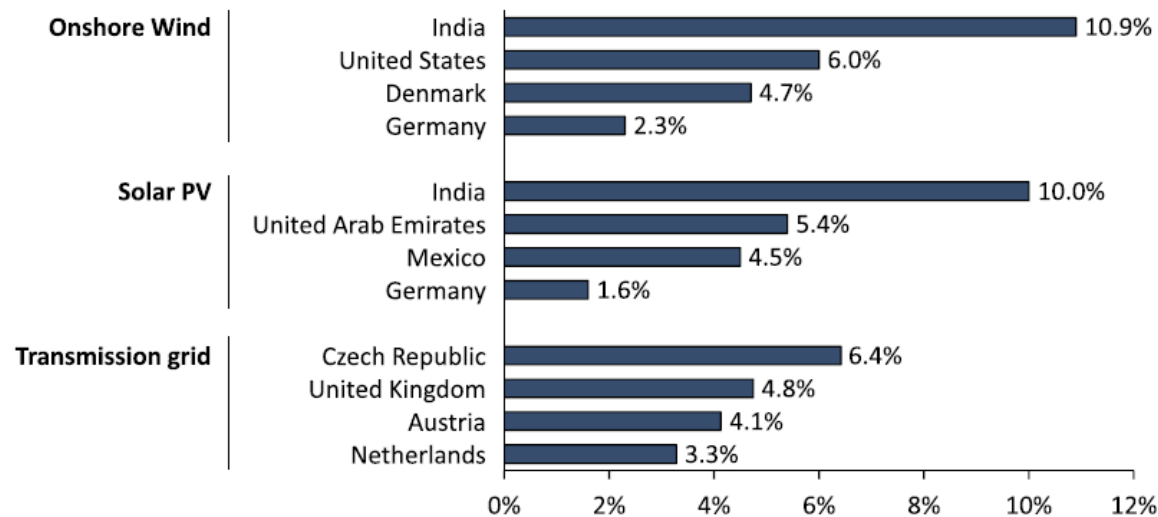
With changing interest rate levels, CoC change over time



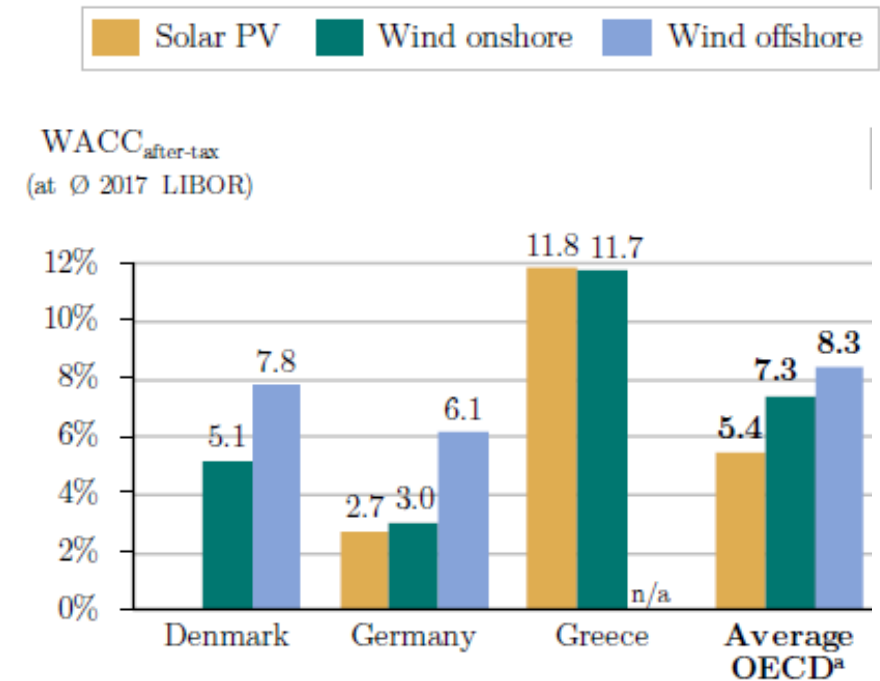
Source: Schmidt TS, B. Steffen, F. Egli, M. Pahle, O. Tietjen, and O. Edenhofer, "Adverse effects of rising interest rates on sustainable energy transitions," *Nature Sustainability*, vol. 2, pp. 879–885, 2019.

CoC differs not just over time, but also by country and technology

Cost of capital by technology (Estimates for nominal $WACC_{after-tax}$ in 2016/2017)

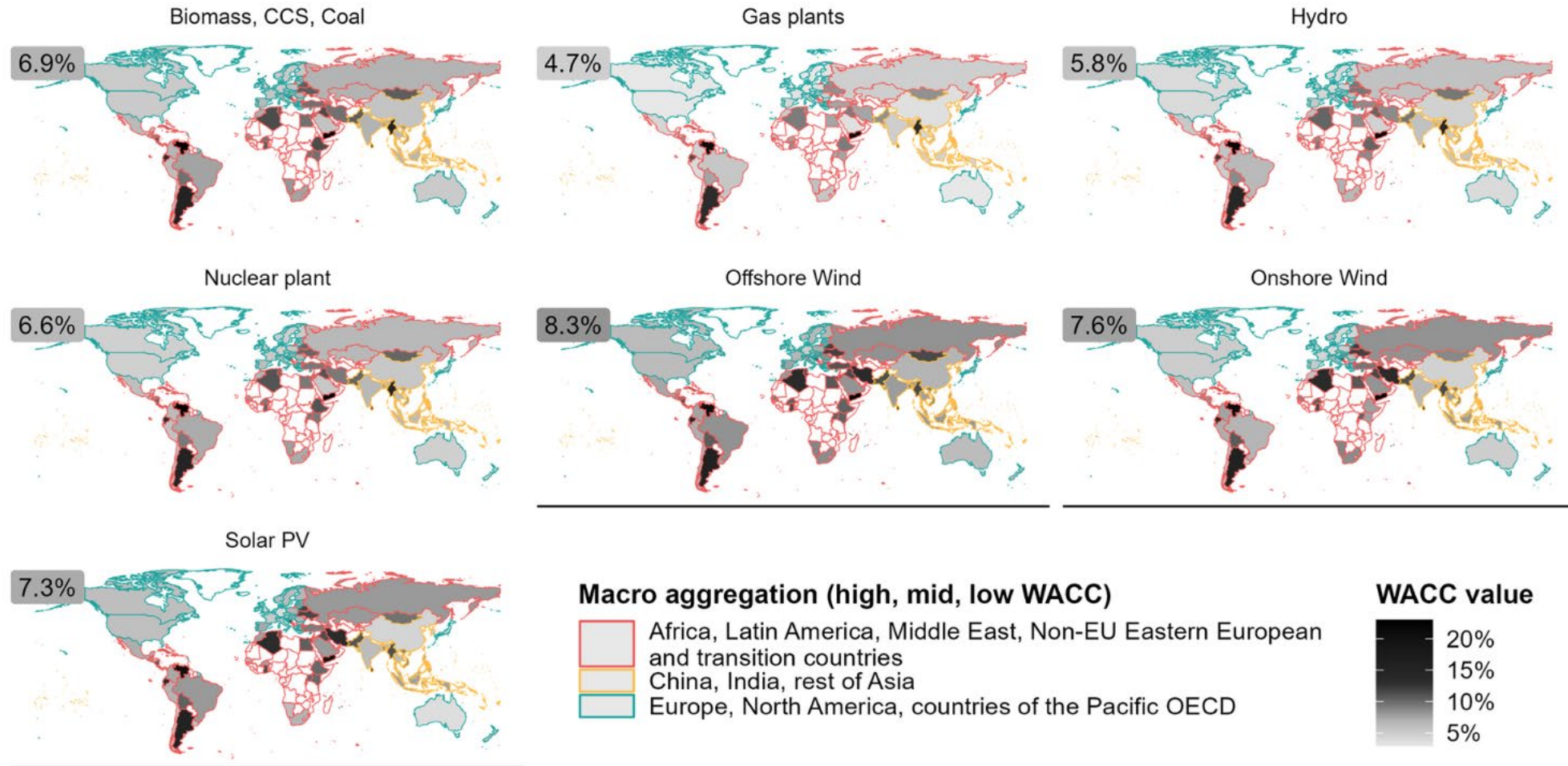


Meta analysis of after-tax WACC per country



Sources: Steffen, B., & Waidelich, P. (2022). Determinants of cost of capital in the electricity sector. *Progress in Energy*, 4(3). Steffen, B. (2020). Estimating the cost of capital for renewable energy projects. *Energy Economics*, 88, 104783

CoC differs not just over time, but also by country and technology

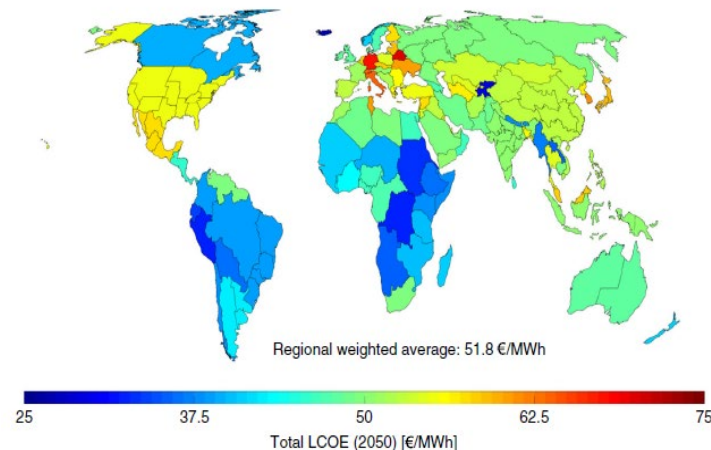


Source: Calcaterra M, et al. (2024), Reducing cost of capital to finance the energy transition in developing countries: a multi-model analysis. *Nature Energy* 9, 1241–1251.

