Aloe Energy

Carbon, certificates and the bottom line: what carbon credits and renewable energy certificates do for solar and mini-grid finance in Southern Africa

Carbon credits and renewable energy certificates are often presented as the money that will make clean power projects work. We built simple, open financial models of four typical projects to see how much they really change the tariff a project needs, the return to its investors and the case for its lenders.

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Key findings

- **The grid decides what a carbon credit is worth.** A megawatt-hour of solar earns about 0.73 tonnes of carbon credits on South Africa's coal-heavy grid and about 0.06 tonnes in Zambia, which runs mostly on hydro. Same panels, a twelvefold difference.
- **In South Africa, carbon credits can matter a lot for grid solar.** At US$10 per tonne they cut the tariff a 50 MW plant needs by about 10%, and at US$25 by about 27%, if the project can show it would not happen without that money. Using the UN's new default factor instead of a calculated one cuts the benefit to about 1%.
- **In Zambia, carbon credits do not pay for grid solar.** Their value barely covers the cost of certifying them: they break even only at about US$17 per tonne.
- **Renewable energy certificates are small change for the seller.** I-RECs at today's South African price of US$0.59/MWh lower the tariff a project needs by under 2%. Their real value is to buyers, who need them to claim clean power.
- **For mini-grids, grants matter far more than carbon.** Our model mini-grid needs about US$0.81/kWh with a 50% capital grant, against about US$0.30 that households can afford. D-RECs and carbon credits close only about 2-16% of that gap, even in the best case; raising the grant to 70% closes more than either. Carbon helps most when a buyer pays for credits up front and many sites share the cost of certification.

Three ways to sell the extra value of clean power

A solar plant produces electricity and something else: proof that the electricity is clean. That proof can be sold in three main forms. They answer different questions and are bought by different people, and in most cases the same megawatt-hour can only be sold once.

Renewable energy certificates (I-RECs)

One certificate proves that one megawatt-hour came from a renewable plant. Companies buy them to report lower emissions from the power they use. Any registered plant qualifies, old or new. In Southern Africa, five countries issue them; South African solar and wind certificates traded at US$0.59/MWh in August 2026.

Impact labels (D-RECs and P-RECs)

Labels on I-RECs from small distributed solar (D-RECs) or from projects in fragile places (P-RECs). Buyers pay for the story of new access to power: about US$20-30/MWh for D-RECs and US$45 on average for P-RECs. Volumes are small and only part of the price reaches the project.

