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Reducing the cost of capital through international climate finance to accelerate the renewable energy transition in developing countries

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6 Reducing the cost of capital through international climate
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9 finance to accelerate the renewable energy transition in
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12 developing countries
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16 Briera Thibault^{*1,2} and Lefèvre Julien^{1,2}
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28 **Abstract**

29
30 Despite a vast potential, the accessibility of low cost finance remains a critical
31 barrier to the deployment of Variable Renewable Energy (VRE) in many develop-
32 ing countries. High financing costs threaten the competitiveness of renewable energy
33 technologies and impede progress in the energy transition. This study aims to assess
34 the extent to which international climate finance could help reduce the cost of capital
35 for VRE investments and accelerate the renewable energy transition in developing
36 countries. We employ the IMACLIM-R multi-regional Integrated Assessment Model
37 (IAM) to examine various climate finance scenarios, factoring in the interaction be-
38 tween public and private capital through a dedicated model for the average cost of
39 capital (CoC). The results show that international climate finance can significantly
40 enhance the adoption of renewable energy in regions that receive this support. For
41 instance, Africa could achieve +43% electricity generation from VRE by 2030 in a
42 scenario with deep risk sharing and mitigation for VRE investments, compared to a
43 no-policy scenario. Our study demonstrates that reducing the financing costs of VRE
44 investment through international climate finance encourages clean and affordable en-
45 ergy development. However it must be complemented by other policies to achieve
46 more ambitious climate and sustainable development objectives.
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Keywords: International climate finance; Cost of Capital; Renewable energy investments;

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1 Introduction

Modern renewable energy sources are ready to supply the future (Victoria *et al.*, 2021). Recent declines in construction costs (Haegel *et al.*, 2019) combined with improved efficiency of new and future power plants (Wiser *et al.*, 2020) argue for a strong penetration of Variable Renewable Energy (VRE) technologies (wind and solar power) into electricity systems worldwide now and in the future (Bogdanov *et al.*, 2021). However, it is not just a matter of time before wind and solar power displace fossil fuel-fired power plants. The path to a renewable energy future is full of obstacles that must be overcome (Nijssen *et al.*, 2022), particularly in developing markets (IRENA, 2016). High VRE shares pose challenges to system integration: variability must be balanced by increased flexibility to match electricity supply and demand. However, the VRE shares in developing countries are not high enough for system integration to be problematic (Arndt *et al.*, 2019). In this paper, we focus on the take-off phase of VRE deployment, which has not yet occurred in many developing countries outside of China. Indeed, despite being favorably endowed with solar and wind resources, developing countries are far from installing renewable energy infrastructure at a pace comparable to that of developed countries (IEA, 2022c). We rather identify the prohibitive cost of finance as a key barrier to investment that needs to be removed to enable large-scale adoption of VRE technologies. For utility-scale solar PV projects in 2021, financing costs constituted about half of the levelized cost of electricity (LCOE) in emerging markets versus less than 30% for developed economies (IEA & IFC, 2023). Investors still consider VRE investments in developing countries risky due to a weak enabling environment: weak local political institutions, macroeconomic and currency risks, or lack of local skills and track records can discourage investors (World Bank, 2023). It is also due to the nature of renewable energy projects, which are characterized by high upfront costs, a long and uncertain development phase before generating revenue (Painuly, 2001). As a result, part of renewable energy projects won't be financed by risk-averse investors. Projects that are actually financed are in turn subject to a risk premium according to the principle of risk-return relationship (Sharpe, 1964). Higher financing costs undermine the economic viability¹ and hinder the development of renewable energy

¹as illustrated by the cancellation of a 1.4GW offshore wind plant by its developer Vattenfall in the UK, due to increasing cost, including the cost of finance. See

1 projects because their life-cycle costs are highly sensitive to changes in financing costs
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3 (Schmidt, 2014). As a result, developing countries face a "climate investment trap" char-
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5 acterized by low investment in renewable energy, weak commitment to these technologies
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7 by the local and international financial sectors, and low profitability relative to fossil-fuel
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9 power utilities.

10 This VRE investment lag in developing countries is caused in part by investors' lack of
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12 knowledge and experience with renewable energy infrastructure, despite renewable energy
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14 technologies being mature from an industrial perspective. In developed economies, track
15
16 records have lowered the cost of capital (CoC, or financing costs) for PV projects due
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18 to financing expertise, investor confidence, and reliance on previous deals (Polzin *et al.*,
19
20 2019). The lack of an enabling environment for VRE investment in developing countries
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22 indicates that renewable energy markets are not yet mature, which may require public
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24 intervention to create and shape markets (Mazzucato & Penna, 2016). However, given
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26 current inflation and tight public budgets in the post-Covid period (International Mone-
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28 tary Fund, 2022), local public funding for a low-carbon transition in developing countries
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30 will remain limited, requiring the involvement of the international community (IRENA,
31
32 2023). In particular, international public actors such as international development fi-
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34 nance institutions (IDFIs²) have been highlighted as critical players in removing barriers
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36 to renewable energy investment in developing countries (Steffen & Schmidt, 2017). By
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38 providing climate finance and mobilizing private capital to secure low-cost finance for
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40 VRE projects, IDFIs are expected to help unlock developing countries' renewable en-
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42 ergy potential. In particular, blended finance is drawing increasing attention as a key
43
44 tool to reduce the perceived risks by private investors. It consists of using concessional
45
46 development finance to mobilize additional commercial finance for sustainable develop-
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48 ment purposes in developing countries, with IDFIs being key players of blended finance
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50 (Development Finance Institutions, 2022).

51 Despite the role that international climate finance could play in securing affordable
52
53 finance for VRE projects and accelerating the low-carbon transition, it has not yet been

54 <https://www.reuters.com/sustainability/vattenfall-says-it-is-stopping-british-norfolk-boreas-offshore-wind-farm-2023-07-20/>, consulted on September 8, 2023.

55 ²we use the term "IDFI" in its broadest sense, including bilateral and multilateral development banks,
56 as well as climate finance institutions such as the Green Climate Fund. Only National Development Bank
57 from developing economies are excluded.
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1 integrated into the models and scenarios used to explore the future of energy systems
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3 in developing countries. Indeed, large-scale energy models and Integrated Assessment
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5 Models have started taking into account heterogeneous cost of capital across countries
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7 and exploring scenarios of decreasing financing costs in developing countries, showing
8
9 their benefits in terms of VRE deployment and global CO₂ emissions (*e.g.* Ameli *et al.*,
10 [2021](#)). However, the reduction in the cost of capital is typically prescribed exogenously,
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12 with scenarios of convergent financing conditions for VRE investments between developing
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14 and developed countries in the long run. To our knowledge, none of these studies addresses
15
16 the role of international climate finance and how it shapes the financing cost for VRE.
17
18 Sweerts *et al.*, [2019](#) is a rare example that includes international public climate finance to
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20 quantify changes in the cost of capital, but does not consider risk sharing and mitigation
21
22 due to IDFI interventions.
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24 In this article, we aim to fill this gap by examining scenarios of climate finance-
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26 induced reductions in the cost of capital and assessing their energy and economic impacts
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28 in developing countries. Due to the degree of uncertainty and the complexity of the finan-
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30 cial mechanisms at stake, we rely on scenario analysis to explore this research question.
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32 Various scenarios of IDFI's ability to shift the risk-return profile of VRE projects are
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34 considered, including a scenario in which IDFI's generalize blended finance principles. We
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36 focus on VRE technologies (onshore and offshore wind and solar power) because they
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38 represent the bulk of future renewable energy investment in developing markets (IEA,
39
40 [2022c](#)) while still requiring financial support to maintain their competitiveness now and
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42 in the future. We incorporate the climate finance scenarios into a hybrid energy - macroe-
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44 conomic multi-regional dynamic model of the world economy (IMACLIM-R) to capture
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46 both future transformations of developing countries' power systems and wider economic
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48 impacts (Sassi *et al.*, [2010](#)). The contribution of this study is twofold. First, we contribute
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50 to a broader effort aiming at improving the representation of finance in policy-relevant
51
52 tools like Integrated Assessment Models (Lonergan *et al.*, [2023](#)) by introducing a specific
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54 model for the cost of capital into an IAM. In addition, we provide quantitative insights
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56 into the role IDFI's can play in lowering the cost of capital for VRE investments in devel-
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58 oping countries and on the implications for the energy transition in these regions. The
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60 rest of the paper is structured as follows: Section 2 details the methods of the study,
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1 including the introduction of the CoC model and how it allows accounting for climate fi-
2 nance; Section 3 describes the climate finance scenarios that feed the CoC model; Section
3 4 develops the main results and Section 5 draws the conclusions and policy implications.
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8 **2 Methods**

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11 In this section, we describe the main methodological innovation of this study: the in-
12 tegration of international climate finance to estimate the cost of capital, starting from
13 the existing literature on the impact of public finance on financing terms for VRE in-
14 vestments. The CoC model is integrated in the IMACLIM-R model to quantify climate
15 finance-induced CoC reductions and assess their implications for the evolution of energy
16 systems in developing countries.
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24 **2.1 Evidence of the impact of public financing on the financing condi-** 25 **tions for VRE investments**

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28 Because the cost of capital is paramount for the competitiveness of renewables, lowering
29 the cost of capital in developing economies would theoretically encourage the deployment
30 of renewables. Unfortunately, it is still unclear how policies and changes in investors'
31 behavior could effectively reduce the cost of capital for renewable energy projects at the
32 regional level, especially given the multiple factors and complexity of the mechanisms at
33 stake (Steffen & Waidehlich, 2022). Very few studies have attempted to quantify the impact
34 of international and domestic policies on the cost of capital and used these estimates to
35 examine the future of the energy system (*e.g.* Sweerts *et al.*, 2019). Two effects must be
36 considered when introducing public financing in our analysis :
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- 47 • The provision of affordable public capital

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49 International climate finance can take the form of concessional finance *e.g.* sub-market
50 loans ³ (IMF, 2003). Public lenders can offer finance at a cheaper cost than the market,
51 resulting in a lower average cost of capital.
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- 56 • The improvement of risk-adjusted return through risk sharing and mitigation

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58 ³In practice this is not always the case as DFI (especially their commercial branches) look for econom-
59 ically viable businesses to finance and can be reluctant to offer sub-market loans
60

1 Public financing is expected to attract private investors by reducing the perceived risks
2 for VRE investment, sometimes referred to by the broad term "de-risking" (Schinko &
3 Komendantova, 2016). We distinguish between the market-level impact of IDFI inter-
4 ventions and project-level risk mitigation and sharing in cofinanced projects. IDFI first
5 play an "educational" role through demonstration effects when there is no track record
6 (Deleidi *et al.*, 2020), and by disseminating knowledge and helping standardize contracts
7 for renewable energy projects. This is also referred to as the "catalytic effect" of the IDFI
8 intervention (MDBs, 2018): IDFI mitigate risk for all renewable energy investments,
9 which benefits the entire market.
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18 At the project level, IDFI can mitigate the risks borne by private investors, for
19 instance by signaling bankable projects (Geddes *et al.*, 2018) and increasing the likelihood
20 of reaching the operation phase for selected projects. IDFI can also assume some of the
21 risks otherwise borne by private investors, by investing in equity or subordinated debt
22 rather than senior debt, or by providing risk-sharing facilities and guarantees. Such
23 risk-sharing structures fall into the category of "blended finance", through which public
24 investors seek to improve risk-adjusted returns on investments due to imperfect markets
25 and externalities (Attridge & Engen, 2019).
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34 Ultimately, both the provision of public finance and the reduction of perceived risks by
35 private investors lead to a reduction in the average cost of capital for VRE investments.
36 The integration of these two effects into a cost of capital model is described hereafter.
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41 **2.2 Modeling heterogeneous Cost of Capital in an IAM**