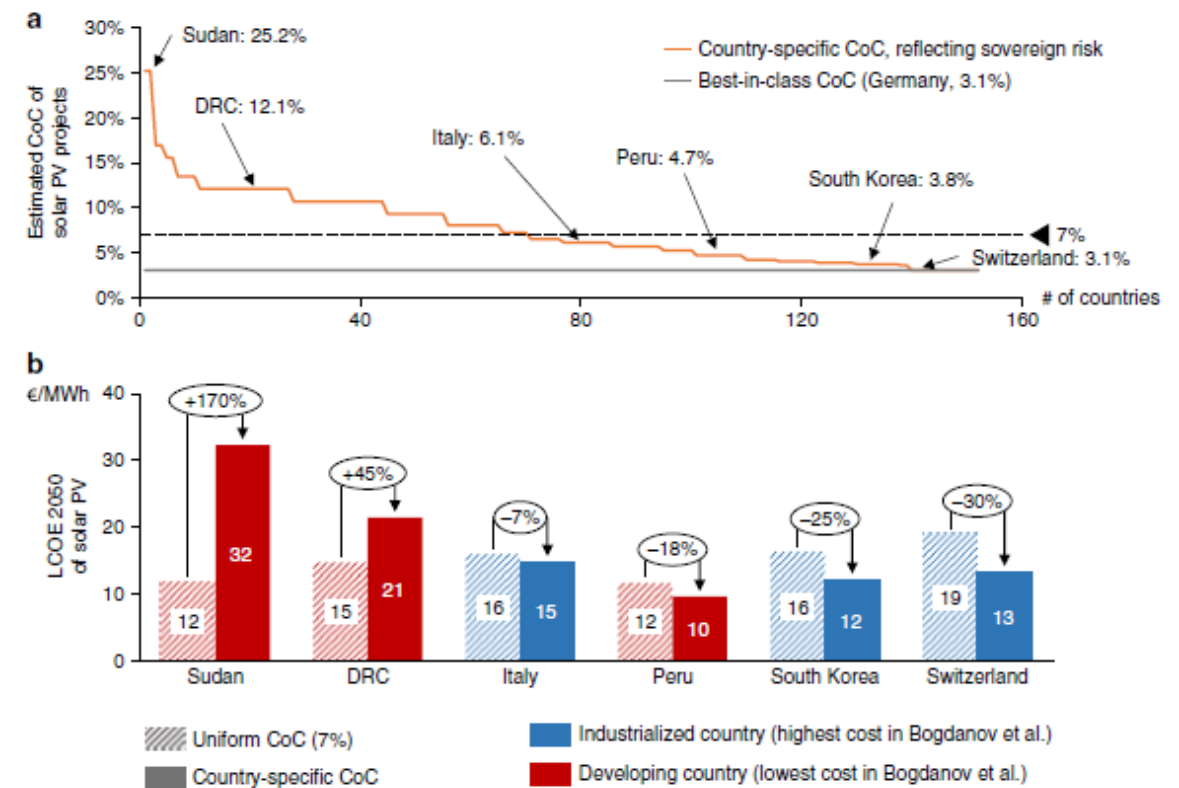
How CoC differences matter (1/3): Example solar PV cost globally

Example: Global RE cost comparison

- Ongoing academic debate on realistic assumptions for global “100% RE” models
- E.g. Bogdanov et al. 2019 showing lowest LCOE in Sudan & DR Kongo

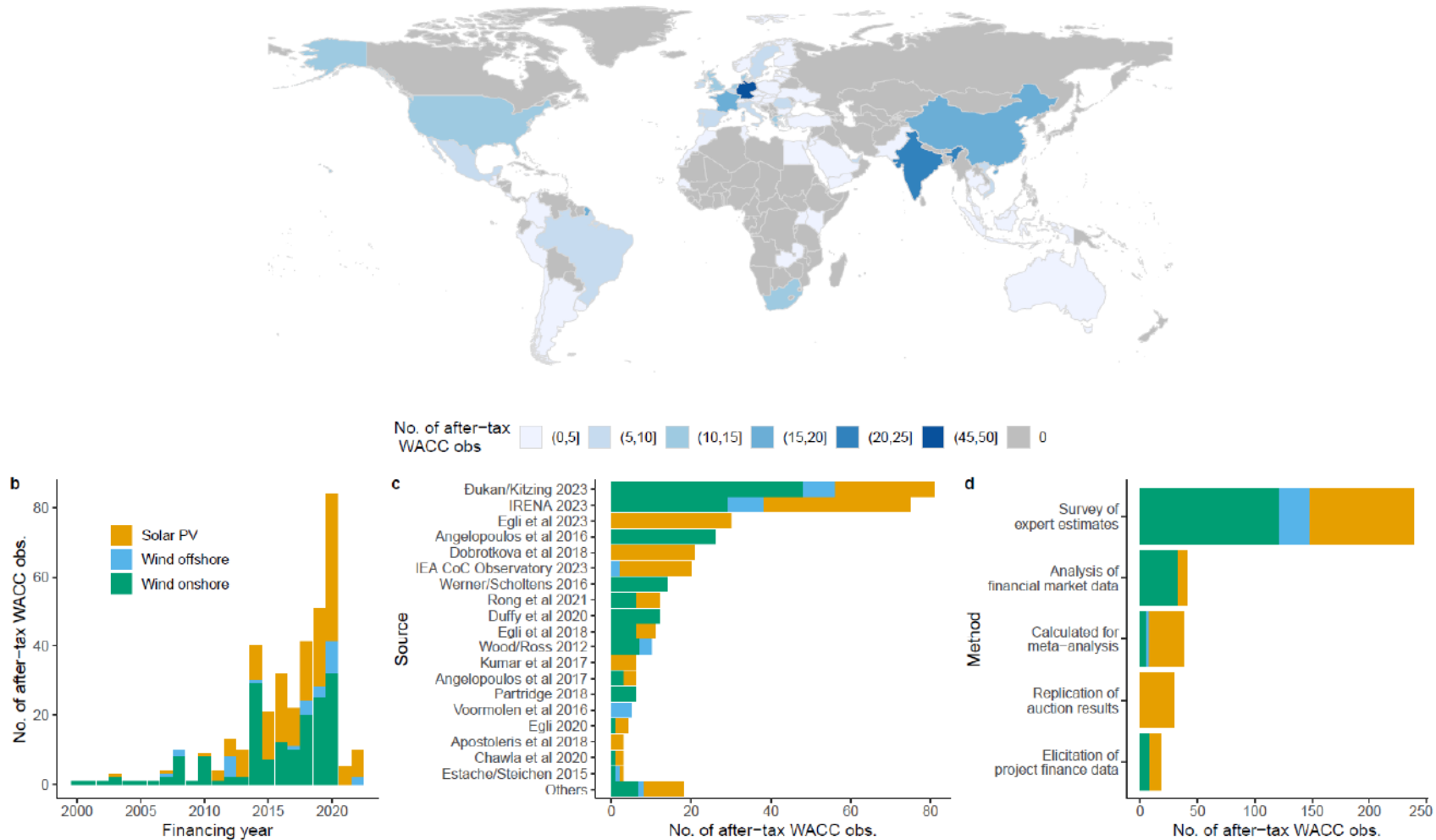


Assuming uniform cost of capital can lead to misleading results



Source (left): D. Bogdanov et al., “Radical transformation pathway towards sustainable electricity via evolutionary steps,” *Nature Communications*, vol. 10, no. 1, p. 1077, 2019.; (right): Egli F, B. Steffen, and T. S. Schmidt, “Bias in energy system models with uniform cost of capital assumption,” *Nature Communications*, vol. 10, pp. 4588–4590, 2019.