Carbon credits

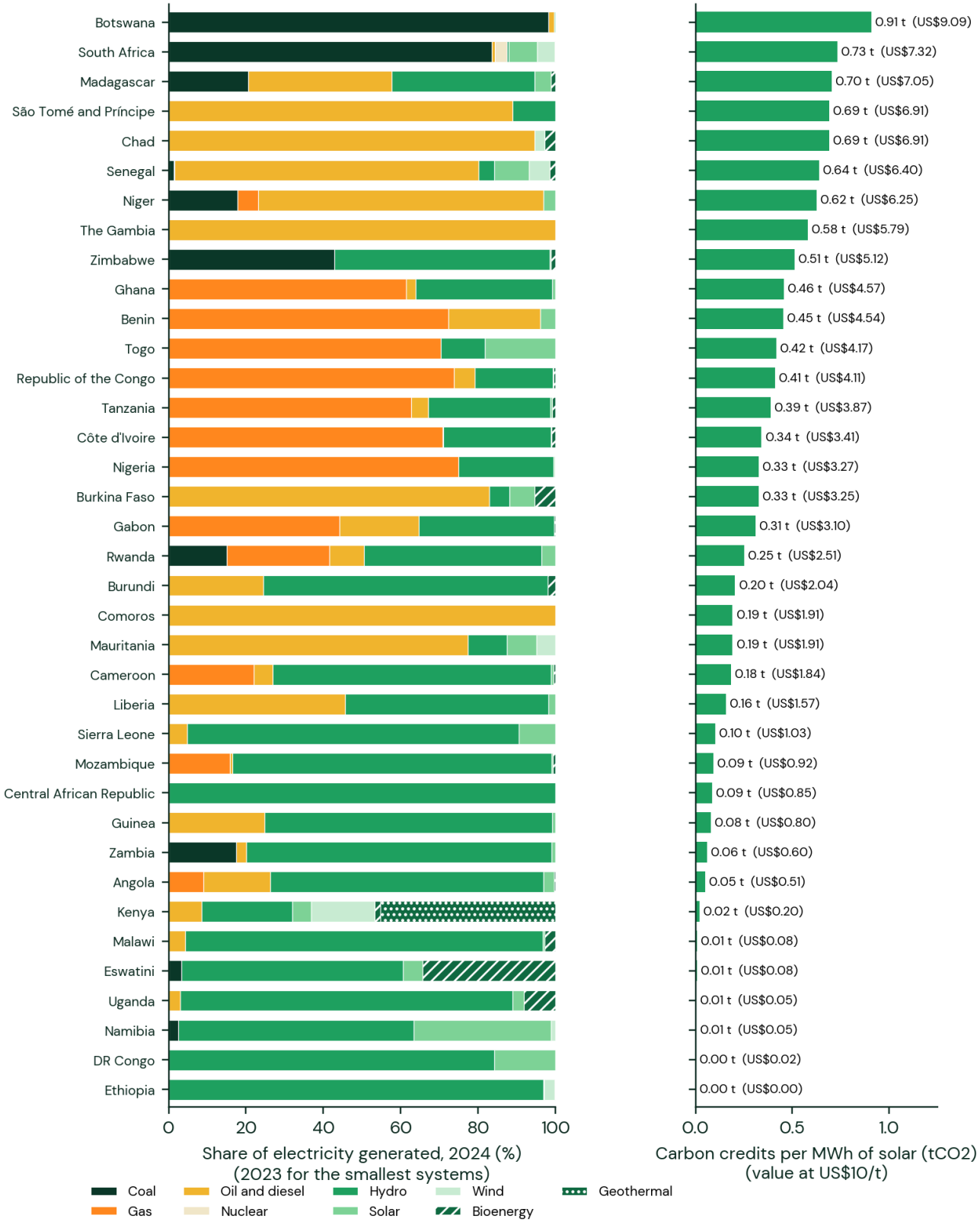
One credit is one tonne of CO2 avoided compared with what would have happened without the project. Credits are bought to offset emissions or, under Article 6 of the Paris Agreement, traded between countries. The project must be additional: it would not have gone ahead without the carbon money. How many credits a megawatt-hour earns depends on what it replaces: the grid's emission factor for grid-connected plants, diesel and kerosene for off-grid ones.

The grid decides what a carbon credit is worth

Figure 1 puts each country's generation mix next to the carbon credits a megawatt-hour of new solar would earn under the combined margin of the UN's new electricity tool (A6.4-AMT-007), using our open grid emission factors. Coal-heavy Botswana and South Africa sit near 0.7-0.9 tonnes. Oil-run grids in West and Central Africa, such as Niger, Chad and Senegal, are close behind, and gas grids such as Nigeria and Ghana sit near 0.3-0.5. Hydro grids sit near zero. A carbon price of US$10 per tonne is worth about US$7 per megawatt-hour in South Africa, a quarter of the price at which South Africa's newest solar plants sell their power, and almost nothing in the DR Congo or Malawi.

The chart explains most of what follows. Wherever the grid is clean, carbon credits for grid-connected renewables are thin, and the case for them rests on certificates or on other support. Where the grid burns coal, carbon credits can be a real revenue stream.

Figure 1. Grid mix and carbon credits per megawatt-hour of new solar, 36 African countries



Generation mix 2024 from Ember yearly electricity data (built on US EIA statistics), with Energy Regulation Board figures for Zambia; 2023 for the Central African Republic and São Tomé and Príncipe. Carbon credits: combined margin for wind and solar under A6.4-AMT-007 weights, from Aloe Energy's grid emission factors. Lesotho (no generation data for 2024) and the Comoros (no recent new capacity) are not shown. Sierra Leone is likely understated: the data misses a leased oil-fired powership.