42 Many Integrated Assessment Models lack explicit representations of finance and financing
43 barriers to the low-carbon transition (Pollitt & Mercure, 2018, Battiston *et al.*, 2021).
44 For the cost of capital, this translates into a homogeneous cost of capital for all power
45 generation technologies, countries, and time periods, which is the standard assumption for
46 Integrated Assessment Models and large-scale energy models. In these models the cost of
47 capital is used as a proxy for the discount factor. It is involved in cash flow discounting, to
48 compare the life-cycle cost of electricity generation technologies with different lifetimes,
49 and particularly shape the outcomes of energy system models (García-Gusano *et al.*,
50 2016). The homogeneity assumption yields a biased representation of the cost of renewable
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1 electricity generation (Ondraczek *et al.*, 2015) and of the optimal allocation of climate
 2 change mitigation efforts (Iyer *et al.*, 2015). Therefore, it is misleading for policy advising
 3 since it overestimates abatement costs in the power sector in developed countries with an
 4 actual lower cost of capital than under the homogeneous assumption (Egli *et al.*, 2019).
 5 Conversely, it underestimates these costs in developing countries.
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10 Many factors justify that financing costs tend to be technology- and region-specific
 11 (Grubb *et al.*, 2020). Financing costs change over time due to learning-by-doing (Polzin
 12 *et al.*, 2021), country economic convergence (Sweerts *et al.*, 2019), and depending on the
 13 share of countries' GDP invested in electricity generation technologies (Ekholm *et al.*,
 14 2013). While there is no single, standardized method for capturing the time-, region-,
 15 and technology-specific dimensions of the cost of capital in the power sector, most studies
 16 rely on a formula for the weighted average cost of capital of the following form to provide
 17 heterogeneous estimates:
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$$CoC_{i,r,t} = \left(\frac{D_{i,r,t}}{V_{i,r,t}}\right) K_{i,r,t}^D (1 - \tau_r) + \left(\frac{E_{i,r,t}}{V_{i,r,t}}\right) K_{i,r,t}^E \quad (1)$$

26
 27
 28
 29 with $CoC_{i,r,t}$ the cost of capital for technology i , in region r at time t . The cost
 30 of capital is expressed as a percentage of investment costs (or CAPEX), which is an
 31 average of the cost of debt K^D (net of tax-deductible interests paid on debt, hence the
 32 corporate tax rate τ in the formula) and of equity K^E , weighted by their share in the
 33 total volume of investment V , with $V = D + E$. We base the CoC model used in this
 34 study upon this formula, with estimates for the three main variables: the cost of debt, the
 35 cost of equity and the share of debt (or resp. equity) in the total volume of investment
 36 determined by the electricity module of the IMACLIM-R model. $\frac{E}{V}$ is also known as
 37 the equity requirement because it sets a minimum amount of equity in the total volume
 38 of investment required to attract lenders. The cost of debt is modeled as a sum of a
 39 risk-free rate, a country risk, and a technology risk premium, which decreases over time
 40 due to learning-by-doing, proxied by capacity additions. The cost of equity is modeled
 41 using a Capital Asset Pricing Model (CAPM). The detailed description of the CoC model
 42 used, with the underlying assumption and data sources for calibration are given in the
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Appendix (subsection *Element-wise description of the Cost of Capital model*).

Based on Equation 1 and state-of-the-art approaches to building a CoC model, we thus contribute to the global effort to provide heterogeneous cost of capital estimates for Integrated Assessment Models (Sanders *et al.*, 2022). Figure 1 shows our estimates for the cost of capital in 2019 for world regions represented in the IMACLIM-R model for a variable renewable technology (utility-scale PV) and fossil technologies. These CoC estimates rely on aggregate financial data and do not include international climate finance yet.

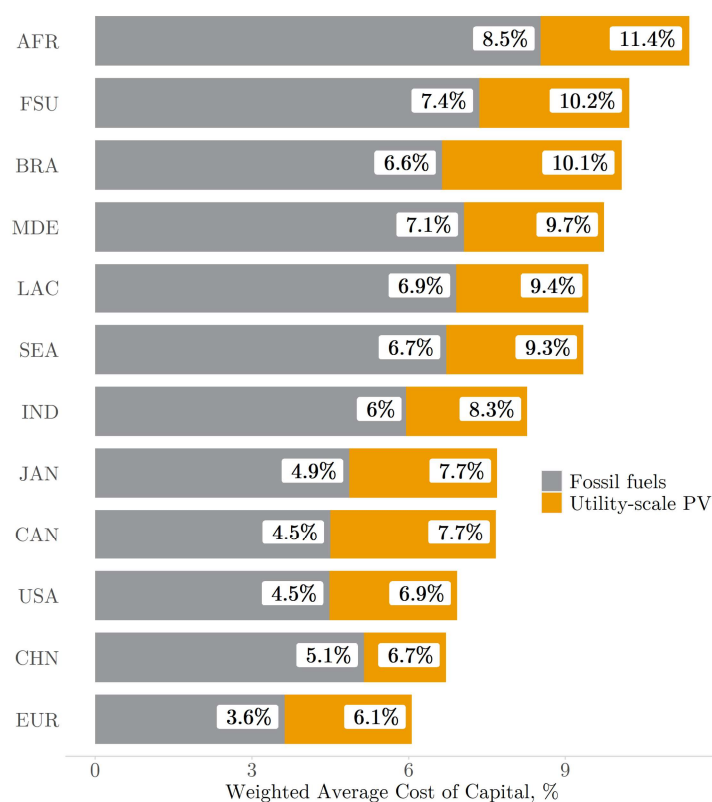


Figure 1: **Cost of Capital in 2019 for investments in utility-scale PV and thermal plants** (after tax, estimates from IMACLIM-R). More transparent dots indicate lower CoC. The regions represented are: Europe (EUR), China (CHN), USA (USA), OECD Pacific (JAN), India (IND), South East Asia (SEA), Latin America and the Caribbean except Brazil (LAC), Middle East (MDE), Brazil (BRA), Former Soviet Union (FSU), Africa (AFR).

As noted above, the differences in the cost of capital between developed and developing economies, as well as within the group of developing economies, are substantial. In 2019, the cost of capital for solar PV in Africa (11.4%) was very high due to a combination

of high cost of debt, high cost of equity, and high equity requirements. These estimates are consistent with the most recent observations: the cost of capital is two to three times higher in developing markets than in developed economies (IEA, 2022a). Note that the figures given are regional averages, which may hide even lower CoC for specific countries.

2.3 A cost of capital model with public finance provision and private risk reduction

The CoC model that builds on Equation 1 is expanded to account for the provision of public capital. First, a term for the concessional public loans $D_{i,r,t}^{public} K_{i,r,t}^{D^{public}}$ is added, resulting in a cost of capital for co-financed projects (Equation 2, dropping the indexes for the sake of clarity):

$$CoC^{climfin} = \left(\left(\frac{D}{V} \right)^{climfin} (K^D)^{climfin} + \frac{D^{public}}{V} K^{D^{public}} \right) (1 - \tau) + \left(\frac{E}{V} \right)^{climfin} K^E \quad (2)$$

where D^{public} is populated with projected flows of renewable energy finance determined in the climate finance scenarios. This ensures that the reduction in CoC due to the provision of concessional finance is embedded in the empirical trends of renewable energy finance.

Then, risk sharing and mitigation effects are added, at both market- and project-level. To proxy the catalytic effect of international climate finance at the market level, we assume that equity requirements $\left(\left(\frac{E}{V} \right)^{climfin} \right)$ for VRE projects decrease gradually with IDFI's interventions. Equity requirements are typically higher in high-risk countries (IEA, 2022a) to protect private lenders against the risk of bankruptcy. Lower equity requirements reflect an enabling investment environment with low risks for lenders. Since the cost of debt is much lower than the cost of equity, lowering equity requirements decreases the average cost of capital. This applies to both supported ($CoC^{climfin}$) and unsupported (CoC^{priv} , Equation 3) VRE projects, as we assume that IDFI interventions improve the investment environment for all VRE projects, hence the $\left(\frac{E}{V} \right)^{climfin}$ term in Equation 3. The de-risking effect at the project-level is modeled through a reduction of the cost of private debt $(K^D)^{climfin}$ for co-financed projects. Because IDFI's mitigate and

share the risks on VRE investments, private lenders accept a lower rate of return when they co-invest with IDFI in blended finance structures.

In the end, the final estimate of the cost of capital for a technology i in a region r is given by the modified CoC model (Equation 4). Since all renewable projects in developing regions do not benefit from public co-financing, the cost of capital is the average of the cost of capital for co-financed projects ($CoC^{climfin}$) and of the cost of capital for private financed-only projects (CoC^{priv}), weighted by the share of renewable projects receiving financing from IDFI ($share^{climfin}$). $share^{climfin}$ is computed such that the share of total VRE projects receiving financing from IDFI is compatible with the yearly volume of climate finance available D^{public} . Thus, CoC reductions are constrained by IDFI resources: only a limited share of annual renewable energy investments in developing countries will benefit from IDFI interventions.

$$CoC^{priv} = \left(\frac{D}{V}\right)^{climfin} K^D (1 - \tau) + \left(\frac{E}{V}\right)^{climfin} K^E \quad (3)$$

$$CoC = share^{climfin} CoC^{climfin} + (1 - share^{climfin}) CoC^{priv} \quad (4)$$

Equation 4 provides the final Cost of Capital estimate per technology, region, and period of time. Equation 4 is then inserted into the bottom-up, technology-rich electricity module of the IMACLIM-R model to provide heterogeneous CoC estimates that include climate finance features. Note that for developed countries, the cost of capital formula is reduced to Equation 1 as we assume no climate finance is provided in these countries.

2.4 The CoC in the electricity module of the IMACLIM-R model

IMACLIM-R is a hybrid energy - macroeconomic multi-regional recursive dynamic model with twelve world regions that includes a technology-rich bottom-up electricity module. Key aspects of the electricity supply are represented: capital vintages and lifetimes, fuel efficiency, utilization rate, storage, or renewable energy integration constraints. Techno-

economic parameters are calibrated using sectoral models and information from the literature (Briera, 2023). For immature technologies such as VRE, capital expenditures decrease over time due to global learning processes (Neij, 2008). Both investment and dispatch decisions are made on an annual basis, from the model's first run year (2015) to 2100, to provide meaningful insights into future electricity systems, their decarbonization pathways, and their connections with the rest of the economy. Long-term investment decisions are represented by a nested modified multinomial logit structure in which explicit technologies compete based on electricity generation costs, as described in Figure 2.

$$S_{k,i}(t+10) = \frac{\alpha_{k,j} LCOE_{k,i}^{\gamma}(t)}{\sum_{j=1}^N \alpha_{k,j} LCOE_{k,j}^{\gamma}(t)} \quad (5)$$

The first 'logit nest' determines the aggregate dispatchable market share and the variable renewable market shares for a medium horizon (10 years by default) for onshore wind, offshore wind, rooftop and central PV based on their (system) levelized cost of electricity (LCOE) as shown on Equation 5. The modified multinomial logit structure allows to describe the global market share per technology in competitive electricity markets and to capture important stylized facts of the electricity sector (Clarke & Edmonds, 1993). $S_{k,i}(t+10)$ refers to the $t+10$ market share of technology i in region k of the model, γ the logit exponent and α 's the share weights (Joint Global Change Research Institute, 2022). The share weights are calibrated to reproduce 2018 observed market shares per region. From $S_{k,i}(t+10)$ is derived an annual investment schedule between t and $t+1$ aligned with the desired market shares in $t+10$, taking into account existing installed capacities and future electricity demand. Electricity demand is fully endogenous in IMACLIM-R, so expectations for future demand are formulated based on past trends. Finally, the annual investment schedule marginally modifies the existing capacity available for dispatch. Each period, the electricity module determines the utilization rate of the existing capacity according to the merit order. Electricity generation technologies compete on seven load bands : a peak load band (730 hours), a base load band (8760 hours) and five intermediary load bands of 1460 h each.

In this framework, the cost of capital serves as a proxy for the discount factor in the LCOE formula. Therefore, it is an important factor for investment decisions in the electricity module, as it directly affects the choice of market shares in Equation 5. Additionally, electricity market prices are based on production costs in the model, which include the cost of capital. Thus the CoC affects the electricity demand and the rest of the economy through the price of electricity in the macroeconomic core of the IMACLIM-R model. Electricity prices and demand variations as computed by the model can further be used as proxies for implications for access to affordable electricity, a key development issue for developing countries.