Nota bene: CoC data availability for renewables is pretty good now



Source: Steffen B, Egli F, Gumber A, Dukan M, Waidelich P (2025): A global dataset of the cost of capital for renewable energy projects. Mimeo ETH Zurich

How CoC differences matter (2/3): Example electrification



Grid extension

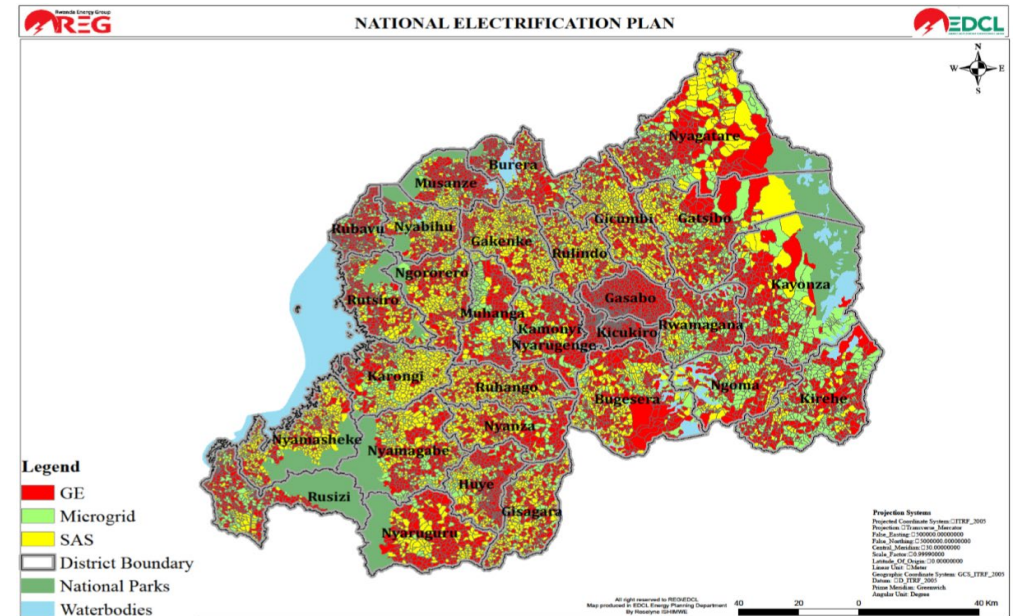


Minigrids



Standalone systems

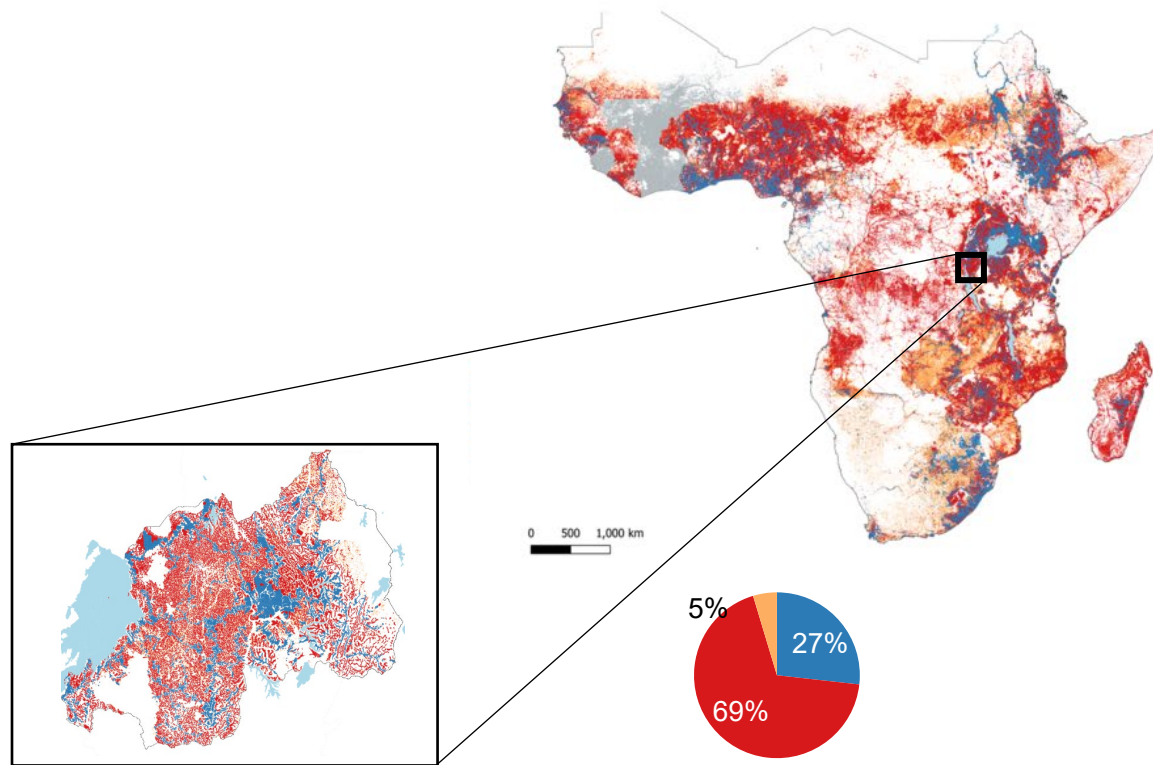
Map showing electrification approaches per village for the Rwanda National Electrification Plan 2019