How we modeled it

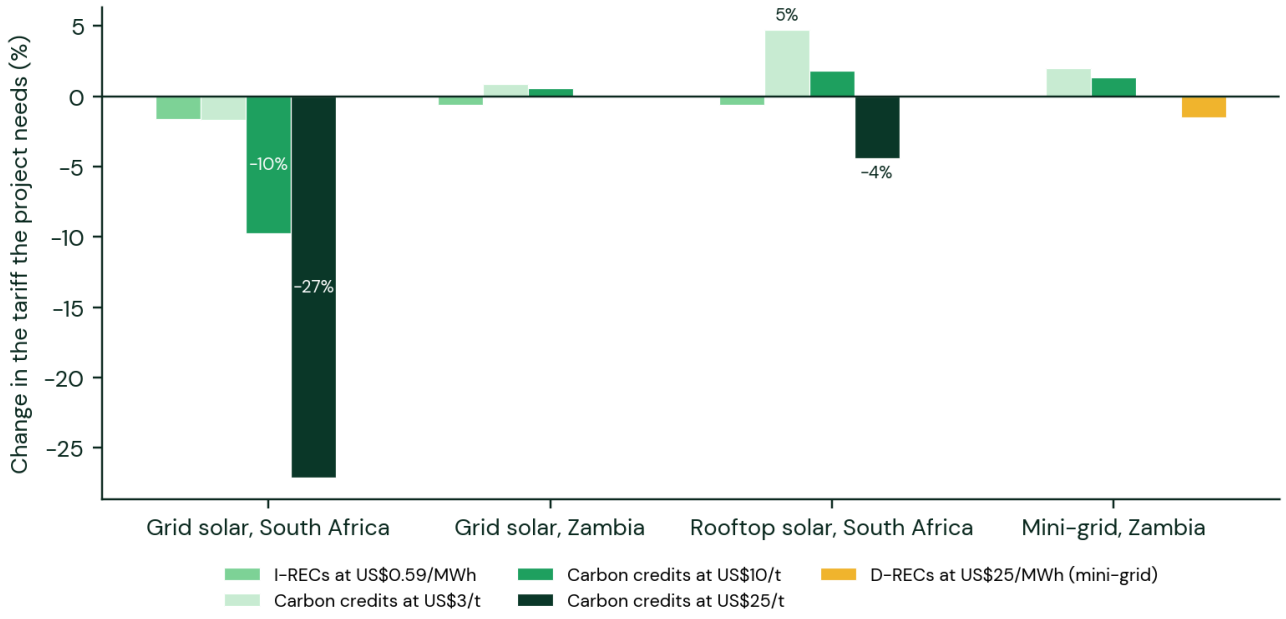
We built four illustrative projects, each with a simple annual cash-flow model in real US dollars before tax. All inputs come from public sources or are clearly marked as assumptions (see the annex):

- **Grid solar, South Africa:** 50 MW, inputs set so the tariff it needs lands near the latest REIPPPP solar prices (about US$28/MWh).
- **Grid solar, Zambia:** the same plant on commercial terms, with higher costs and a higher return for country risk.
- **Rooftop solar, South Africa:** a 500 kWp system selling power to a business at about 25% below the utility tariff.
- **Mini-grid, Zambia:** 100 kWp of solar with batteries serving about 450 households and businesses, with a 50% capital grant.

For each, we find the flat tariff at which equity investors earn their target return, then add one extra revenue stream at a time and see how far that tariff falls. We also report the equity return and the lowest debt service coverage ratio (cash available for debt payments divided by those payments) at the original tariff. Carbon revenue starts two years after operations, lasts ten years and carries set-up and verification costs, levies and a broker's share.

Results: South Africa yes, Zambia no

Figure 2. How much each revenue stream lowers the tariff a project needs



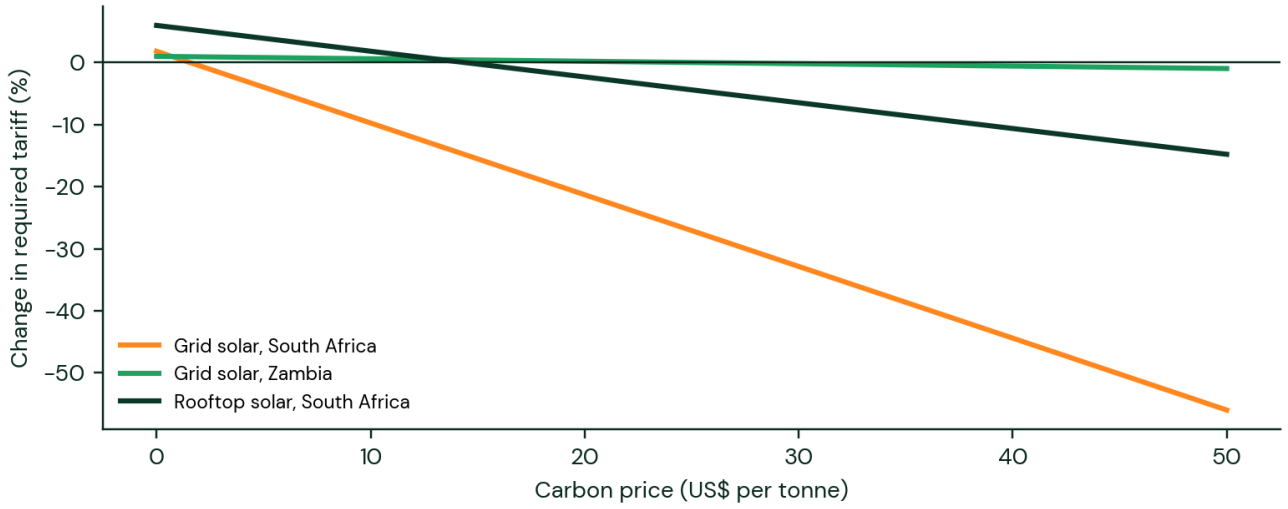
Change in the flat real tariff needed for the target equity return. Positive values mean the stream costs more to certify than it earns. Source: Aloe Energy model, assumptions in the annex.