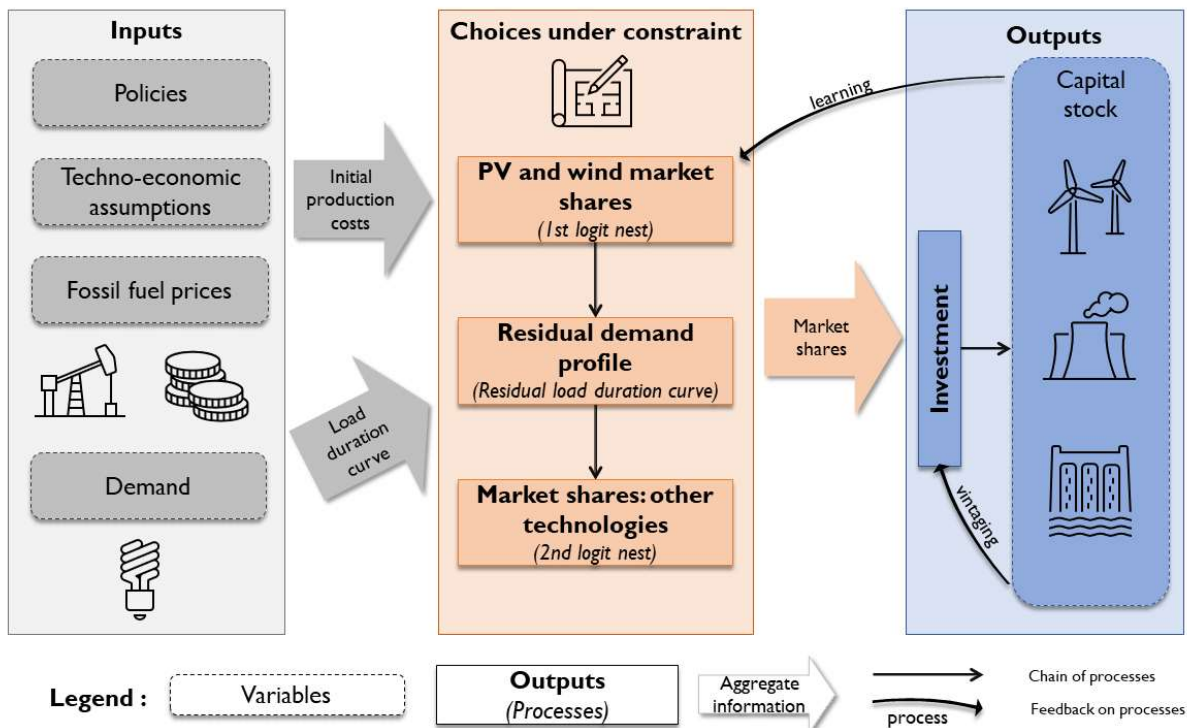


Figure 2: Summary of the investment procedure in the electricity module of IMACLIM-R

3 Climate finance scenarios

We explore climate finance scenarios based on current and expected international climate finance flows (3.1) and alternative assumptions about risk sharing and mitigation effects of international climate finance (3.2).

3.1 International renewable energy finance

The scenarios of decreasing renewable energy financing costs are based on current and expected international renewable energy financing flows. They are derived from both aggregate climate finance data and project-level, bottom-up data. Aggregate climate finance is drawn from the OECD Statistics, which compiles OECD Development Assistance Committee (DAC) data and the United Nations Framework Convention on Climate Change (UNFCCC) data. Data from the OECD contains historical data up to 2020, and forward-looking scenarios for the 2021-2025 period (OECD, 2021a; OECD, 2021b). We estimate that renewable energy finance represented approximately \$6bn in 2020 and will increase to \$9bn by 2025. Since the OECD forward-looking scenario stops in 2025, we assume that international climate finance for VRE stabilizes after 2025 and is maintained over the horizon of this study (2060). The detailed calculation is given in the Appendix (*Construction of climate finance scenarios*).

Aggregate renewable energy finance is distributed across world regions of the IMACLIM-R model, using project-level from the OECD DAC Statistics (Figure 3). We assume that the regional distribution pattern observed between 2017 and 2020 applies to the entire commitment period of international climate finance⁴⁵. Considering our estimates of the regional allocation of finance flows, we expect negligible effects in the Middle East (1%) and conversely larger impacts in Africa (36%) and South East Asia (19.6%).

Five solar and wind technologies (onshore wind, offshore wind, central solar PV, rooftop solar PV, and concentrated solar power) receive renewable energy finance. The IMACLIM-R model generates a total demand for VRE investment per region and technology, only a portion of which is debt. Debt demand for VRE projects is aggregated and compared to available renewable energy finance to determine $share^{climfin}$, the share of VRE projects financed by IDFI. $share^{climfin}$ is not technology specific, but is calculated simultaneously for the five VRE technologies. If a particular VRE technology is

⁴It is worth noting that the African continent has historically been the main beneficiary of international financial support for renewable energy. This region faces issues with financing renewable energy investments. This may explain why IDFI have targeted Africa in the past. In addition, renewable infrastructure (both on-grid and off-grid) helps meet electricity access targets that remain at the core of IDFI activities.

⁵The "Unspecified" share was redistributed evenly to the regions. Brazil was excluded from the analysis: its electricity mix is already very low-carbon due to important hydro resources (International Energy Agency, Data and Statistics, 2020)

overrepresented in the pooled investment demand, then it will receive a larger volume of climate finance. This is consistent with the demand-led nature of IDFI's interventions: the portfolio of technologies in which IDFI's invest depends on the investment plans and financing needs of project sponsors (Carter *et al.*, 2019).

Overall the assumptions about international climate finance flows for our scenarios mainly draw on OECD data. It is worth noting that OECD and Official Development Assistance accounting rules have been the subject of heated debate, with accusations of overreporting, problematic definitions of the relation to climate change mitigation or adaptation (the Rio markers), and diversion of existing development assistance to climate-related issues (Roberts *et al.*, 2021). Novel methods have been developed to overcome some limitations of self-reporting (Toetzke *et al.*, 2022). Nevertheless, statistics from OECD DAC and the Creditor Reporting System remain a reliable source of annual data and can be used as a proxy for climate finance (Colenbrander *et al.*, 2022).

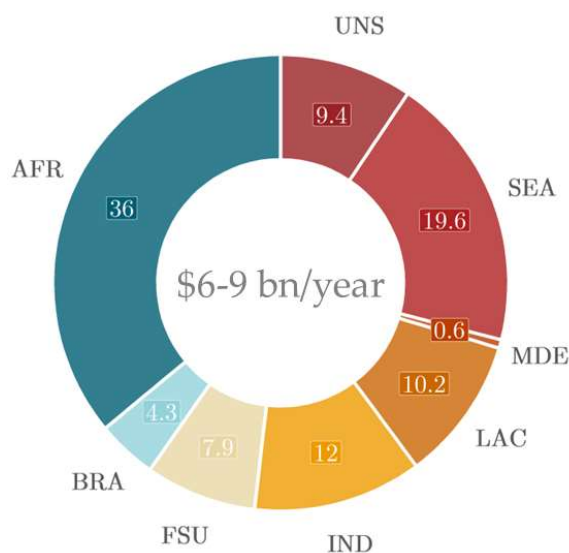


Figure 3: **Regional allocation rule of international renewable energy finance**, in %. 2017-2020 average. Source: OECD DAC statistics, authors' calculation. UNS = Unspecified

3.2 Climate finance and benchmark scenarios

Renewable energy finance is factored in the IMACLIM-R model to drive reductions of the cost of capital for VRE projects, due to both the provision of affordable public capital and the reduction in perceived risks by private investors. The latter effect is addressed by a scenario analysis in which three contrasted scenarios are examined based on the same total amount of international public climate finance but different levels of de-risking for private investors. This scenario approach is justified by two reasons. First, outside of developed economies and main emerging markets, there is a lack of data on the cost of capital (IEA, 2022b), which makes it difficult to establish a solid empirical basis for the de-risking effect of international climate finance. Second, and more importantly, the reduction of perceived risks in VRE projects is a multidimensional process, and to squeeze it into a single mathematical formula is to oversimplify. Therefore, examining different scenarios of risk mitigation and sharing by IDFI allows us to capture part of the uncertainties associated with the impact of IDFI on the financing terms of VRE projects. Thus, three different climate finance scenario narratives are developed based on the various degrees of IDFI to create an enabling environment for private investment and to modify the risk-return profile for VRE investments (Table 1):

- (*Provide*). International finance institutions provide affordable capital for renewable energy investment but do not share nor mitigate risks for private investors. Concessional loans are provided with a 6% pre-tax interest rate (versus 12.6% in Africa, see Table 5 in the Appendix). IDFI provide concessional finance but do not change the perception of risks by private investors, either for supported projects or unsupported projects.
- (*Catalyze*). IDFI provide concessional finance at lower cost (4%) and catalyze private investment by creating an enabling investment environment, improving the financing conditions for all VRE projects over time (catalytic effect): equity requirements decrease with cumulative IDFI interventions. IDFI do not seek to "crowding in" private lenders in blended finance structures, so the de-risking effect does not materialize at the project level.

- 1 • (*Catalyze&Blend*). IDFI provide concessional finance at very low interest rates
2
3 (3%), catalyze private investment, and make strategic use of their resources through
4
5 blended finance structures. Going further than in the *Catalyze* scenario, IDFI
6
7 co-invest with private lenders in syndicated loans, sharing and mitigating the risks
8
9 borne by private investors for supported projects⁶ (de-risking effect). Therefore, the
10 required returns by private investors in blended finance structures are lower than
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12 for private deals: the pre-tax cost of private debt is reduced by 2 pp (percentage
13
14 point) for blended finance projects.
15

16
17 These three climate finance scenarios are further compared to two benchmark scenar-
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19 ios:
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- 21 • a counterfactual "no-policy" scenario (*NoPolicy*) which does not include any specific
22 financial support from IDFI.
23
24 • a long-term convergence scenario in which the CoC for developing countries con-
25
26 verges to the level of all-time, best-in-class developed countries (4.5%) by 2050
27 (*Converge*). *Converge* is a benchmark scenario that illustrates the potential of
28 VRE deployment reachable by reducing the cost of capital in high-risk countries,
29 disregarding the means needed to achieve this goal. In this scenario, long-term
30 convergence to the best-in-class cost of finance is not assumed to be supported by
31 any policy. Comparing the climate finance scenarios to the *Converge* case provides
32 a measure of the potential VRE deployment that can be achieved due to lower fi-
33 nancing costs, regardless of how credible that reduction in financing costs is. In this
34 scenario, the CoC in developing countries equalizes that of developed countries in
35 the long run. If the *Catalyze&Blend* estimate is lower than the linear convergence
36 from the *Converge* scenario, it is used instead (Figure 5).
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51 In every climate finance scenario, the provision of public capital starts in 2020. The
52 scenarios do not include a carbon tax, in order to isolate the effects of climate finance on
53 the VRE deployment and their wider economic and environmental impacts.
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56 ⁶In the *Catalyze&Blend* scenario, we assume the following syndicated loan structure: 50% of the
57 volume of debt is covered by IDFI, the remaining 50% by private lenders. In the *Provide* and *Catalyze*
58 scenarios, IDFI either finance 100% of a project's debt or do not provide financing to the project.
59
60

Scenario name	Climate finance in developing economies - description
<i>NoPolicy</i>	None
<i>Provide</i>	Provision of international public climate finance
<i>Catalyze</i>	Provision of international public climate finance + catalytic effect of IDFI
<i>Catalyze&Blend</i>	Provision of international public climate finance + catalytic effect + risk shar- ing and mitigation in blended finance structures
<i>Converge</i>	Implicit. Linear decrease of the cost of capital towards developed economies levels by 2050

Table 1: **Summary of the climate finance and benchmark scenarios**

The three climate finance scenarios (*Provide*, *Catalyze*, *Catalyze&Blend*) translate into changes in the cost of capital for renewable energy projects in developing economies, as summarised in Figure 4.