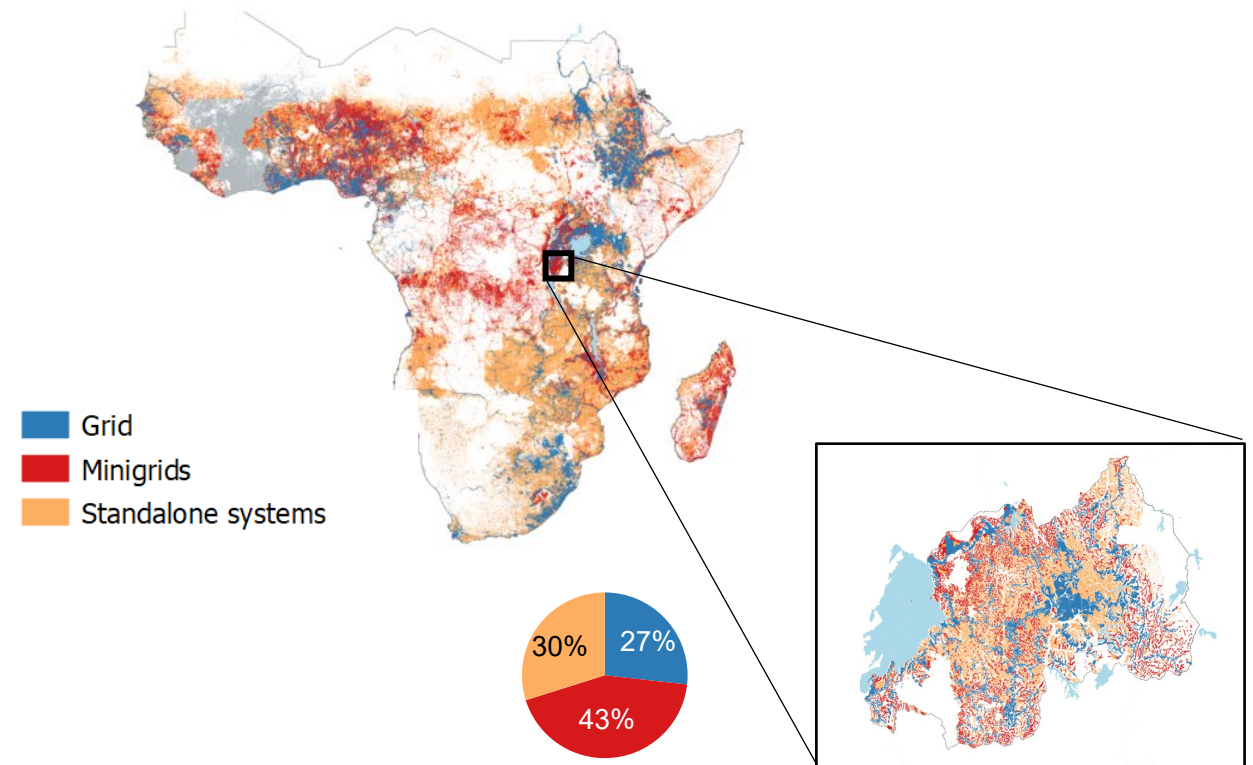
Source: Rwanda Energy Group, 2019

How CoC differences matter (2/3): Example electrification

Baseline scenario
Uniform discount rate

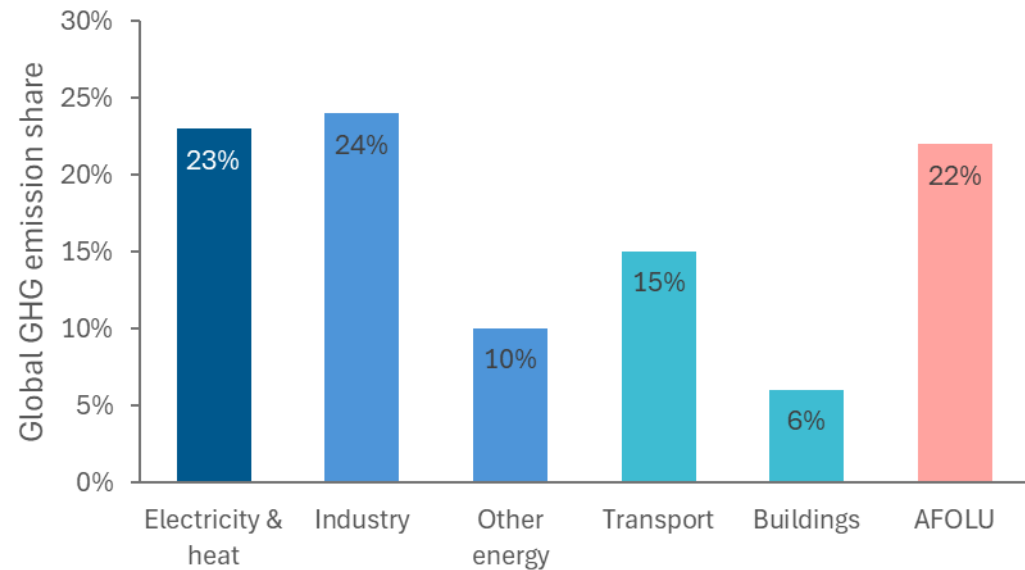
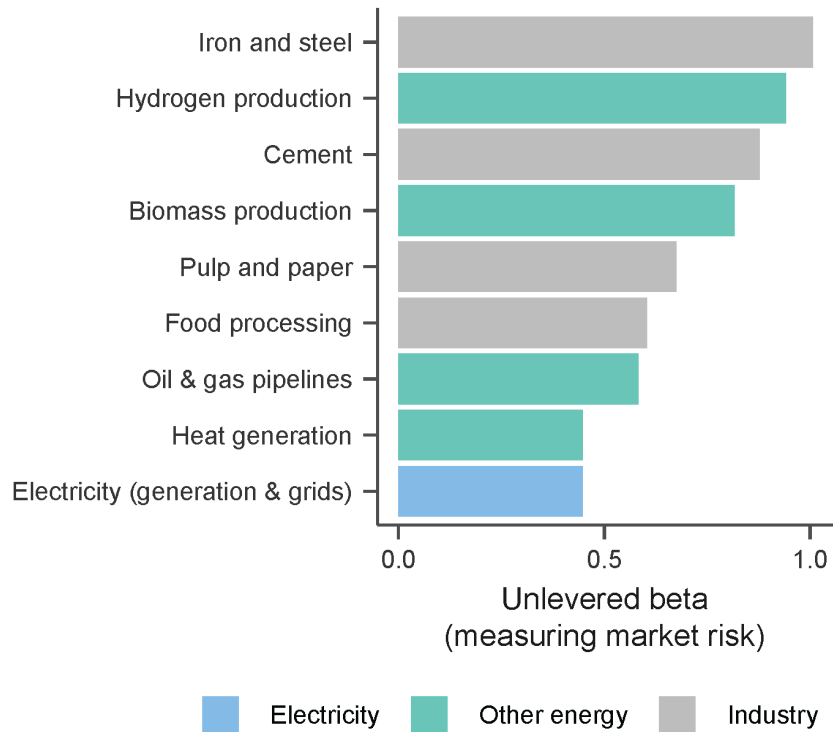


Realistic financing scenario
Reflecting current status of financial market access



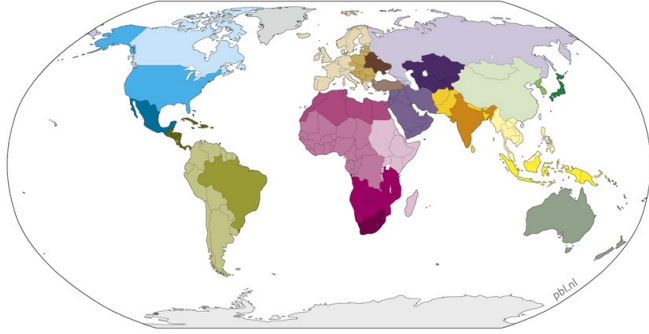
Source: Agutu, C., Egli, F., Williams, N. J., Schmidt, T. S., & Steffen, B. (2022). Accounting for finance in electrification models for sub-Saharan Africa. *Nature Energy*, 1-11.

How CoC differences matter (3/3): Looking beyond power generation?



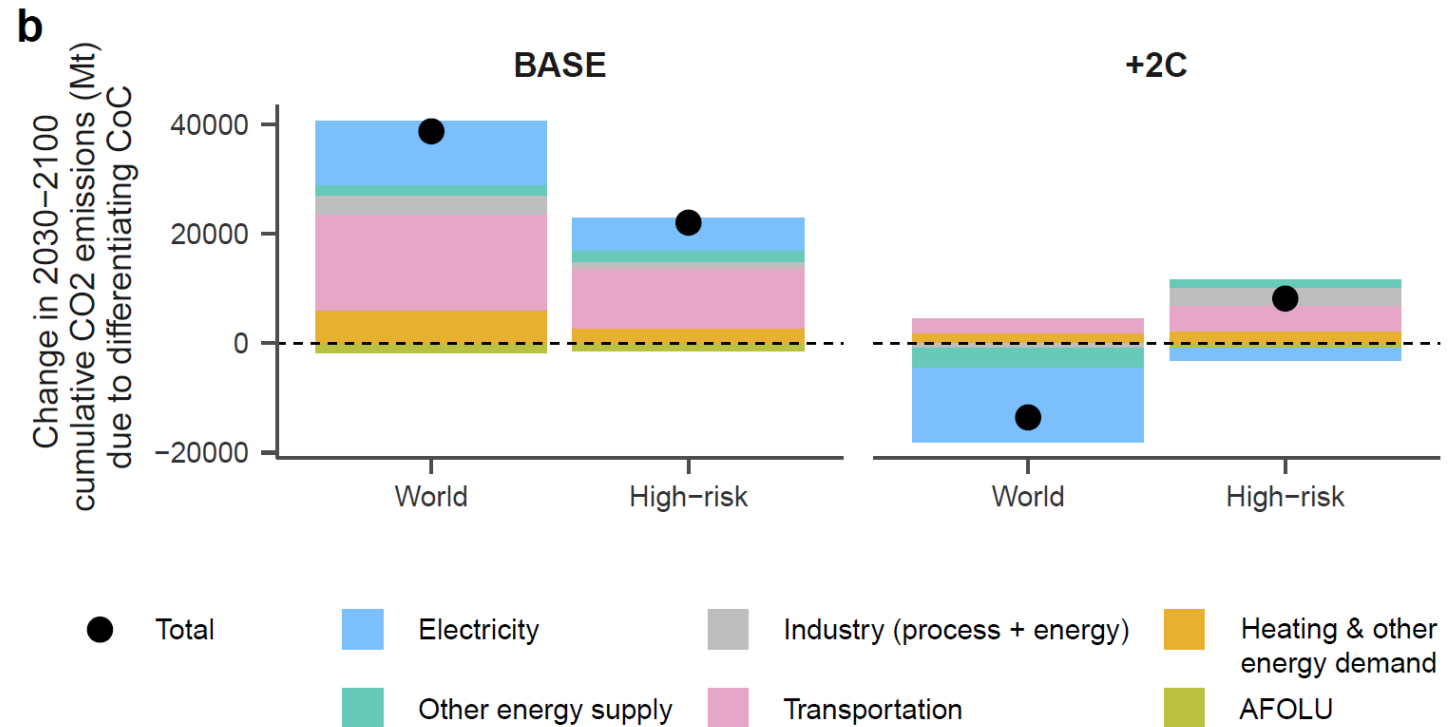
- Recent studies have incorporated CoC heterogeneity into integrated assessment models (e.g., Ameli et al., 2021; Calcaterra et al., 2024) but only for electricity generation, which has ...
 - a < 20% share in global emissions
 - relatively low sectoral risks (= lower financing cost)
 - relatively low abatement costs

How CoC differences matter (3/3): Looking beyond power generation?