Grid solar in South Africa. Carbon credits at US$10 per tonne lower the tariff the plant needs from US$28.9 to US$26.1/MWh, about 10%. At US$25 the needed tariff falls to US$21.1/MWh. Put the other way, at the original tariff the equity return rises from 12% to 16.5% at US$10 and 24.5% at US$25. Figure 5 shows where the value of a credit goes before it reaches the project.

Two caveats are large. First, additionality: a plant that wins a REIPPPP contract at a competitive tariff will struggle to show it needed carbon money, so in practice this applies to projects outside the program,

such as merchant or private wheeling projects, or to deals designed around carbon from the start. Second, the factor used: if a developer takes the UN tool's cautious default (0.2 tCO2/MWh for South Africa) instead of calculating the grid's combined margin, the benefit at US$10 shrinks to about 1%. Good grid data is worth money.

Figure 3. Required tariff as the carbon price rises

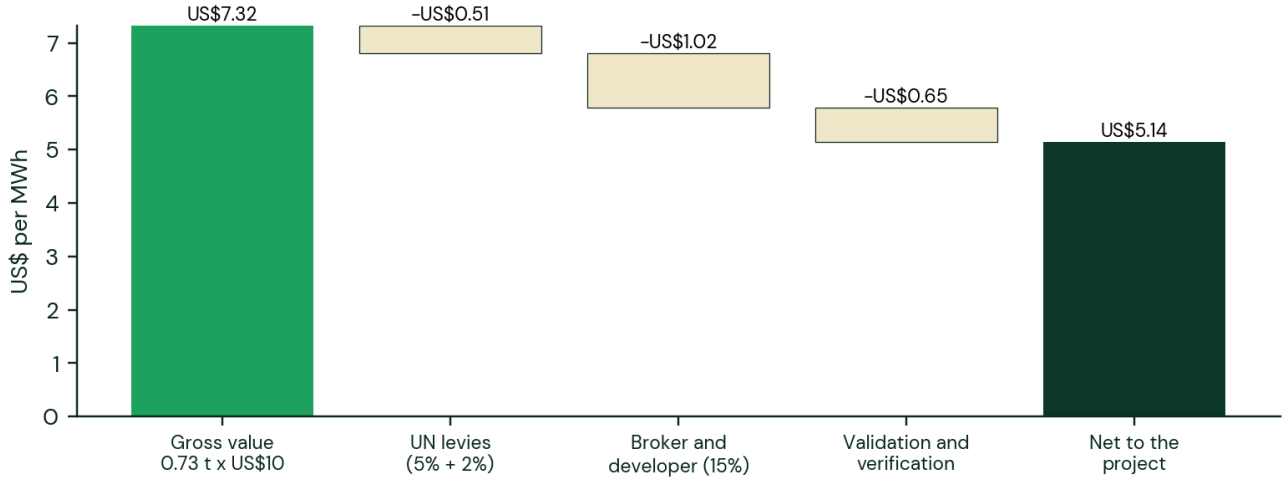


Source: Aloe Energy model. At zero carbon price the line sits above zero because the project still pays to set up and verify its carbon credits.

Grid solar in Zambia. With about 0.06 tonnes per megawatt-hour, a 50 MW plant earns roughly 6,000 credits a year. At US$10 that is about US$60,000 before costs, which is what a yearly verification costs. Carbon credits only start to pay above about US$17 per tonne, and even at US$25 they make no visible difference to the tariff. Zambia's own carbon scheme with Norway, a premium paid for verified results from new solar with storage, may change this, but its price is not public.

Certificates. I-RECs lower the needed tariff by about 1.6% in South Africa and 0.6% in Zambia. They are cheap to register and simple to sell, so they are worth having, but they do not change whether a grid project gets built.