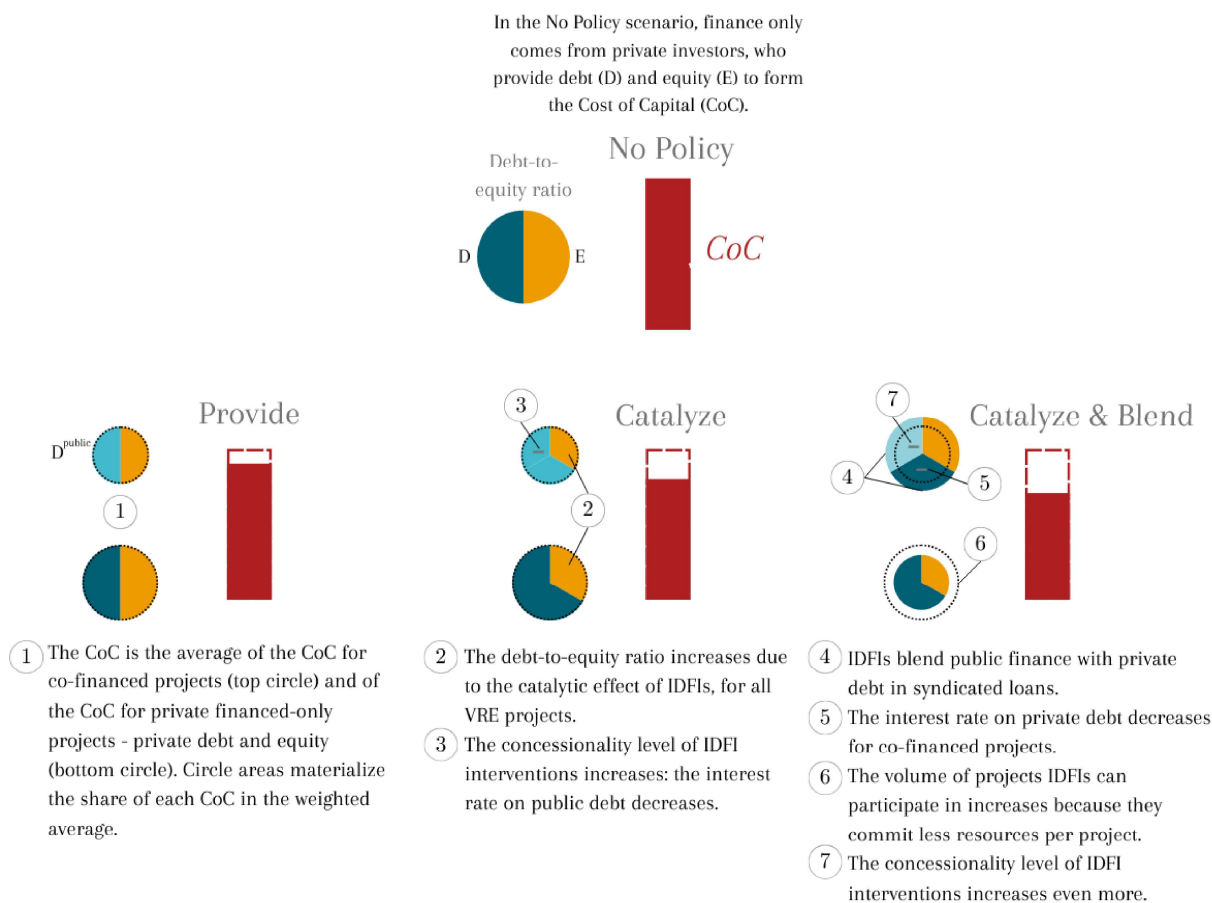


Figure 4: Summary of the impact mechanisms of international climate finance on the Cost of Capital.

These evolutions are driven by three factors: renewable energy finance flows, which are the same in all scenarios, with their degree of concessionality, the catalytic effect of IDFI interventions, and the effect of blended finance. In addition, the CoC model includes endogenous reductions of the financing costs through learning which is a feature of the model common to all scenarios. Therefore, the CoC will follow a slowly decreasing trajectory even in the *NoPolicy* scenario, as described in the next section.

4 Results

4.1 Cost of capital and international climate finance

The CoC for VRE investments in developing countries (Figure 5) is the first key output of our simulations as it further drives how climate finance influences the dynamics of VRE technologies and electricity prices in the model. In the *NoPolicy* scenario, the CoC for VRE projects (weighted average) has a similar dynamic across regions. The high initial interest rate is offset by endogenous financing experience in the long run, which leads to a slow decline of the CoC even in the absence of climate public finance. Comparing the CoC in climate finance scenarios with the *NoPolicy* case highlights the specific impacts of IDFI interventions on the CoC. The results show significant impacts, mainly in Africa and South East Asia, to a lesser extent in LAC and India, and very limited impacts in other regions (Former Soviet Union and Middle East). This is driven by the climate finance portfolio that favors Africa and South East Asia in the allocation of financial flows (Figure 3). For instance in Africa by 2030, the *Provision* case reduces the CoC by around 2 pp and the *Catalyze* scenario that includes a stronger enabling environment for all VRE projects leads to a further reduction of around 1 pp. The more ambitious *Catalyze&Blend* in terms of concessionality and private risk reduction adds a 1 pp reduction in the CoC compared to the *Catalyze* scenario. Overall, the *Catalyze&Blend* results in a permanent decrease in the CoC of almost 4pp compared to the *NoPolicy* scenario. The final decrease in the CoC rely on plausible evolutions of each of the CoC component, including the cost of private debt in blended finance structures (Figure 12 in the Appendix).

In the *Provision* scenario, the CoC reduction is only transitory. Indeed, the volume of international renewable energy finance stagnates after 2025 by assumption, while the demand for VRE investment keeps rising over time. Thus, the share of VRE projects benefiting from IDFI intervention decreases ($share^{climfin}$, Figure 6). In the *Catalyze* and *Catalyze&Blend* scenarios, the persistence of the catalytic effect on the investment environment mitigates this phenomenon.

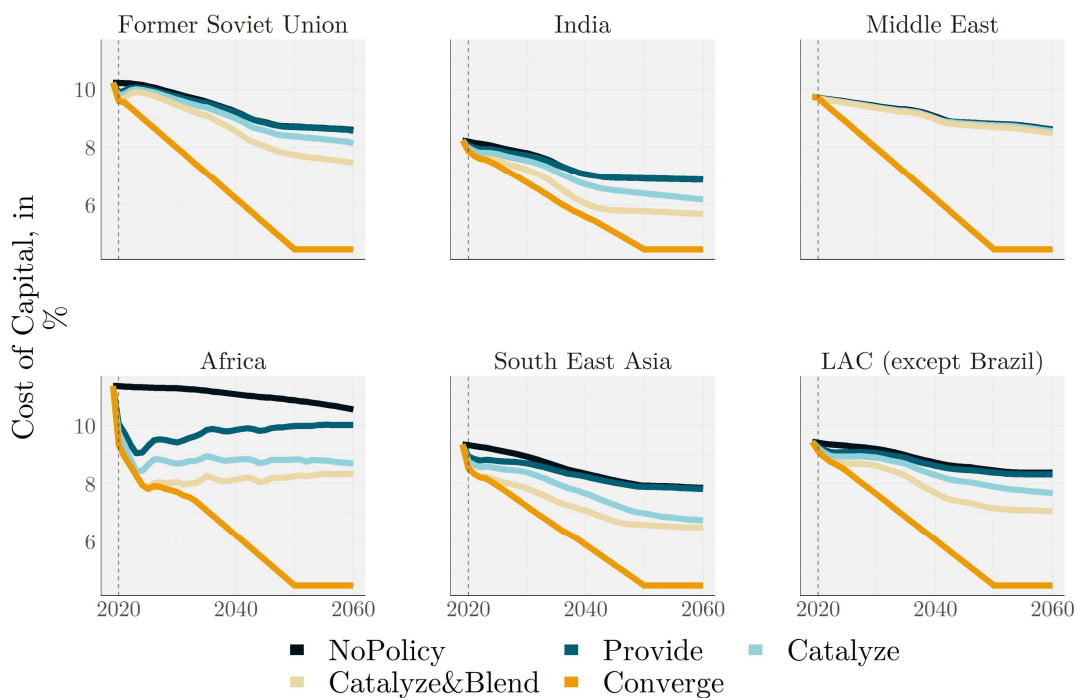


Figure 5: **Cost of capital (weighted average) for renewable investments across developing regions.**

Outside of Africa and Southeast Asia, the allocation of international renewable energy finance does not result in significant support for renewable energy investment in the short run. In India and LAC, the *Catalyze&Blend* lead to a reduction of the CoC of around 1 pp by 2050 compared to the *NoPolicy* case due to the catalytic effect of IDFI interventions. In these two regions, the *Provide* and the *Catalyze* scenarios do not trigger significant CoC reductions, even in the long run. Due to the weakness of climate finance in the Middle East (and to a lesser extent Former Soviet Union), the climate finance-driven scenarios do not change the financing costs for VRE investment in this region.

The case of Africa delivers fruitful insights into the mechanisms behind the CoC reduction due to IDFI interventions. For all three climate finance-driven CoC reduction scenarios, the share of co-financed VRE projects starts by increasing until 2025, then decreases due to an increasing VRE investment demand (Figure 6). In the *Catalyze* scenarios, fewer VRE projects receive co-financing from IDFI compared to the *Provide* scenario. Indeed, because of a combination of increased concessionality and catalytic effect of IDFI activities, the demand for VRE investment is higher in the *Catalyze* scenario, so

1 a smaller share receives international climate finance. In the *Catalyze&Blend* scenario,
 2
 3 IDFI's seek to maximize the share of VRE projects that can be supported through the
 4 strategic use of public capital according to blended finance principles. In this scenario,
 5 between 2020 and 2030, virtually all the projects receive support from IDFI's in Africa.
 6
 7 It suggests that the bottleneck is on the side of the investment demand rather than on
 8 the supply side of financing. This interpretation is consistent with the main challenges
 9 reported by climate finance providers: IDFI's identify the lack of investment opportunity
 10 as a main barrier for scaling up private finance, along with risk and return (OECD,
 11 2022b). In our framework and under our set of assumptions, this means that increasing
 12 international climate finance in the *Catalyze&Blend* scenario would have no effect on
 13 VRE deployment in Africa because of a lack of project pipeline development in the short
 14 run. This advocates for a wider policy package to stimulate VRE investment demand,
 15 because IDFI can only finance existing projects.

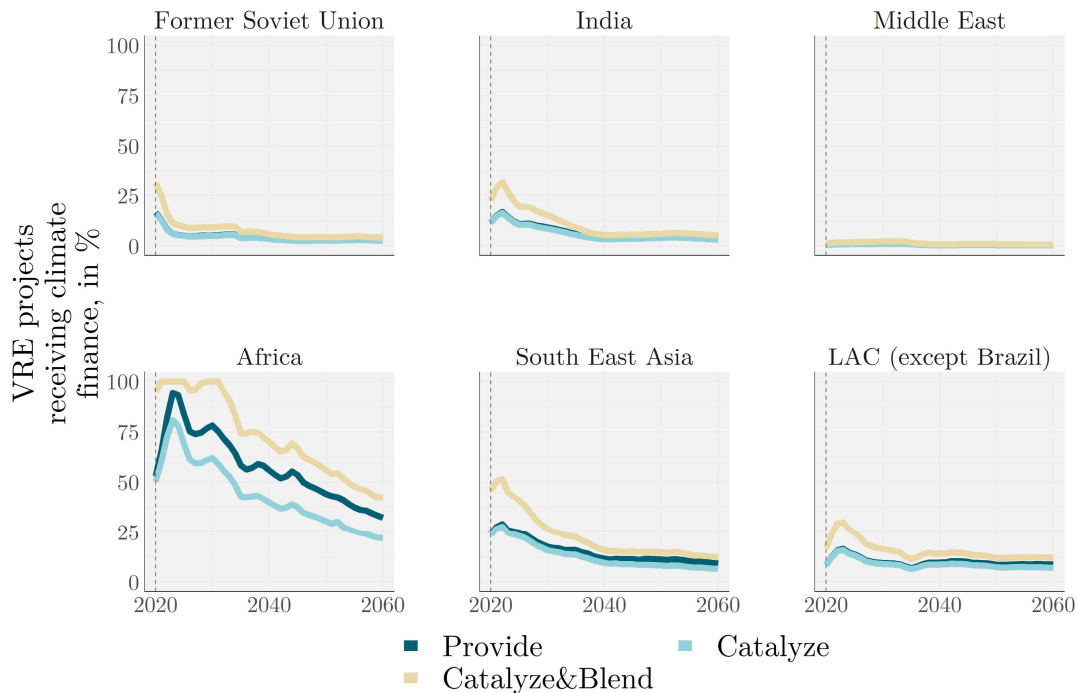


Figure 6: **Proportion of VRE investment receiving international renewable energy finance from IDFI's, as a share of total VRE investments** ($share^{climfin}$). In the *Catalyze&Blend* scenario, IDFI's provide 50% of a total project's volume of debt, versus 100% in the other climate finance scenarios. Therefore, $share^{climfin}$ goes up in this scenario because IDFI's crowd in private lenders, which increases the overall number of projects IDFI can invest in.