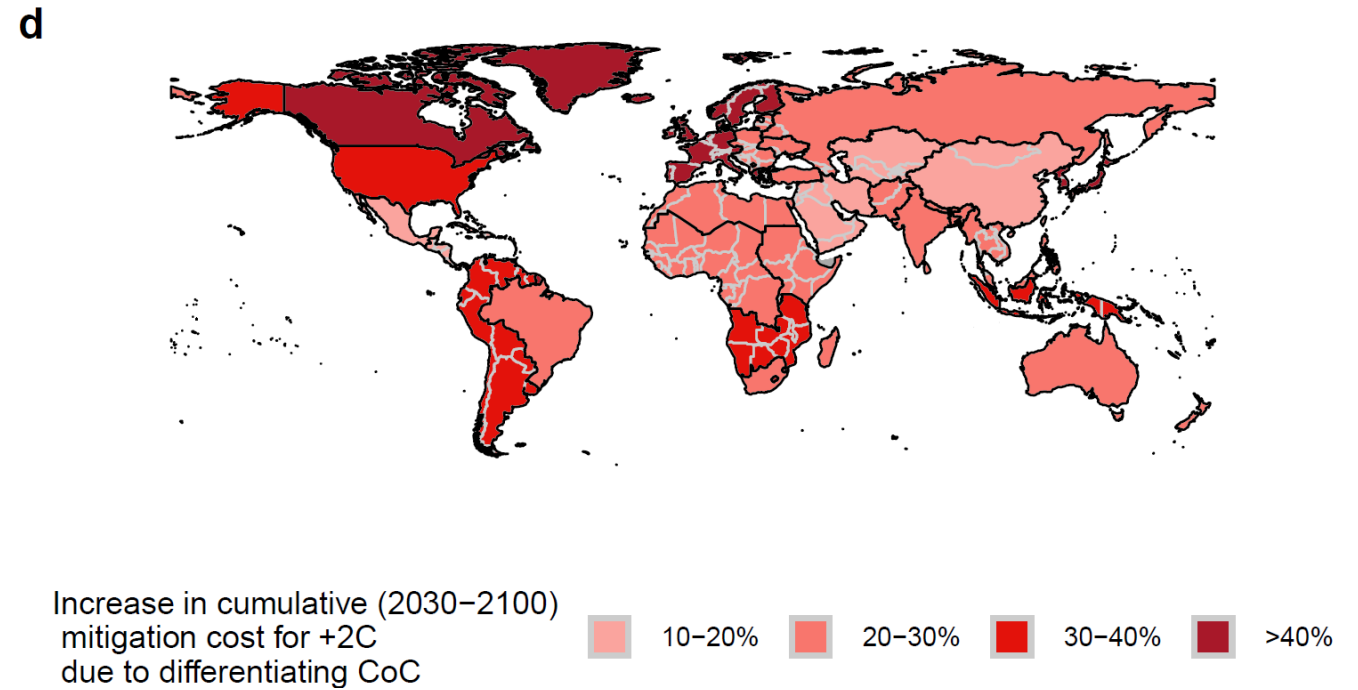
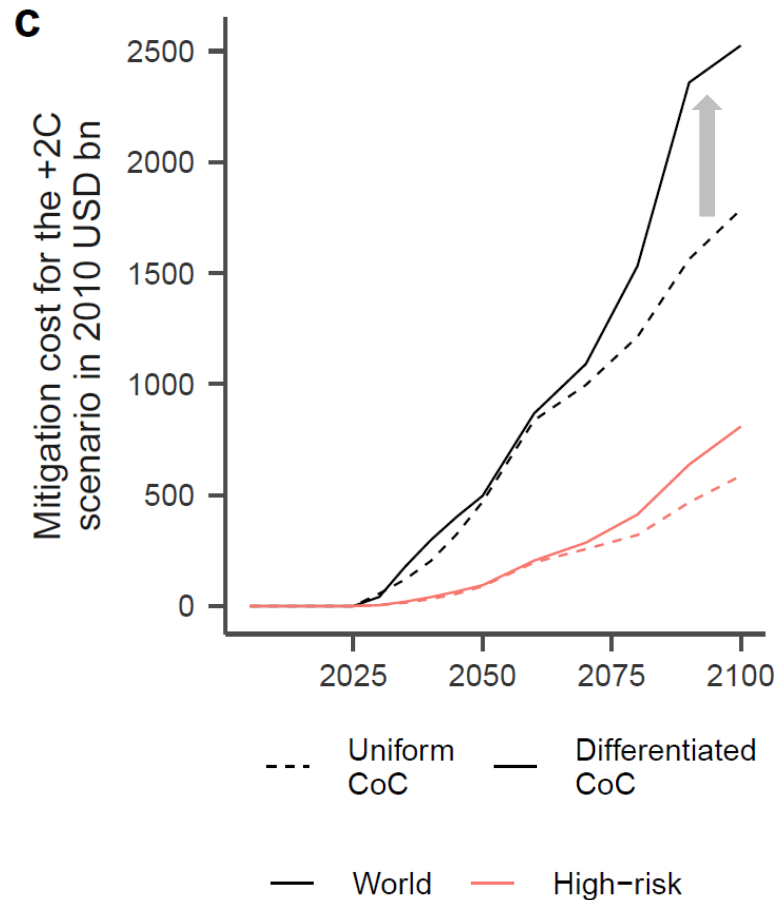
Analysis using the IMAGE model

- 26 regions with global coverage, high sector & technology granularity
- BASE (simulation), +2C (cost minimization)
- Using country- and sector-specific CoC
- Relationship between GDP/growth and CoC
- Comparing results to uniform 5% CoC



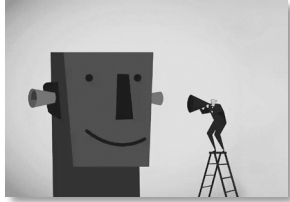
Source: Waidelich P, Crassier C, de Boer HS, Tautorat P, van Vuuren D, Steffen B (2025). The impact of financing conditions on global deep decarbonization. IAEE International Conference.

How CoC differences matter (3/3): Looking beyond power generation?



Source: Waidelich P, Crassier C, de Boer HS, Tautorat P, van Vuuren D, Steffen B (2025). The impact of financing conditions on global deep decarbonization. IAEE International Conference.

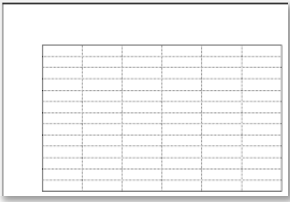
So why is CoC heterogeneity often disregarded in models?



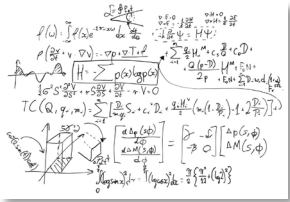
Lack of awareness of the relevance of CoC to model results



Absence of best practices for how CoC rates ought to be differentiated



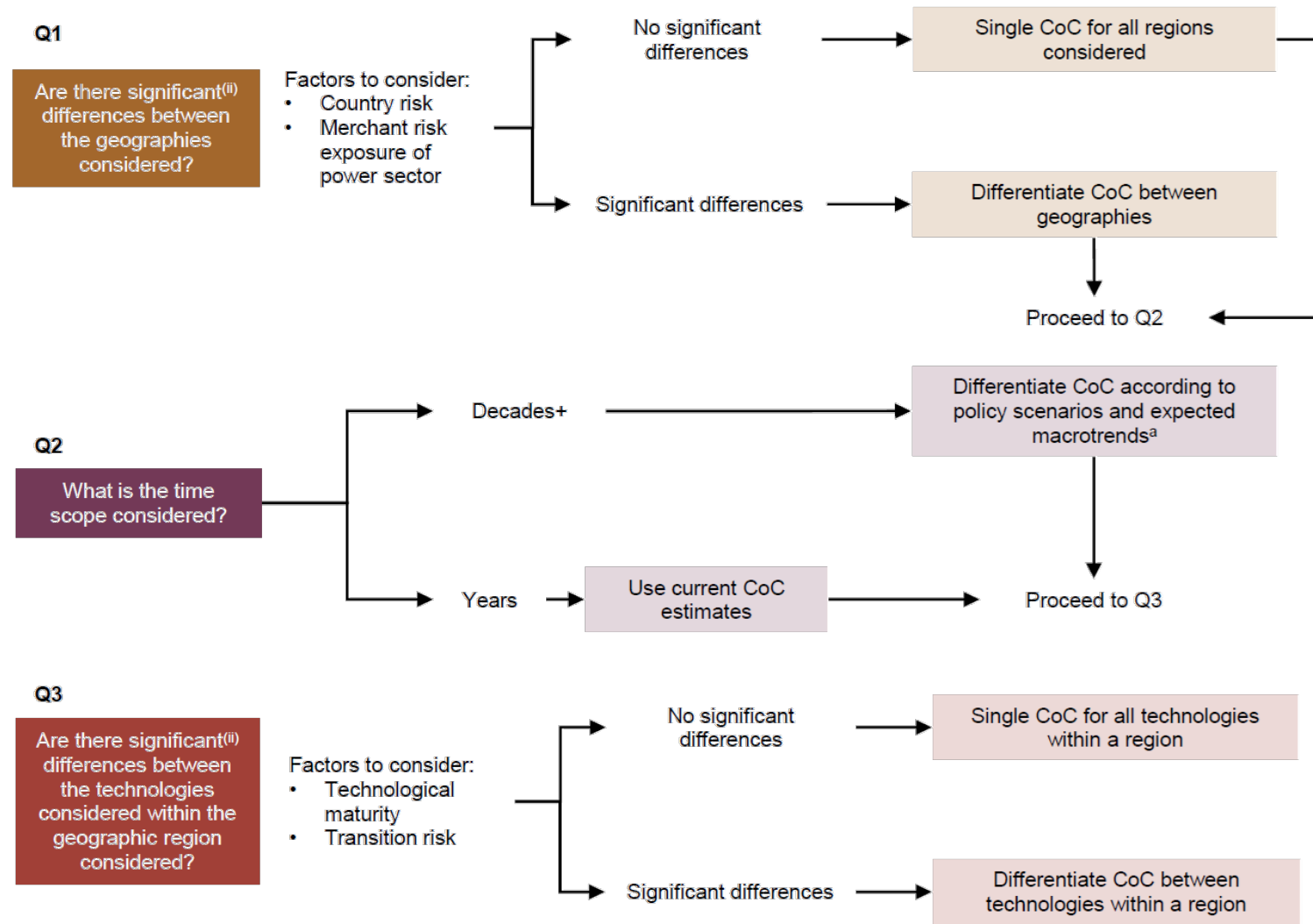
Unavailability of data needed to inform CoC rates



Complexity associated with integrating CoC into models

Source: Lonergan, K. E., Egli, F., Osorio, S., Sansavini, G., Pahle, M., Schmidt, T. S., & Steffen, B. (2023). Improving the representation of cost of capital in energy system models. *Joule*, 7(3), 469-483.