Figure 5. Where the value of a carbon credit goes: grid solar in South Africa at US$10 per tonne



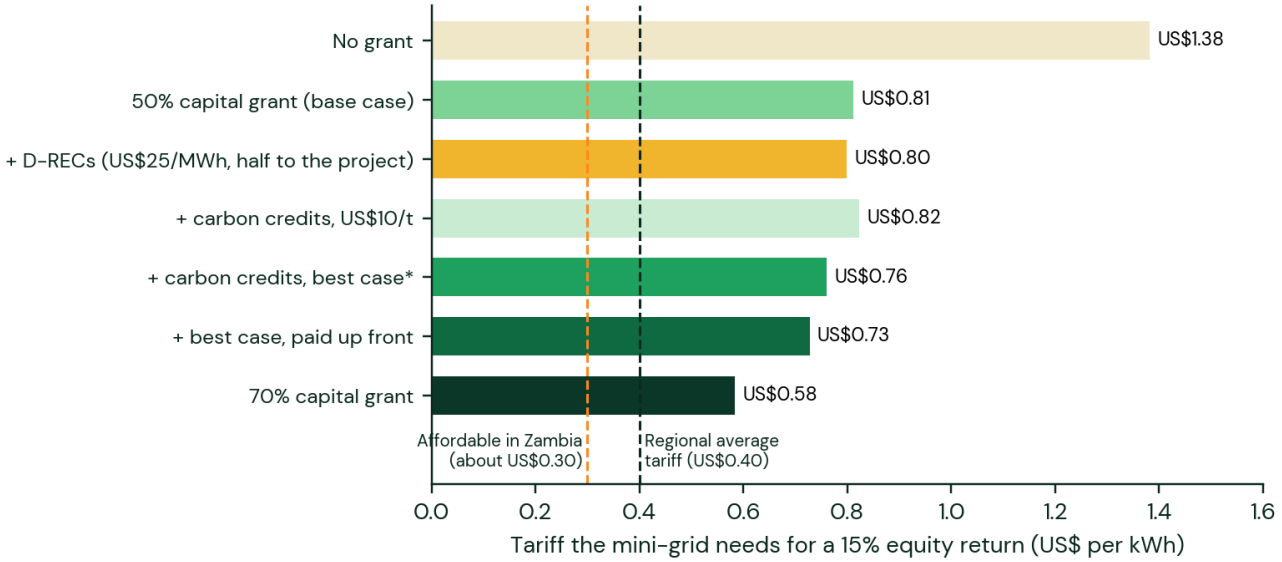
US$ per MWh during the crediting years. UN levies apply under the Paris Agreement Crediting Mechanism outside least developed countries. Broker share and costs are assumptions within the ranges reported by the World Bank (2024).

Mini-grids: small volumes, big gap

Mini-grids replace diesel generators and kerosene lamps, not the national grid, so each megawatt-hour avoids more carbon. The old UN method for rural electrification (AMS-I.L) credits the first 55 kWh per household at 6.8 tonnes per megawatt-hour, reflecting kerosene lighting. A 2022 draft proposed 2.72 instead, and the Paris Agreement mechanism has yet to settle its own rule. We use three cases: 0.8, 1.73 (with the 2022 draft) and 3.18 tonnes per megawatt-hour on average across the mini-grid's sales.

The problem is volume. A village mini-grid sells about 70 MWh a year, so even at the high factor it earns a few hundred credits. Certification costs that are trivial for a 50 MW plant eat most of that value. In our mid case, carbon credits cost slightly more than they earn; they break even at about US$15 per tonne.

Figure 4. The tariff a 100 kWp mini-grid needs, and what closes the gap



*Best case: 3.18 tCO2/MWh, US$40 per tonne, verification shared across a large program (US$300 per site a year) and a 15% broker share. "Paid up front": a buyer prepays ten years of credits, discounted at 8% a year. Source: Aloe Energy model.

Grants decide whether a mini-grid can charge what people can afford. Carbon credits and certificates help at the margin, and most when they are paid up front.

Our model mini-grid needs about US$0.81/kWh for a 15% return even with half its capital paid by a grant. Zambian households can afford about US$0.30, and the regional average mini-grid tariff is about US$0.40. D-RECs, with half their price reaching the project, lower the needed tariff by about 1%. Carbon credits in the best case lower it by about 6%, and by about 10% if the buyer pays up front, because money now is worth more to a mini-grid developer than money in five years. Raising the grant from 50% to 70% lowers it to US$0.58/kWh, more than any instrument.