4.2 Renewable electricity generation

Overall, a lower CoC for VRE investments implies an increase in VRE investments and power generation from VRE sources compared to the *NoPolicy* scenario (Figure 7). The *Converge* scenario outcomes benchmark the potential for accelerating the renewable energy transition through CoC reductions in the different regions, which depends on initial CoC levels. The higher the CoC in 2020, the larger the potential for accelerating VRE deployment: renewable power generation could increase by 50% by 2040 in Africa whereas the potential is limited to + 20%-40% in other developing regions (Former Soviet Union, India, Middle East, South East Asia, and LAC). In the climate finance-driven scenarios, the results are much more contrasted than in the *Converge* case and are directly linked to the variation of CoC compared to the *NoPolicy* scenario. Due to the allocation of the climate finance portfolio, Africa and South East Asia record the highest drops of the CoC compared to the *NoPolicy* case, which lead to the highest increase of VRE deployment. On the contrary, climate finance has a very low impact over VRE generation in FSU, and the Middle East. In India and LAC, the *Catalyze&Blend* scenario achieves a small increase in renewable electricity generation in the long run mostly due to the catalytic effect of IDFI.

Africa receives a significant amount of climate finance compared to its renewable energy investment needs, which lead to a significant increase in renewable electricity generation. The sole provision of concessional finance (*Provide*) induces almost 25% higher renewable electricity generation by 2030. Consequently, when the initial CoC is very high, the provision of public capital at low cost is important for promoting renewable energy deployment, regardless of the magnitude of the ability of IDFI to mitigate and share risks with private investors. When IDFI shift the risk-return profile of VRE investments (*Catalyze&Blend*), it becomes clear that a second lever to promote PV and wind capacity expansion is to improve the ability of IDFI to attract affordable private capital. Figure 7 actually shows a significant surge in renewable electricity generation between the *Catalyze* and *Catalyze&Blend* cases. By 2030 in Africa, renewable electricity generation increases by around 10 pp more in the *Catalyze&Blend* scenario than in the *Catalyze* scenario, compared to the *NoPolicy*. Overall, the impact on annual renewable

1 electricity generation in the most optimistic climate finance-driven scenario (+38 pp in
 2
 3 *Catalyze&Blend*) can be almost twice as large as in the less favorable *Provide* scenario
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 5 (+ 21 pp) at a 2035 horizon. This finding argues for a clear mandate to mobilize private
 6
 7 capital for IDFI: securing low-cost private financing sources is important to accelerate
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 9 the pace of the energy transition in developing countries. A sensitivity analysis is carried
 10
 11 out for the key parameters driving the impact of international climate finance on the cost
 12
 13 of capital (Figures 10 and 11 in the Appendix). The sensitivity analysis supports our find-
 14
 15 ings: the results are robust to changes in assumptions about the impact mechanisms of
 16
 17 international climate finance. Therefore, our results are based on robust evidence despite
 18
 19 the uncertainties in quantifying the impact of international climate finance on the cost of
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 21 capital. We also assess the sensitivity of the results to changes in the main parameters
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 23 of the CoC model and of the electricity sector module of the IMACLIM-R model (see
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 25 Appendix).

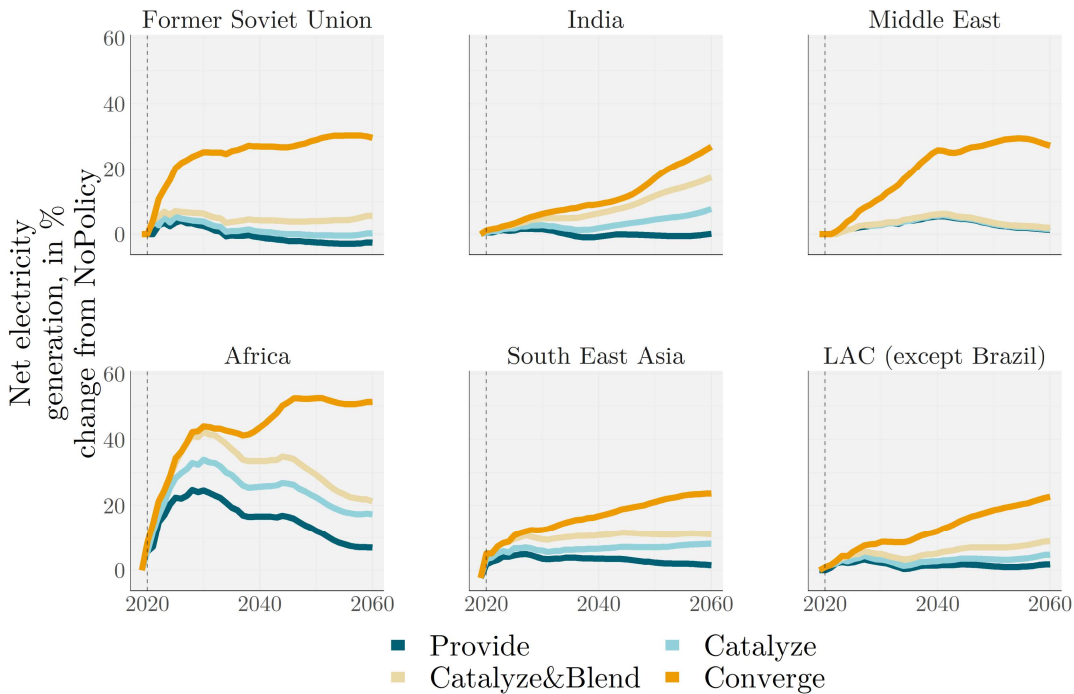


Figure 7: Electricity generation from VRE, % change from *NoPolicy*.

4.3 Access to affordable energy and CO2 emissions in Africa

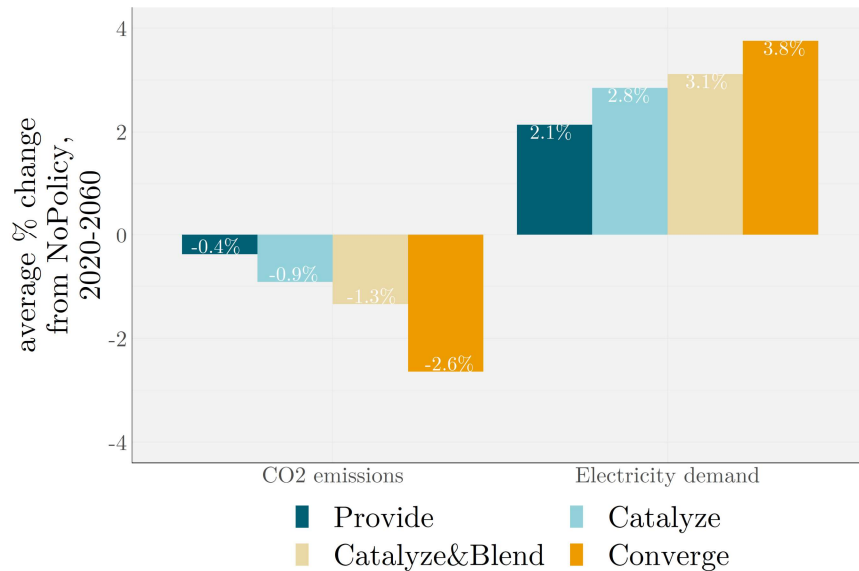
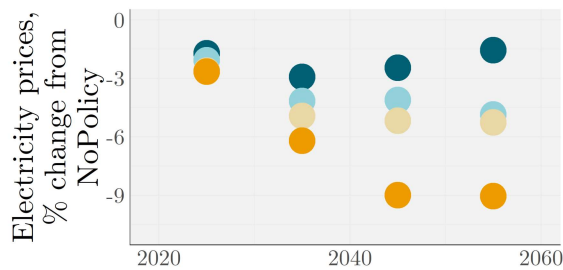
We finally provide results about the indirect impacts of CoC reductions on electricity prices, electricity demand and total CO2 emissions in Africa (Figure 8).

Results show that climate finance-driven CoC reductions is also an opportunity to limit the increase in electricity prices by reducing average power generation costs. Providing full access to low-cost finance for VRE investments (*Converge* case) could reduce electricity prices by up to 10% in the medium run compared to the *NoPolicy* case (Figure 8.a). In the *Provide*, *Catalyze* and *Catalyze&Blend* scenarios, the moderation of electricity prices would be smaller but still significant, ranging from -3% (*Provide*) to -5% (*Catalyze&Blend*) by 2035. Furthermore, reducing electricity prices induces an increase in final electricity demand compared to the *NoPolicy* scenario, particularly household consumption in Africa, of around 2-4% across scenarios (Figure 8.b.). The more ambitious the climate finance scenario (from the perspective of risk sharing and mitigation for private investors), the higher the effect on electricity demand. Lower electricity prices combined with higher demand are signs of improved access to modern and affordable energy, which is a main development priority in Sub-Saharan Africa where almost 50% of households still do not have access to electricity today (IEA, 2023). In a nutshell, the relative cost reduction of renewable technologies through IDFI interventions can provide a significant boost to renewable energy in Africa without compromising, even supporting other main development goals such as increasing access to affordable electricity.

In addition, Figure 8.b. also shows the average % change in total CO2 emissions during the 2020-2060 period compared to the *NoPolicy* scenario in Africa. We can observe that all CoC reduction scenarios imply slightly lower CO2 emissions than the *NoPolicy* case up to -2.6% in the *Converge* scenario. It means that reduction the COC for VRE investment induces higher electricity consumption and access to affordable energy but without implying additional CO2 emissions, even reducing total emissions. Additional CO2 emissions induced by higher electricity demand are actually offset by the faster decarbonization of energy supply (through decarbonization of power generation due to VRE development and accelerated electrification of final uses). It is also interesting to note that the virtuous circle is maximum in the *Converge* scenario, which combines the

lowest electricity prices, highest demand, and lowest emissions. Overall, these results indicate that reducing the cost of capital for VRE through climate finance can help to accelerate low carbon development in Africa by reconciling renewable energy development, improved access to affordable modern energy and CO2 emissions reductions.

(a) Electricity prices (annualized life-cycle costs) in Africa, % change from *NoPolicy*



(b) Global CO2 emissions and electricity demand in Africa, average % change from *NoPolicy* between 2020 and 2060

Figure 8: Change in electricity prices, CO2 emissions and electricity demand in Africa under CoC reduction scenarios.

5 Conclusion and Policy Implications

Overall, our findings suggest that international climate finance could lead to a substantial acceleration in the deployment of Variable Renewable Energy in developing economies. This is because the cost of capital would decrease, particularly as public finance mobilizes

1 private capital and shifts the risk-return profile of VRE investments. Using Africa as a
2 key study because of its high perceived risks for VRE investment, the key message of this
3 article is that reducing the cost of capital for VRE investments in developing economies
4 through international public climate finance is highly relevant, as it facilitates the renew-
5 able energy transition but also improve access to affordable and clean energy. However,
6 to accelerate and sustain a faster deployment of renewable energy in all developing re-
7 gions, shifting the risk-return profile of private investors is crucial, as illustrated by the
8 gap between the *Provide* and the *Catalyze&Blend* scenarios. Additionally, to achieve
9 renewable energy penetration at the scale required for deep decarbonization of power
10 systems in the context of rising energy demand in developing countries, international cli-
11 mate finance must be integrated into a broader policy mix. This study only examines the
12 impact of international climate finance on variable renewable power generation technolo-
13 gies and finds modest reductions in total CO2 emissions in developing regions, as fossil
14 fuels remain dominant in the energy systems (Figure 14 in the Appendix). Not surpris-
15 ingly, IDFI interventions cannot fully substitute for national authorities in creating an
16 enabling environment for VRE investments and disincentivizing high-carbon investments,
17 for example through carbon pricing and ruling out fossil-fuel subsidies.