Heuristic for determining cost of capital in model-based analyses

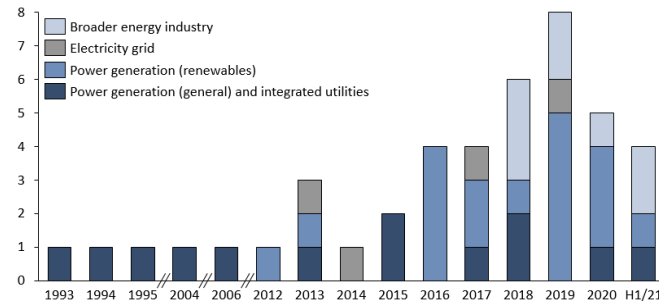


Source: Lonergan, K. E., Egli, F., Osorio, S., Sansavini, G., Pahle, M., Schmidt, T. S., & Steffen, B. (2023). Improving the representation of cost of capital in energy system models. *Joule*, 7(3), 469-483.

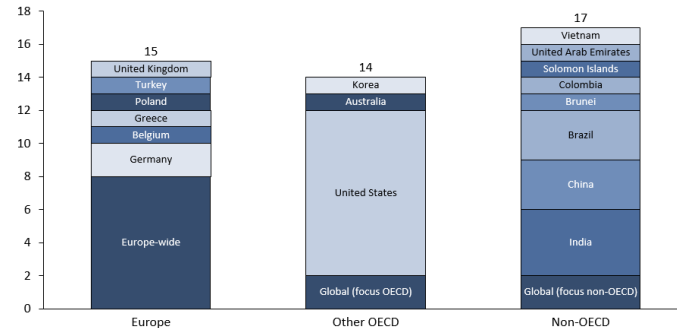
Not just a parameter, but a lever: The role of policymaking

Determinants of cost of capital in the electricity sector

No. of studies addressing cost of capital drivers



No. of studies addressing cost of capital drivers



CoC drivers on different levels

A. Macroeconomic & country level

- A.1 Sovereign risk/general country risk
- A.2 Impact of economic crises/credit crunches, monetary policy reactions

B. Energy sector level

- B.1 Structure of electricity markets/generators' exposure to price risk
- B.2 Design of renewable energy support policies
 - Type of support (e.g. feed-in tariff, premia, quotas, carbon price)
 - Duration of potential revenue support
 - Allocation of potential revenue support/auction design
- B.3 Design of grid regulation
- B.4 Credibility/expected stability of policies & regulation

C. Financial sector level

- C.1 Financial sector maturity and competitiveness level
- C.2 Financing/investment experience for energy technologies
- C.3 Availability of concessional finance (e.g. subsidized loans)

D. Technology level

- D.1 Portfolio of generation technologies and fuels, emission intensity
- D.2 Maturity of technology/technologies

In case of corporate finance:

E. Company level

- E.1 Company scope and contracts (vertical integration, elec. procurement)
- E.2 Company track record and local experience
- E.3 General firm characteristics (e.g. size, ownership, spatial diversification)
- E.4 Financial firm characteristics (liquidity, capital market access, audit quality)
- E.5 ESG characteristics (environmental disclosure, sustainability index inclusion)

In case of project finance:

F. Project/asset level

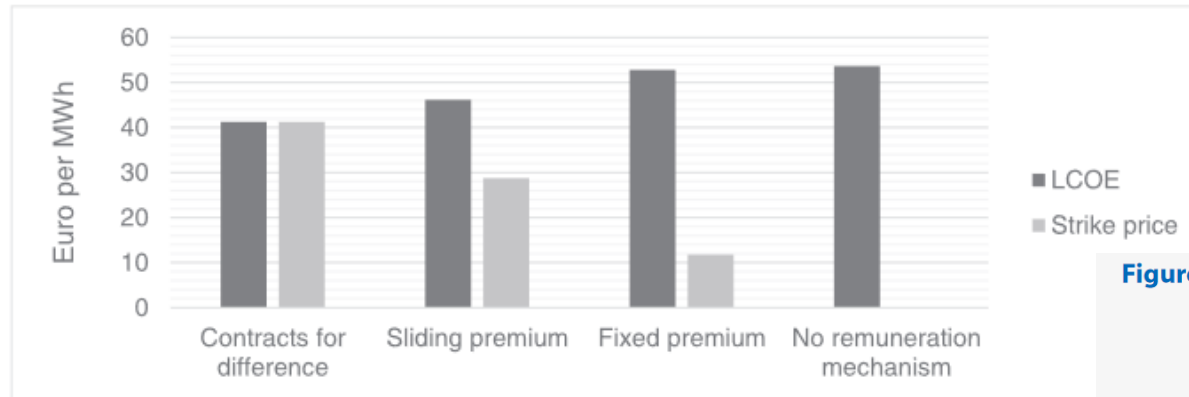
- F.1 Project characteristics
 - Project development stage
 - Specific resource risk and operational risks
 - Specific project size
- F.2 Project finance structure (e.g. financing of construction period, loan tenors, gov. guarantees)

Cost of capital

Source: Steffen B, Waidelich P. (2022), Determinants of cost of capital in the electricity sector. *Progress in Energy* 4, 033001.

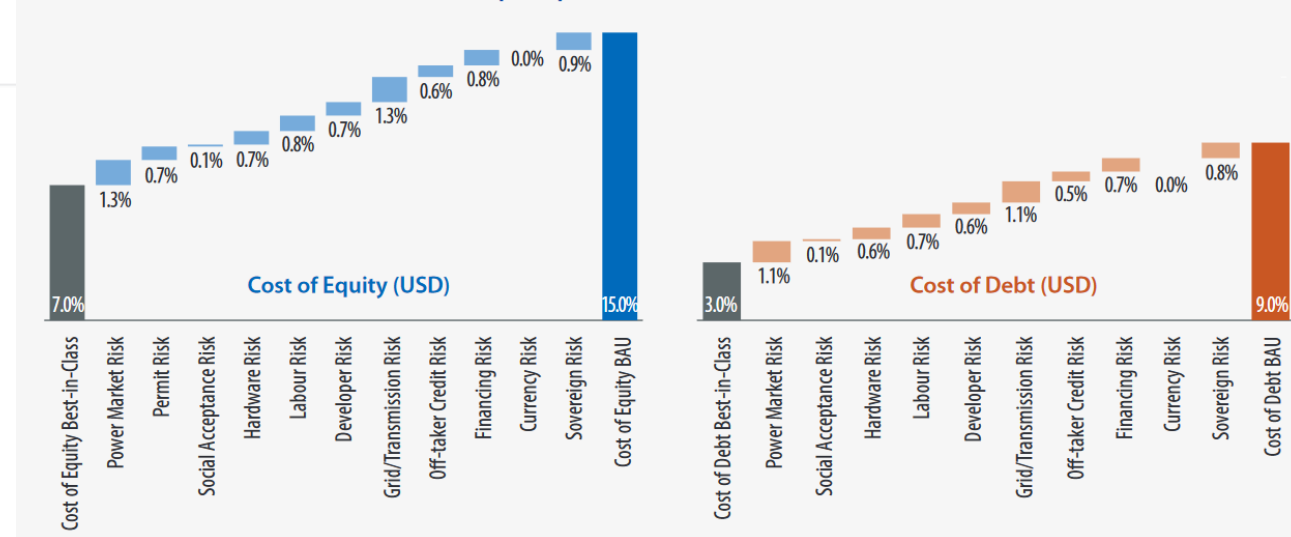
Energy sector level: Support policy design & overall regulation affect CoC

Solar PV cost under different remuneration mechanisms (Germany)



Solar PV CoC markup by regulatory risks (Cambodia)