That does not make carbon useless for mini-grids. It makes structure decisive: programs that pool many sites, buyers that prepay, and results-based payments that arrive early. Cookstove programs, where carbon has been about a quarter of company revenue, show what is possible when volumes are large.

Rooftop solar: a buyer's tool, not a lender's

Our 500 kWp rooftop system already earns about 20% for its equity investors when it sells power at 25% below the utility tariff, so it does not need extra revenue. Carbon credits only pay above about US$11 per

tonne for a site this size, unless it joins an aggregated program. I-RECs lower the needed tariff by under 1%. For rooftop solar, certificates matter to the business buying the power: they let it claim the electricity is clean in its emissions reporting.

What lenders count

The debt service coverage ratio barely moves in our models, even where carbon credits raise equity returns sharply. That is because the lowest coverage falls in the first years, before credits arrive, and because lenders rarely count carbon at all. Carbon prices are volatile, issuance depends on verification, and rules are still changing. To make carbon or certificates count toward bankability, projects need some combination of:

- **Fixed-price offtake:** a buyer that commits to a price and volume for several years, such as Switzerland's KliK Foundation under its Article 6 deals.
- **Up-front payment:** prepaid credits or certificates that reduce the capital a project has to raise.
- **Results-based public schemes:** premiums paid per verified megawatt-hour or tonne, like Zambia's carbon feed-in premium with Norway.
- **Lower transaction costs:** programs that certify many sites at once, and digital metering that cuts verification costs.

What would help

For developers

- Check the grid factor before planning on carbon revenue: in hydro countries it is close to zero for grid projects.
- Calculate the combined margin rather than taking the UN default, where good grid data exists.
- Register for I-RECs where available: it is cheap, and buyers increasingly ask for them.
- Join or form aggregated programs for small sites, and seek buyers who prepay.

For funders

- Treat carbon and certificates as a complement to capital grants and results-based finance for mini-grids, not a replacement.
- Back prepayment and price-floor structures that turn uncertain future credits into money at financial close.

For governments and regulators

- Publish official, current grid emission factors and grid data: they decide how much carbon finance flows in.
- Keep national shares of carbon proceeds predictable and moderate, and publish them; uncertainty is itself a cost.
- Approve I-REC issuing in the countries that cannot yet issue them: Angola, Eswatini, Malawi, Mozambique and Tanzania.

Limits of this analysis

These are illustrative models, not project appraisals. They leave out tax, currency risk, inflation, construction delays and the detailed rules of each carbon standard, and they assume one price per instrument for all years. Several inputs, including interest rates, target returns and carbon program costs, had no public source and are our assumptions. The results show direction and rough size, and the assumptions are published so anyone can test their own.

Annex A. Results

Project	Case	Tariff needed	Change	Equity return at base tariff	Lowest DSCR
Grid solar, South Africa	Base case	US$28.9/MWh	-	12.0%	1.27
	I-RECs, US$0.59/MWh	US$28.4/MWh	-1.6%	12.7%	1.29
	Carbon, US$3/t	US$28.4/MWh	-1.7%	12.7%	1.27
	Carbon, US$10/t	US$26.1/MWh	-9.8%	16.5%	1.27
	Carbon, US$25/t	US$21.1/MWh	-27.1%	24.5%	1.27
	Carbon, US$10/t, UN default factor	US$28.5/MWh	-1.4%	12.6%	1.27
Grid solar, Zambia	Base case	US$75.8/MWh	-	14.0%	1.31
	I-RECs, US$0.59/MWh	US$75.3/MWh	-0.6%	14.3%	1.32
	Carbon, US$3/t	US$76.4/MWh	+0.9%	13.6%	1.31
	Carbon, US$10/t	US$76.2/MWh	+0.6%	13.7%	1.31
	Carbon, US$25/t	US$75.8/MWh	+0.0%	14.0%	1.31
	Carbon, US$10/t, UN default factor	US$76.4/MWh	+0.8%	13.6%	1.31
Rooftop solar, South Africa	Base case	US$69.5/MWh	-	14.0%	1.18
	I-RECs, US$0.59/MWh	US$69.1/MWh	-0.6%	14.2%	1.19
	Carbon, US$3/t	US$72.8/MWh	+4.7%	12.4%	1.14
	Carbon, US$10/t	US$70.8/MWh	+1.8%	13.4%	1.20
	Carbon, US$25/t	US$66.5/MWh	-4.4%	15.5%	1.23
	Carbon, US$10/t, UN default factor	US$72.9/MWh	+4.8%	12.4%	1.13
Mini-grid, Zambia	Base case	US$0.81/kWh	-	15.0%	-
	I-RECs, US$0.59/MWh	US$0.81/kWh	-0.0%	15.0%	-
	Carbon, US$3/t	US$0.83/kWh	+2.0%	14.5%	-
	Carbon, US$10/t	US$0.82/kWh	+1.4%	14.6%	-
	Carbon, US$25/t	US$0.81/kWh	-0.0%	15.0%	-
	D-RECs, US$25/MWh	US$0.80/kWh	-1.5%	15.4%	-
	Carbon, best case	US$0.76/kWh	-6.3%	16.7%	-
	Carbon, best case, prepaid	US$0.73/kWh	-10.3%	18.2%	-