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34 To increase the impact of international climate finance, more incentives are needed
35 for IDFI to create an enabling environment for private investors and shift the risk-
36 return profile of VRE investments. Otherwise, international climate finance will have little
37 impact on the deployment of VRE and CO2 emissions. The contrasted VRE deployment
38 pathways described by *Provide*, *Catalyze* and *Catalyze&Blend* tell us how important
39 it is to both provide capital and scale up private finance to keep the cost of capital low
40 for renewable energy investments. In a nutshell, this study adds quantitative insights to
41 the recent thinking on the role and tools IDFI are using support the renewable energy
42 transition in developing economies. This leads us to point out two limitations of our
43 study. First, we consider a single lending instrument for climate finance because it is
44 consistent with the current practice of IDFI in financing renewable energy. Nonetheless,
45 increased risk-taking by IDFI, such as through the development of equity investments, is
46 cited as one way to increase the leverage of private investment (Attridge, 2022). This also
47 applies to guarantee mechanisms, which are proving to be effective risk mitigation tools.

1 Second, this study investigates the impact of IDFI activities over the cost of capital, and
2 the cost of capital only. Our IAM framework does not allow to represent capital scarcity
3 other than by a price effect (higher cost of capital). The barriers to VRE investment can
4 be higher than those represented in the IMACLIM-R model, meaning that even bankable
5 VRE projects would fail to be financed by reluctant private investors. For this reason, this
6 study probably underestimates the role of IDFI in accelerating the pace of the low-carbon
7 transition in developing economies.
8

9 To improve the accuracy of policy-oriented results, further efforts are needed to in-
10 corporate financing constraints and opportunities into integrated assessment models. In
11 particular, empirical analysis of the relationship between private and public capital is
12 needed to increase the robustness of climate finance-driven CoC reduction scenarios. In-
13 novative techniques that increase the availability of data on financing conditions for VRE
14 investment may help address this issue in future research (Egli *et al.*, 2023).
15

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Appendix

Element-wise description of the Cost of Capital model

Estimating the overall cost of capital requires collecting data on three key elements: the cost of debt, the cost of equity and the leverage ratio, each being computed separately based on established methods and guidelines (Grubb *et al.*, 2020).

- the cost of (private) debt

Multiple methodologies for estimating the cost of debt coexist. We choose the one that suited the most to cross-country or region-level analysis, namely using financial market data (Steffen, 2020). Hence, the cost of debt for renewable projects is given by the sum of a risk-free rate, a country-risk premium and a renewable risk premium (Angelopoulos *et al.*, 2017):

$$K_{i,r,t}^D = R_{r,t}^f + CRP_r + RRP_{i,r,i} \quad (6)$$

$$RRP_{i,r,t} = \max(RRP^{inf}, (1 - \frac{Cap_{i,r,t}}{Cap_{i,r}^{sup}})RRP^{max}) \quad (7)$$

The Renewable Risk Premium (RRP) follows Sweerts *et al.*'s (Sweerts *et al.*, 2019) specification of a linear relationship between absolute installed capacity - rather than relative capacity (Rickman *et al.*, 2022) - and incremental borrowing costs for renewable projects. The Renewable Risk Premium is 6% when the renewable energy technology under study is completely immature (no installed capacity). This 6% threshold is consistent with previous surveys of European experts, when renewable energy investments were still considered risky and the technologies immature (Noothout *et al.*, 2016). We assume that the Renewable Risk Premium does not drop to zero for fully mature VRE markets but stays positive, to account for debt margins (Egli *et al.*, 2018). In general, corporate bonds offer higher yields than government bonds to compensate for higher risks, even in low-risk environments. The minimum premium (RRP^{inf}) is set at 1.2%, following Agutu

1 *et al.*, 2022.

2
3 The country risk premium is based on Damodaran’s calculations (Damodaran, 2020).
4
5 10-year Treasury Bonds (2015-2022 averages) are used as proxies for the risk-free rate:
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7 German bonds for Europe (European Central Bank, 2022), US bonds (Board of Governors
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9 of the Federal Reserve System (US), 2022) for the rest of the world.

10
11 In the *Catalyze&Blend* scenario, we assume that the Renewable Risk Premium is
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13 reduced by $Riskdec^{climfin}\%$ for co-financed projects, as the provision of public capital in
14
15 blended finance decreases the risk perceived by private lenders who require lower rates of
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17 return (Gurara *et al.*, 2018). We also assume that IDFI interventions reduce the minimum
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19 Renewable Risk Premium in the *Catalyze&Blend*: because IDFI share risks, for instance
20
21 through investment in subordinated debt, private lenders will accept lower debt margins.
22
23 Thus, in blended finance structures, the minimum Renewable Risk Premium is divided
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25 by two (0.6% versus 1.2%).

$$(K_{i,r,t}^D)^{climfin} = R_{r,t}^f + CRP_r + \max(0, RRP_{i,r,t} - Mob^{climfin}) \quad (8)$$

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- 33 • the cost of equity
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36 The cost of equity, defined as the financial return expected by shareholders in exchange
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38 for providing capital (IEA, 2022b), is approximated using a capital asset pricing model
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40 (CAPM), with ERP_r the equity risk premium and β the CAPM’s beta who measures the
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42 volatility of an asset’s return compared to the entire market’s volatility:
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$$K_{i,r,t}^E = R_r^f + \beta_{i,r}(ERP_r) \quad (9)$$

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51 The equity risk premium is equal to the country risk premium adjusted by a factor
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53 that takes into account the specific risks of the equity markets. The overall risk associated
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55 with renewable energy investments is reflected by the beta. To our knowledge, data on
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57 technology-specific betas are not yet available. The existing information is aggregated into
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59 a “renewable energy” sector and more work is needed overall to improve understanding
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of the renewable energy equity market and financing (Zhou *et al.*, 2021). As such, we did not include any de-risking effect of public capital on the cost of equity.

- the leverage ratio

The leverage ratio is a major driver of change in the cost of capital of renewable energy projects considering the gap between the cost of debt and the cost of equity. The leverage ratio can also be expressed in terms of equity requirements by debt providers. Debt providers will require higher shares of equity for riskier projects (or perceived as), as it limits their potential losses since debt is repaid prior to equity in case of default. As a consequence, the observed leverage ratio tends to be lower in developing economies as well as for projects that are exposed to market risks, *e.g.* not covered by feed-in tariffs (IEA, 2020). Without international climate finance, we assume fixed equity ratios of 50% ($(\frac{E}{V})^{sup}$) in developing economies and 20% ($(\frac{E}{V})^{inf}$) in advanced economies. In the *Catalyze* and the *Catalyze&Blend* scenarios, we assume that IDFI enable the environment for VRE investment through knowledge and standard diffusion, the so-called catalytic effect. We use cumulative renewable energy finance as a proxy for the catalytic effect, which is captured per region and per technology. Therefore, we assume that equity requirements for VRE projects decrease linearly with cumulative IDFI intervention, to 30% equity when $Cap^{climfin}$ is reached. We limited the decrease in equity requirements in developing economies to account for the fact that they remain more risky investment environments, even for mature sectors.

For co-financed projects ($CoC^{climfin}$), the volume of debt provided by IDFI over the total volume of debt ($share^{D^{public}} = \frac{D^{public}}{D}$) per project is exogenous and depends on the climate finance scenario. In *Catalyze&Blend*, $share^{D^{public}}$ equals 50%, meaning IDFI allow private lenders to participate in cofinanced projects in addition to equity providers. In the *Provide* and *Catalyze* scenarios, $share^{D^{public}}$ equals 100%: IDFI either provide 100% of a project's debt or do not participate in his financing.

The cost of capital in 2022 - calculation

	Description	Assumption	Source and justification
R^f	Risk-free rate	see table 5	European Central Bank, 2022 for Europe, Board of Governors of the Federal Reserve System (US), 2022 for the rest of the world (2015 - 2022 average)
CRP	Country-risk premium	see table 5	Damodaran, 2020 (2017-2020 average)
Cap^{sup}	Threshold to reach technology maturity	200GW	Authors' assumption, inspired from Sweerts <i>et al.</i> , 2019
RRP^{sup}	Maximum Renewable Risk Premium	6%	Observed premiums from Noothout <i>et al.</i> , 2016
RRP^{inf}	Minimum Renewable Risk Premium	1.2% ⁷	(Agutu <i>et al.</i> , 2022)
ERP	Equity risk premiums	see table 4	Damodaran, 2020 (2017-2020 average)
β	CAPM's beta	see table 4	Damodaran, 2020 (2017-2020 average)
$\frac{E^{sup}}{V}, \frac{E^{inf}}{V}$	Equity requirements	50% for developing economies, 20% for developed countries	For projects with market-based revenues (IEA, 2022c) or investments in region with immature renewable energy finance sectors (Agutu <i>et al.</i> , 2022)

Table 2: Parameter settings for the Weighted Average Cost of Capital module

	Description	Provide	Catalyze settings	Catalyze&Blend setting	Justification
$Capq^{public}$	Threshold for the equity requirement to reach 70% debt per project (cumulative \$ billion)		30	10	Authors' assumption
$Riskdec^{clim,fin}$	De-risking effect under IDFI intervention			-2%	Participation of IDFI (MBDs) reduce the loan spread on syndicated loans (Gurara <i>et al.</i> , 2018)
$share^{D^{public}}$	Share of public debt in total debt volume for projects receiving financial support	100%	100%	50%	The <i>Catalyze&Blend</i> scenario follows blended finance principles: public capital is used strategically, to de-risk a larger number of VRE projects
$K^{D^{public}}$	Interest rate on concessional loans	6%	4%	3%	The degree of concessionality increases across scenarios and starts at a close-to-market rate (6%) for developing countries

Table 3: Private capital mobilization in climate finance scenarios

Table 4, 5 and 6 provide the detailed calculation of the 2022 cost of capital for solar PV investments, *Low Mobilization* scenario.

Region	R^f	β	ERP	K^E
USA	2.1	2.3	0	14.8
Canada	2.1	2.3	0	14.9
Europe	0.2	2.4	1	15.7
OECD Pacific	2.1	2.3	0.6	16
Former Soviet Union	2.1	1.1	3.4	11.6
China	2.1	2.4	0.8	17
India	2.1	1	2.2	9.8
Brazil	2.1	2.1	3.5	21.5
Middle East	2.1	1	3.3	11.3
Africa	2.1	1	5.7	13.5
South East Asia	2.1	1	2.9	10.8
LAC (except Brazil)	2.1	1	3.5	11.2

Table 4: Cost of equity in 2022, %

Construction of climate finance scenarios

Renewable energy finance flows are calculated according to a three-step process described in Fig 9.