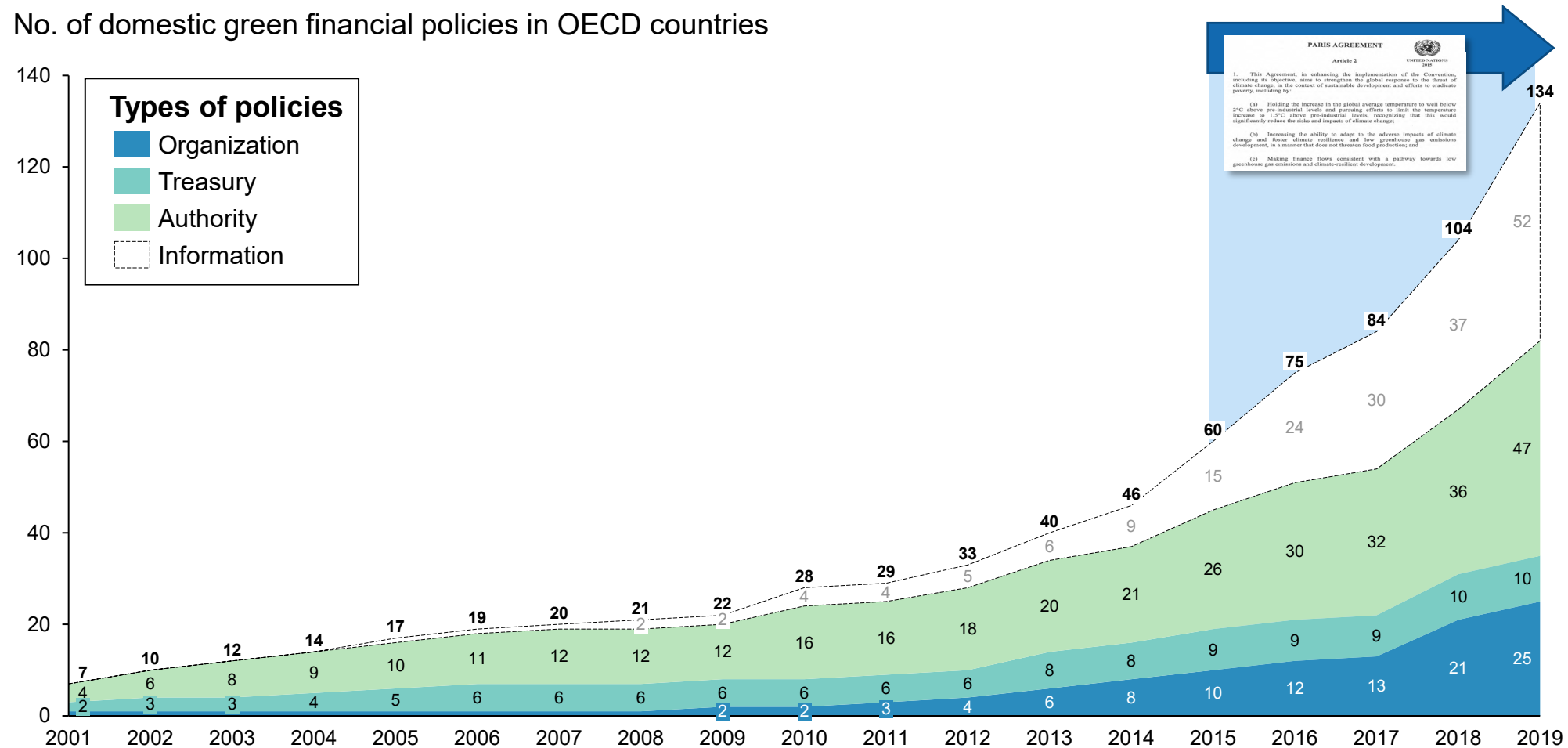
Figure 8: Impact of risk categories on financing costs for utility-scale PV investments in Cambodia, business-as-usual scenario (BAU)



Sources: Neuhoﬀ, K., May, N., & Richstein, J. C. (2022). Financing renewables in the age of falling technology costs. Resource and Energy Economics, 70, 101330.
UNDP (2019). Cambodia: Derisking Renewable Energy Investment. New York, NY: United Nations Development Programme.

Financial sector level: High momentum in *green financial policies*

No. of domestic green financial policies in OECD countries

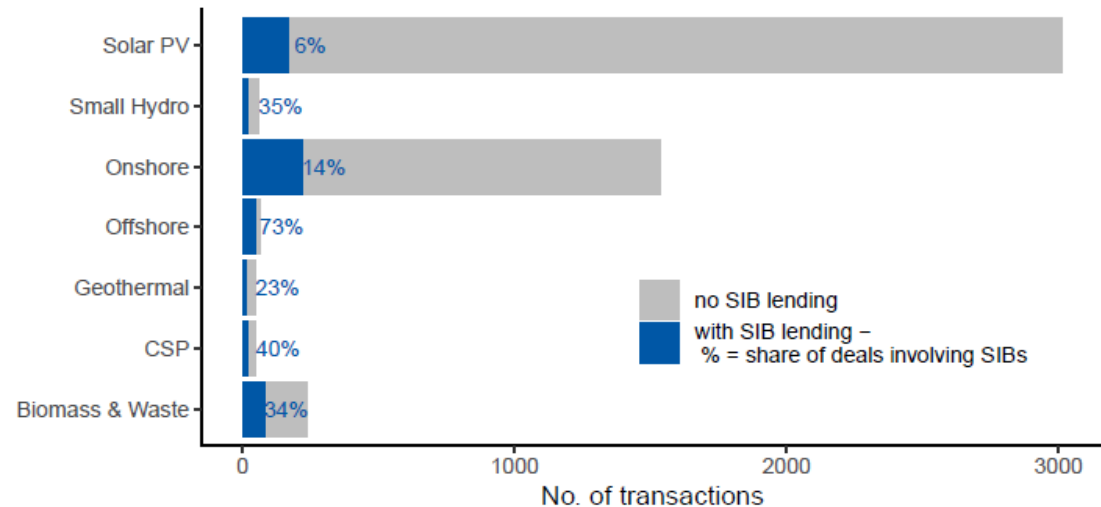
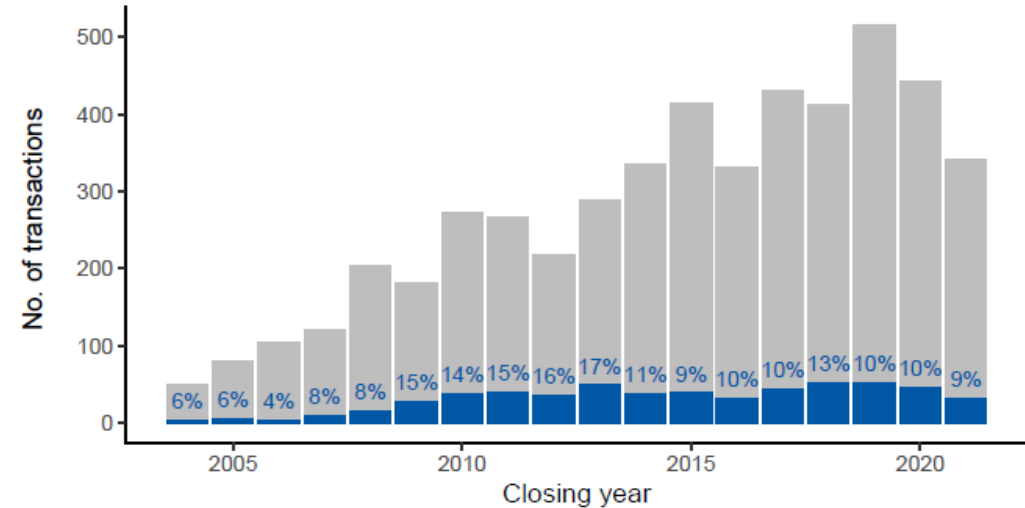


Source: Steffen, B. (2021). A comparative analysis of green financial policy output in OECD countries. *Environmental Research Letters*, 16(7), 074031.

Financial sector level: *Green state investment banks* with impact on CoC



**Green
Investment
Bank**

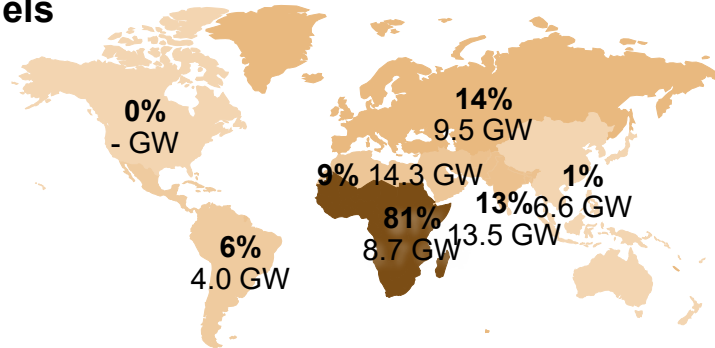


Source: Waidelich, P., & Steffen, B. (2024). Renewable energy financing by state investment banks: Evidence from OECD countries. *Energy Economics*, 132, 107455.