Equity return and lowest debt service coverage ratio (DSCR) are at the base case's required tariff. The mini-grid is all equity, so it has no DSCR. Best case: see Figure 4.

Annex B. Assumptions and sources

Common: carbon prices 3 / 10 / 25 US$ per tonne. Low: voluntary market renewable energy credits averaged US$2.67/t in 2024 (Ecosystem Marketplace, State of the VCM 2025). Mid: Africa-origin voluntary credits US$7.53/t, household devices US$7.30/t (same); correspondingly adjusted credits US$7-22/t (ClearBlue via Carbon Pulse, Nov 2024). High: CORSIA Phase 1 units US$9-22/t in 2025-26 (World Bank State and Trends 2026; CIX H1 2026); Singapore Article 6 tender bids S$25-55/t (OPIS, Mar 2025). I-RECs: Argus, South Africa current-year solar and wind I-RECs, assessed 27 Aug 2026. I-TRACK fee structure 2026 v2.3 (GCC issuer). Agent share is an assumption. D-RECs: D-REC US$20-30/MWh (SEforALL, Dec 2023; Okra Solar, Oct 2022). Share reaching the project is an assumption; for P-RECs CPI (2021) found about 20-37% of the sale price reached developers. At least 2 years from concept to first credits (World Bank Kenya Carbon Guidebook 2024). Crediting period of 10 years is an assumption.

Project	Input	Value	Source or basis
Grid solar, South Africa	Size (kW)	50,000	
	Capacity factor	30%	assumption: single-axis tracker plant, about 30% on AC (SA utility PV fleet average 25-26.3%, CSIR Jan 2025, includes older fixed-tilt plants)
	Capital cost (US$/kW)	600	assumption, calibrated so the required tariff matches REIPPPP Bid Window 7 prices (about US$28/MWh); IRENA 2024 global average US$691/kW
	Operating cost (US$/kW-yr)	13	assumption, calibrated with capex
	Life (years)	25	
	Debt share	75%	Scaling Solar maximum 75%; Ilute about 70% (IJGlobal 2025)
	Loan tenor (years)	18	Ilute senior debt 18 years (IJGlobal 2025)
	Interest rate (real)	7%	assumption, calibrated (no public rate found)
	Target equity return	12%	assumption, calibrated
	Carbon credits per MWh (tCO2)	0.732	combined margin for wind and solar under A6.4-AMT-007 weights, Aloe grid emission factors
	UN and national levies	7%	Article 6.4 share of proceeds 5% plus 2% cancelled (UNFCCC fees and levies 2026); South Africa is not an LDC
	Broker and developer share	15%	assumption within World Bank range 10-50%
	Carbon project set-up (US$)	250,000	World Bank Kenya guidebook US$200-400k
	Carbon monitoring and verification (US$/yr)	60,000	World Bank Kenya guidebook US$50-150k per issuance
Grid solar, Zambia	Size (kW)	50,000	
	Capacity factor	22.5%	1,600-1,800 kWh/kWp-yr (GIZ Zambia 2024), about 22-23% on AC
	Capital cost (US$/kW)	1,100	Ilute 32 MWp about US$1,160/kWp DC (IJGlobal, Dec 2025)
	Operating cost (US$/kW-yr)	22	
	Life (years)	25	
	Debt share	75%	
	Loan tenor (years)	18	
	Interest rate (real)	8%	
	Target equity return	14%	
	Carbon credits per MWh (tCO2)	0.06	combined margin for wind and solar under A6.4-AMT-007 weights, Aloe grid emission factors (ERB 2024 data)
	UN and national levies	0%	Article 6.4 levies waived for LDC hosts (decision 7/CMA.4); Zambia's national share of proceeds not yet published
	Broker and developer share	15%	
	Carbon project set-up (US$)	250,000	
	Carbon monitoring and verification (US$/yr)	60,000	
Mini-grid, Zambia	Size (kW)	100	