Region	R^f	CRP	RRP	τ	K^D	$(K^D)^{climfin}$
USA	2.1	0	2.9	27	3.6	
Canada	2.1	0	5.8	26.5	5.8	
Europe	0.2	0.8	2.1	24	2.4	
OECD Pacific	2.1	0.5	5	29.1	5.4	
Former Soviet Union	2.1	2.9	5.9	19.1	8.8	7.1
China	2.1	0.7	1.2	25	3	
India	2.1	1.9	5.1	30	6.4	5
Brazil	2.1	3	5.8	34	7.1	
Middle East	2.1	2.8	5.5	23.3	7.9	6.4
Africa	2.1	4.8	5.7	27.6	9.1	7.7
South East Asia	2.1	2.5	5.4	24	7.5	6
LAC (except Brazil)	2.1	3	5.4	29	7.4	6

Table 5: Cost of debt in 2022, %

Region	K^D	K^E	$(K^D)^{climfin}$	$\frac{E}{V} / (\frac{E}{V})^{climfin}$	$share^{climfin}$	CoC_{cofin}	CoC_{priv}	CoC
USA	3.6	14.8		20			5.9	5.9
Canada	5.8	14.9		20			7.6	7.6
Europe	2.4	15.7		20			5	5
OECD Pacific	5.4	16		20			7.5	7.5
Former Soviet Union	8.8	11.6	7.1	48.8	16	8.1	10.2	9.8
China	3	17		20			5.8	5.8
India	6.4	9.8	5	47.9	31.6	6.6	8	7.6
Brazil	7.1	21.5		20			10	10
Middle East	7.9	11.3	6.4	49.9	1.9	7.8	9.6	9.6
Africa	9.1	13.5	7.7	41.6	100	8.5	10.9	8.5
South East Asia	7.5	10.8	6	46.1	51.6	7.2	9.1	8.1
LAC (except Brazil)	7.4	11.2	6	47.8	29.5	7.5	9.2	8.7

Table 6: Cost of Capital in 2022, %

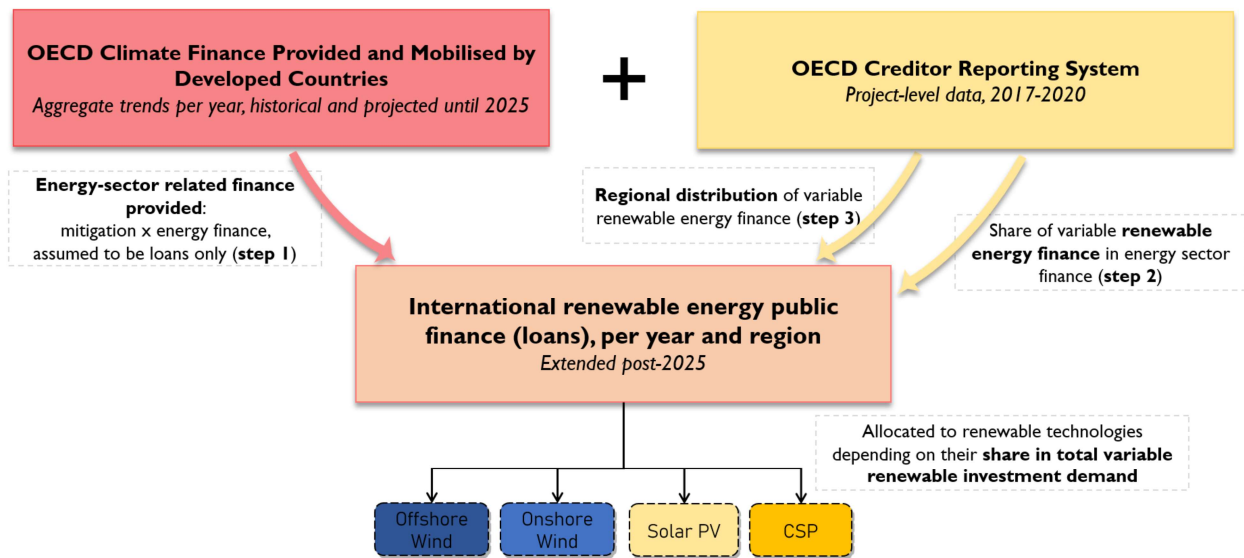


Figure 9: Deriving projected international renewable energy finance from aggregate climate finance trends and project-level data: summary of the process

Step 1. Aggregate energy sector finance (loans). The global climate finance flows are disaggregated to isolate the share oriented toward the power sector, using the sectoral disaggregation provided by the OECD (OECD, 2022b). 2016-2019 averages are used first to separate climate finance for mitigation (70%) from climate finance for adaptation (30%), then to isolate the share for energy sector climate finance (34% of total climate finance). For the sake of simplicity, we make the additional assumption that 100% of the energy sector finance takes the form of loans, even if loans only represent around 70% of total public climate finance provided between 2016-2019 according to the OECD. In practice, for energy investments IDFI provide almost only loans, and very little grants (OECD, 2022a). Reducing energy finance to a single instrument (concessional loans) facilitates its integration into the CoC formula, rather than considering grants, equity, or even more complex instruments. However, this assumption is rather conservative with respect to the potential future evolution of renewable energy finance toward blended finance principles that involve strategic use of concessional resources to maximize the mobilization of private capital (Development Finance Institutions, 2022). For

instance, guarantee mechanisms are currently underutilized by IDFIIs but are known to be powerful tools to mobilize private capital under constrained public resources (Group & Fund, 2018). Thus, the share of the energy sector loans in the total climate finance provided is given by $70\% * 34\% * 100\% = 23\%$.

Year	2020	2021	2025	...	2060
International public climate finance, in current bn USD	68.3	77.7	94.5		94.5
International public renewable energy finance, in current bn USD	6.2	6.6	8.8	...	8.8

Table 7: International public climate finance and renewable energy finance: historical flows (lightgray) and forward-looking estimates (gray) kept constant after 2025 (black)

Step 2. Share of renewable energy finance in total energy finance. Further assumptions are needed to account for the power sector portfolio composition of IDFIIs, which invest both in renewable and non-renewable technologies, and the regional orientation of these financing flows. Multilateral Development Banks in particular are increasingly seeking to "green" their portfolios, but continue to invest in fossil fuel technologies to meet their energy access mandate (Steffen & Schmidt, 2019). To do so, we check project-level financing data from the DAC's Creditor Reporting System (CRS) and remove the sub-sectors of the energy sector related to either fossil-fuel technologies or non-solar/wind technologies (Table 8). Between 2017 and 2020, the share of the energy sector finance directly dedicated to wind and solar projects varies from 29% to 37%. We use 40% as an estimate for the share of VRE finance in the total energy sector finance during the period under study (2020 - 2060), which is higher than the historical values, for two reasons. First, we excluded CRS subsectors that might include direct or indirect VRE finance (*e.g.* 'Hybrid energy electric power plants'). Second, as noted above, the share is likely to increase over time as IDFIIs green their portfolios. Thus, we get an annual volume of finance available for concessional loans to VRE (solar and wind) projects in developing countries (Table 7), which is compatible with aggregate IDFI activities.

Step 3. Regional allocation of renewable energy finance.

Step 3 is described in the *Climate finance scenarios - International renewable energy finance* subsection.

Creditor Reporting System Sub-sector	Renewable energy (wind and PV only)
Energy generation, renewable sources - multiple technologies	X
Solar energy for centralized grids	X
Wind energy	X
Energy policy and administrative management	
Electric power transmission and distribution (centralized grids)	
Energy research	
Geothermal energy	
Biofuel-fired power plants	
Energy generation, non-renewable sources, unspecified	
Retail gas distribution	
Hydro-electric power plants	
Energy conservation and demand-side efficiency	
Energy education/training	
Non-renewable waste-fired electric power plants	
District heating and cooling	
Nuclear energy electric power plants and nuclear safety	
Heat plants	
Hybrid energy electric power plants	
Oil-fired electric power plants	
Natural gas-fired electric power plants	
Coal-fired electric power plants	
Electric mobility infrastructures	

Table 8: From CRS 'Energy sector' to wind and solar finance.

Sensitivity analysis

Climate finance-dependant parameters

A one-at-a-time sensitivity analysis for climate finance-dependant parameters of the CoC model in Africa is presented in Figure 10. These parameters ($Capd^{public}$, $Riskdec^{climfin}$, $share^{D^{public}}$) quantify the impact mechanisms of international climate finance on the cost of capital, as described in section 2.1. They vary between 50% and 200% of their central value used in the main analysis, to reflect the large uncertainties surrounding these parameters' calibration.

Our sensitivity analysis confirms that the results are robust to changes in the climate finance-dependant parameters of the CoC model. Only limit cases for $share^{D^{public}}$ lead to small decrease in electricity generation from renewable sources in *Catalyze&Blend* scenario compared to *Catalyze* scenario, and only in the short run (2030). In this situation, IDFI's reduce the share of total debt they cover per project drastically ($share^{D^{public}}$), leading to an underutilization of the available funds for supporting VRE projects (+30% in VRE electricity generation compared to baseline if $share^{D^{public}}$ equals 50% of its central value vs +33% in *Catalyze* and +41% in central case, *Catalyze&Blend* - 2030 case).

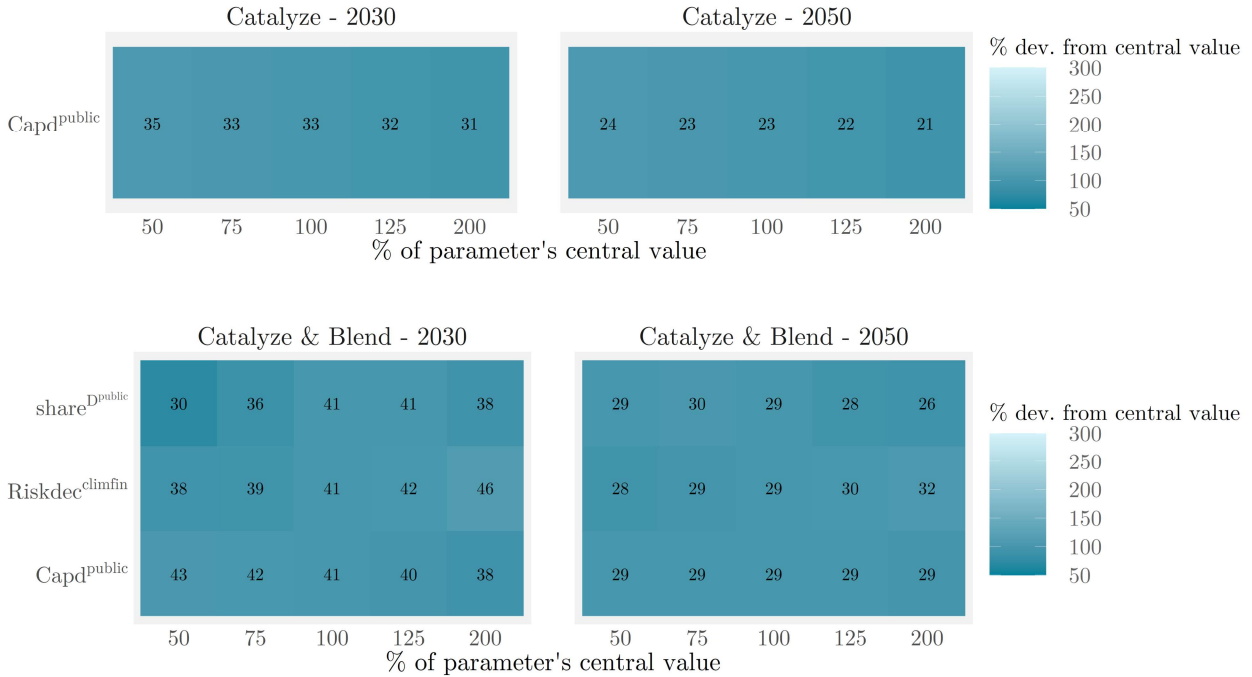


Figure 10: Sensitivity analysis in the *Catalyze* and *Catalyze&Blend* scenarios for Africa, climate finance parameters. Digits indicate the change in renewable electricity production in % from the *NoPolicy* scenario, as in Figure 7. Colors show the % deviation from the central value scenario. Results for the *Provide* case are not displayed because this scenario does not include extra climate finance parameters compared to the *NoPolicy* case.

General parameters

The sensitivity analysis also tests other key drivers of renewable electricity deployment: LR_{renew} , the learning rates of renewable electricity technologies, γ the logit exponent (Equation 5) and two parameters of the standard CoC model, Cap^{sup} and RRP^{sup} (Equation 7). The sensitivity analysis of these parameters checks the robustness of the findings against the calibration of the IMACLIM-R model and its electricity sector module (Figure 11). These parameters are subject to moderate uncertainty, and calibrated based on established knowledge and literature. Therefore, they only change from 75% to 125% of their central value.