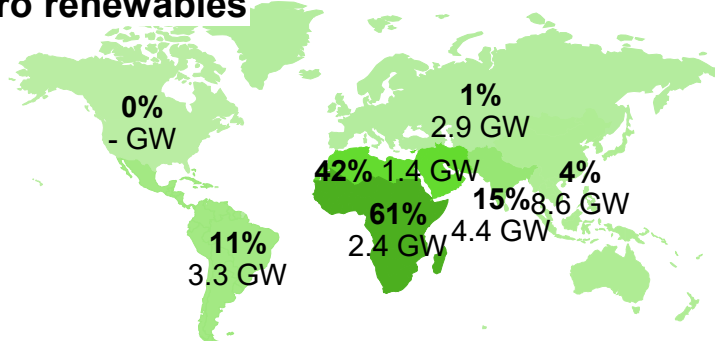
International level: MDBs and ECAs can lower CoC substantially

Share of power-generation capacity added 2007–2015 through projects with MDB participation

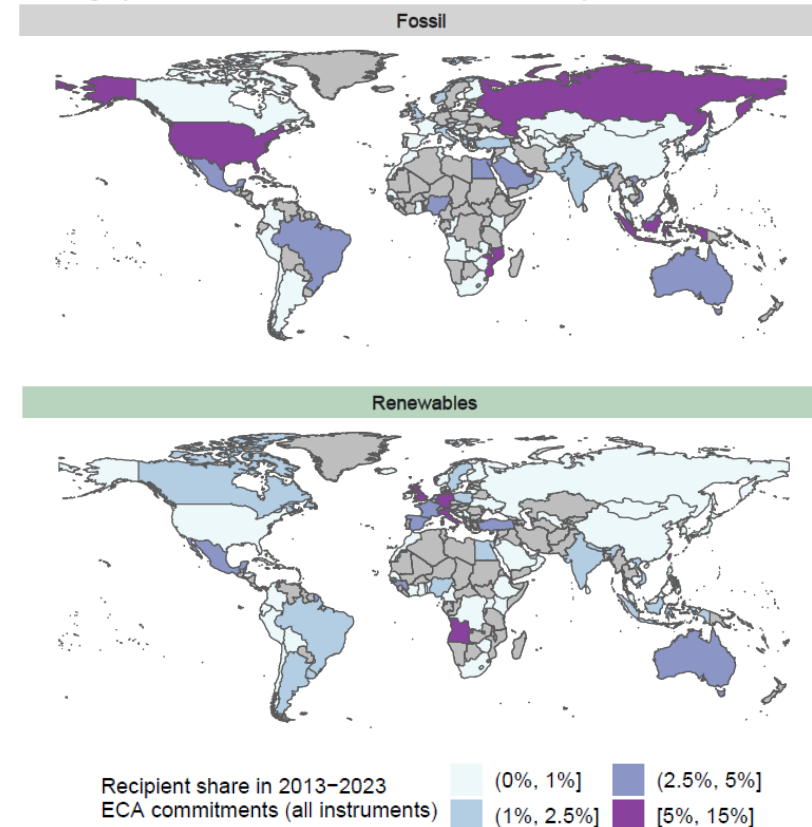
Fossil fuels



Non-hydro renewables



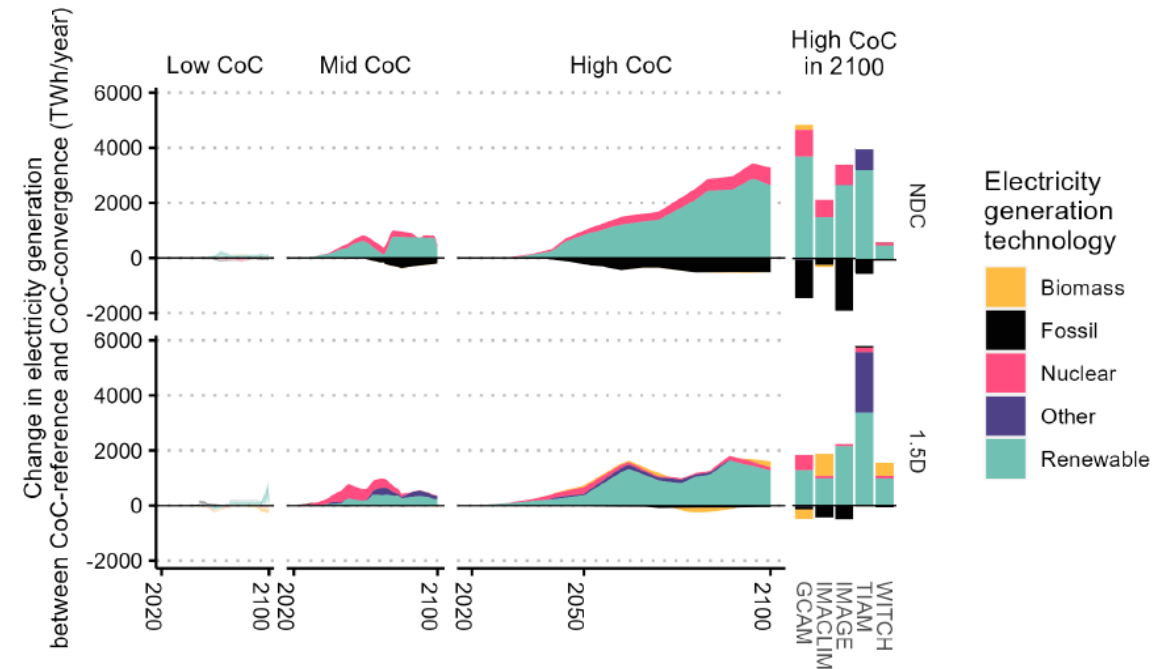
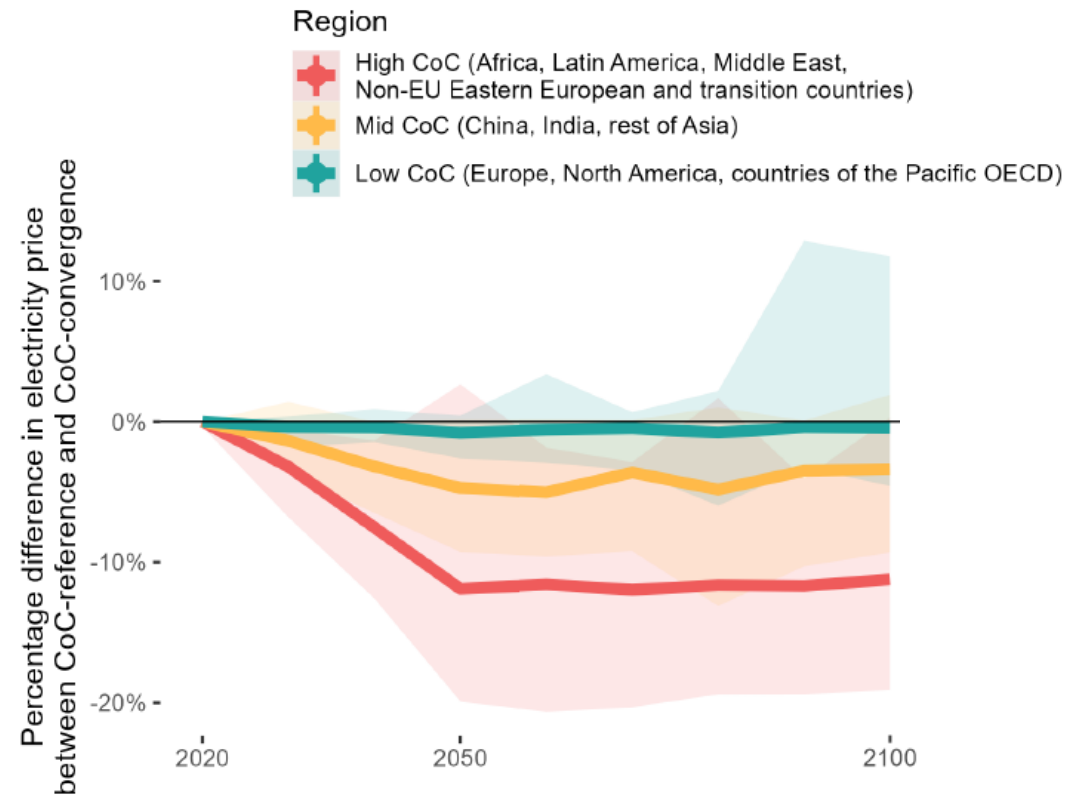
Distribution of ECA energy finance commitments 2013–2023 for fossil fuel and RE projects



Sources: Steffen, B., & Schmidt, T. S. (2019). A quantitative analysis of 10 multilateral development banks' investment in conventional and renewable power-generation technologies from 2006 to 2015. *Nature Energy*, 4(1), 75-82.

Censkowsky P, Waidelich P, Shishlov I, Steffen B (2025), Quantifying the shift of public export finance from fossil fuels to renewable energy, *Nature Communications*

International level: Convergence scenario cf. RE CoC with large effect



Source: Calcaterra M, et al. (2024), Reducing cost of capital to finance the energy transition in developing countries: a multi-model analysis. *Nature Energy* 9, 1241–1251.

Conclusion



Thank you for your attention

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Research presented in this talk received funding from the European Union's Horizon 2020 research and innovation programme (101081604 – PRISMA) and was thereby supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) (contract number: 22.00541). This project also received funding from European Research Council (ERC) (Grant Agreement No. 948220, Project No. GREENFIN), and from the German Federal Ministry of Education and Research under the Kopernikus-Projekt Ariadne (FKZ 03SFK5A). The opinions expressed and arguments employed herein do not necessarily reflect the official views of the Swiss Government.

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