Project	Input	Value	Source or basis
	Capital cost (US$/kW)	5,000	AMDA Benchmarking 2024: PV-battery US$3,000-4,500/kWp; East and Southern Africa average US$5,775/kWp
	Operating cost (US$/kW-yr)	137	AMDA 2024: US$137/kW-yr for PV-battery
	Life (years)	20	
	Debt share	0%	
	Target equity return	15%	assumption; Zambia mini-grid cost of equity 17.3-24.7% (MECS 2026)
	Energy sold (MWh/yr)	70	assumption: 450 connections at about 10 kWh/month (AMDA 2024) plus productive use
	Capital grant	50%	Zambia Chilubi pilot about 50% capex grant (Energy Alliance, 2026)
	Battery replacement, year 10 (US$)	80,000	assumption: about 200 kWh at US$400/kWh in year 10
	Carbon credits per MWh (tCO2)	1.73	Effective factor over 70 MWh/yr (450 households at 120 kWh/yr plus 16 MWh commercial). Mid 1.73: AMS-I.L tiers with the first-tranche factor of 2.72 proposed in the CDM default-values tool draft (MP87, Feb 2022). High 3.18: AMS-I.L para 18 tiers 6.8 / 1.3 / 1.0 tCO2/MWh for the first 55 kWh / 55-250 kWh / above 250 kWh per consumer (version 3.0 no longer active; the Article 6.4 replacement may differ). Low 0.8: AMS-I.F / TOOL33 diesel mini-grid default. Commercial users at 1.0.
	UN and national levies	0%	
	Broker and developer share	30%	assumption within World Bank range 10-50%
	Carbon project set-up (US$)	5,000	assumption: per-site share of a programme of activities
	Carbon monitoring and verification (US$/yr)	800	assumption: per-site share of programme monitoring and verification (best case US$300)
Rooftop solar, South Africa	Size (kW)	500	
	Capacity factor	18.8%	assumption: about 1,650 kWh/kWp-yr
	Capital cost (US$/kW)	773	GreenCape Energy Services 2025: R11.50-14.00/Wp for 500 kWp-1 MWp, about US$0.70-0.85/Wp
	Operating cost (US$/kW-yr)	10	assumption
	Life (years)	20	
	Debt share	70%	
	Loan tenor (years)	10	
	Interest rate (real)	9%	
	Target equity return	14%	
	Carbon credits per MWh (tCO2)	0.732	
	UN and national levies	7%	
	Broker and developer share	30%	
	Carbon project set-up (US$)	10,000	assumption: per-site share of an aggregated programme

Project	Input	Value	Source or basis
	Carbon monitoring and verification (US$/yr)	3,000	assumption: per-site share of programme verification

Sources

AMDA, Benchmarking Africa's Minigrids Report 2024 · CSIR, Utility Statistics Report, January 2025 · DBSA, REIPPPP Bid Window 7 successful bidders (Dec 2024, Jul 2025, Dec 2025) · Ecosystem Marketplace, State of the Voluntary Carbon Market 2025 · Ember, yearly electricity data · Energy Regulation Board of Zambia, Energy Sector Report 2025 · Energy Alliance, Structuring for the last mile, Part II (2026) · GGGI, Zambia carbon feed-in premium (2026) · GIZ, Zambia sector analysis (2024) · GreenCape, Energy Services Market Intelligence Report 2025 · I-TRACK Foundation, fee structure 2026 · IRENA, Renewable Power Generation Costs in 2024 · Argus Media, 1 September 2026 · MECS, Are mini-grids financially viable at scale? Lessons from Zambia (2026) · Modern Cooking for Africa, Unlocking high-value carbon credits from clean cooking (2025) · NREL, Annual Technology Baseline 2024 · SEforALL (2023), D-REC prices · Climate Policy Initiative, P-REC Aggregator Fund (2021) · UNFCCC, A6.4-AMT-007 v02.0 (2026); Fees and levies under Article 6 (2026); AMS-I.L; AMS-I.F · World Bank, Kenya Carbon Guidebook (2024); State and Trends of Carbon Pricing 2026 · Aloe Energy, grid emission factors and renewable energy certificates (aloeenergy.org/research).

Aloe Energy is a not-for-profit initiative working at the grid edge in Sub-Saharan Africa. This paper is indicative analysis, not financial, legal or carbon market advice. Public data only. The model and its inputs are available on request: brandon@aloeenergy.org.