The results are more sensitive to changes in global drivers of VRE deployment in IMACLIM-R's electricity sector module. RRP^{sup} calibrates the renewable risk premium and thus drives the initial costs of capital for renewable technologies. Lower (resp. higher)

1 initial costs reduce (resp. increase) the importance of IDFI in removing barriers to
2 financing. The results are also sensitive to changes in γ , especially in the long term
3 (2050, left panel). γ determines how large the ratio between the costs of two technologies
4 must be to generate a significant difference in market shares in new capacity investments.
5 Higher values of γ exacerbate the impact of international climate finance on VRE market
6 shares compared to the *NoPolicy* scenario. The central calibration value of γ comes
7 from the GCAM model ($\gamma = 3$). It has proven its validity in reproducing the historical
8 behavior of electricity markets as well as projections from more detailed sectoral models
9 and can be used with a certain degree of confidence (Binsted *et al.*, 2022, Calvin *et al.*,
10 2019). The learning rates of electricity generation technologies LR_{renew} also have a major
11 influence on the results, assuming here that they all move together in the same direction.
12 Faster technological learning and progress tends to compensate for the high financing
13 costs of VRE technologies and makes international climate finance less needed to decrease
14 leveled costs. Like the logit coefficient, LR_{renew} is also calibrated on established sources
15 and empirically sound (Briera, 2023).
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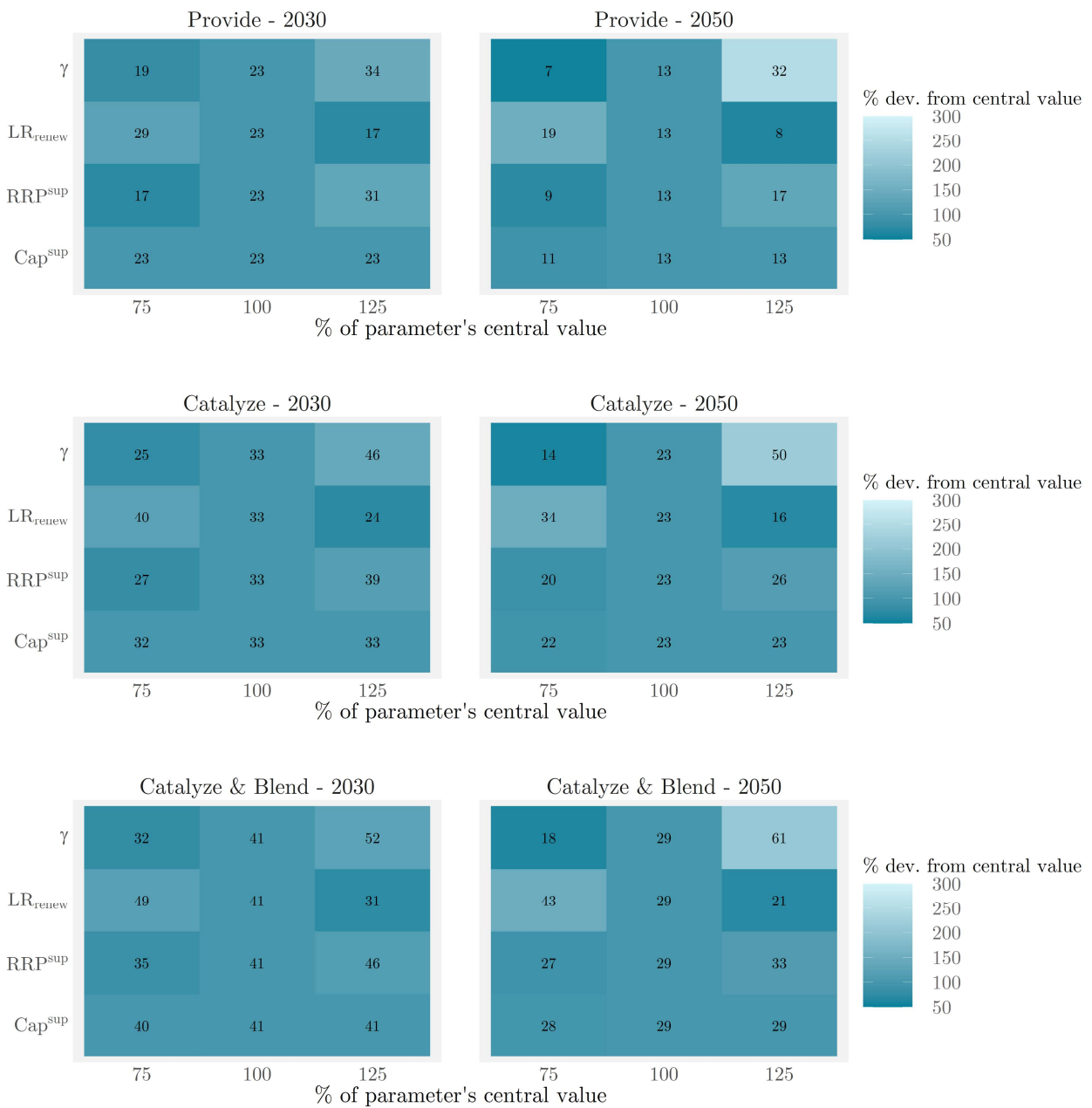


Figure 11: Sensitivity analysis in the three climate finance scenarios for Africa, general parameters of the IMACLIM-R model. Digits indicate the change in renewable electricity production in % from the *NoPolicy* scenario, as in Figure 7. Colors show the % deviation from the central value scenario.

Additional figures

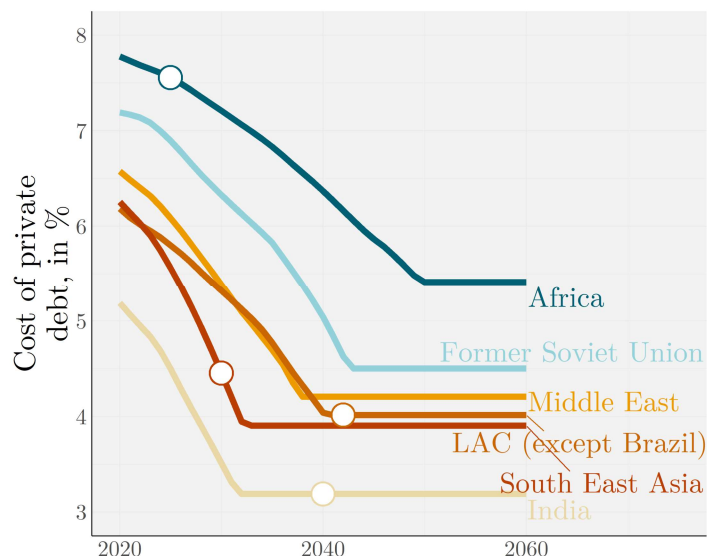


Figure 12: Interest rates on private loans (after tax) in blended finance structures across developing regions (*Catalyze&Blend* scenario). White dots indicate when the VRE finance markets reach maturity due to IDFI activities, *i.e.* when the catalytic effect of IDFI has become maximal, which translates into lower equity requirements for all VRE projects.

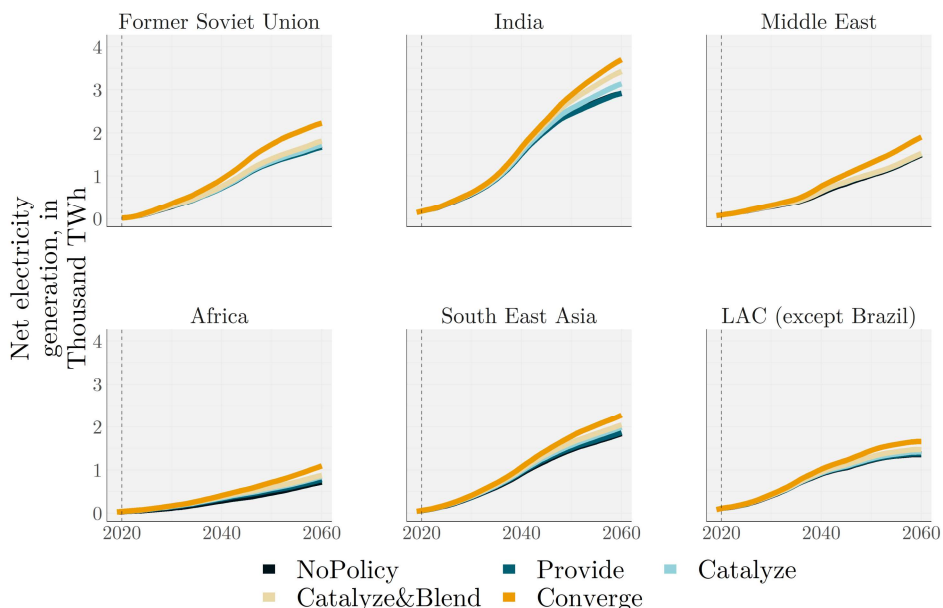


Figure 13: Total variable renewable electricity generation in developing regions, 2020 - 2060

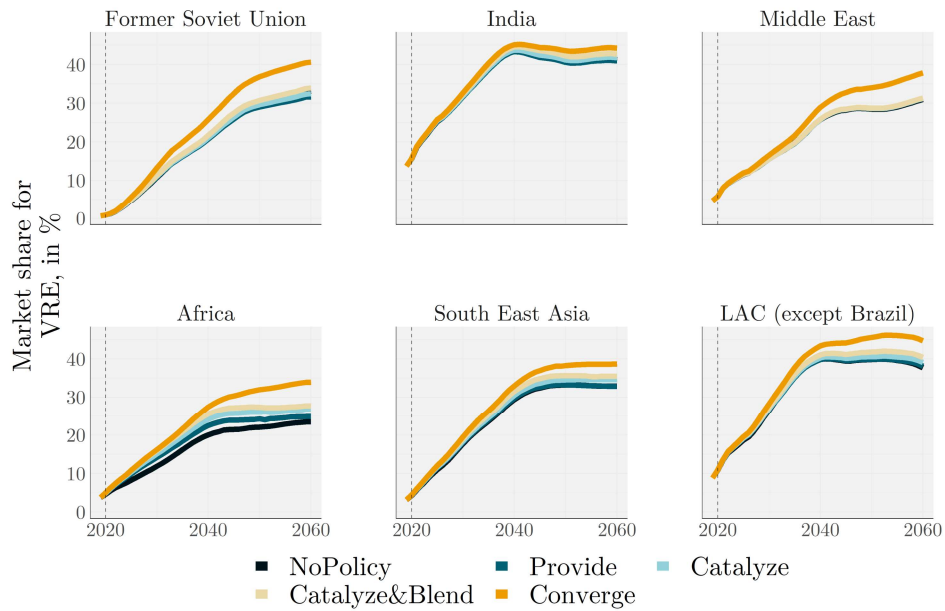
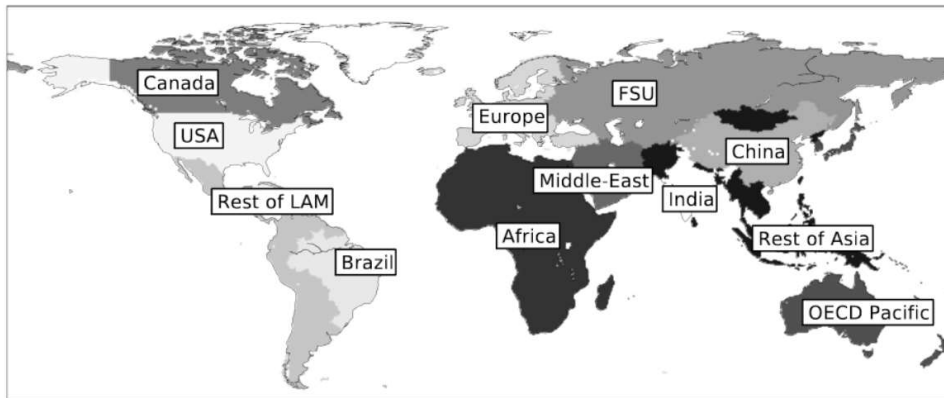


Figure 14: Total variable renewable electricity market shares in developing countries, 2020 - 2060



OECD Pacific includes Australia, New Zealand, Japan and South Korea.

FSU = Former Soviet Union.

Rest of LAM = Rest of Latin America.

Figure 15: Regional disaggregation of IMACLIM-R model, Bibas *et al.*, 2016