



AFRICAN INSTITUTE FOR CLIMATE,
TRADE AND ECONOMIC MODELLING

INFRASTRUCTURE DIAGNOSTIC

Africa Synthesis

A continental synthesis of infrastructure diagnostics for 54 African countries, integrating road connectivity, the inter-urban network, power-system adequacy and power-digital access from spatial-equilibrium, least-cost dispatch and optimal-network models.

AICTEM INFRASTRUCTURE DIAGNOSTIC

Lead Author: Sebastian Krantz

Coverage: 54 African countries

Models: Spatial equilibrium, least-cost dispatch, optimal networks

Key datasets: OpenStreetMap, Africa Infrastructure Database, PyPSA-Earth, Ember

Date: July 2026

Executive Summary

This report reads across the individual infrastructure diagnostics of **54 African countries** to find the patterns that only the continent as a whole reveals. Each country's diagnostic is assembled from four reproducible, open-data pipelines: a gridded spatial-equilibrium model of road connectivity (Section 2), a city-network model that prices road investment and solves for its welfare return (Section 3), a least-cost engineering model of the national power system (Section 4), and a settlement-level assessment of household access to electricity and connectivity (Section 5). The statistics here are built from those pipelines' own model outputs, so the continental picture rests on the same calibrated numbers as the national reports. Together the models cover economies that hold about 1.35 billion people, US\$2.5 trillion of output, and a modelled 270 GW of generation.

The most widespread first-order constraint is on the road side. The median inter-cell trip moves at **35.4 km/h**, the median inter-urban network is **35% longer than straight-line distance**, and bringing every modelled link to its target speed would cost on the order of US\$330 billion continent-wide, a median of 28% of national GDP. Returns to fixing this are highly uneven: the general-equilibrium gain from optimally spending a constrained budget is largest in small, fragmented, low-income economies and smallest in the already-integrated economies of North and Southern Africa.

The 2025 power systems are adequate *on paper* in the median but not in the tail. The median country leaves **0.0% of demand unserved**, yet 13 countries lose more than 1% and 16 run a negative firm reserve margin against their modelled peak; where systems are short, the binding problem is generation and, in a set of small states, import dependence, not the transmission grid. These adequacy results are a planner's optimum, and they overstate delivered reliability: firms across 48 countries report a median of **4.6 power outages a month**, essentially uncorrelated with modelled unserved energy (rank correlation 0.18), because real systems fail through utility finances, fuel, drought, and grid operation, which a least-cost model does not represent (Section 4.4). Generation is more renewable than often assumed (median share 33%), and the least-cost capacity the model would add is **71% solar**.

On the demand side the electricity-access gap is real but localised (a median 9.8% of people live beyond 10 km of mapped power), while the **digital-quality gap is pervasive**: a median 56% of the population has mobile internet below 10 Mbps. Power and digital gaps coincide spatially more than transport gaps do, which is why the strongest case for spatially bundled power-plus-digital investment is in a compact set of regions: the Sudanese Red Sea state, the Ethiopian highlands, the Sahelian belt of northern Nigeria, southern Madagascar, and the eastern DRC. A composite gap index across the four domains ranks the small and fragile states (Comoros, the Gambia, Eritrea, Liberia, Eswatini, the DRC) highest and the North African and South African economies lowest, and it classifies **16 countries as transport-constrained, 14 as power-supply-constrained, 12 as access-constrained**, and 12 as broadly balanced. These are screening results meant to rank priorities, not project appraisals.

Contents

1	Introduction: Africa's Infrastructure System	4
1.1	Four models, one frame	4
1.2	Coverage	4
1.3	The continent at a glance	4
2	Transport Connectivity: Continental Patterns	6
2.1	Speed and market fragmentation	6
2.2	Where road upgrades pay off	7
3	Road Networks and Investment Priorities	10
3.1	Circuitry and the cost of catching up	10
3.2	Returns to a constrained budget	11
4	Power Systems: Supply-Side Adequacy	13
4.1	Adequacy: unserved energy and reserve margins	14
4.2	Generation mix and least-cost expansion	14
4.3	Validation and the role of the grid	16
4.4	Modelled adequacy is not delivered reliability	17
5	Power and Digital Access: The Demand Side	18
5.1	Two gaps with different shapes	18
5.2	Complementarity and bundled priorities	19
6	Synthesis: A Typology of Binding Constraints	22
6.1	Regional patterns	23
6.2	A country typology and composite index	23
6.3	Do the gaps coincide?	24
7	Policy Priorities and Conclusion	26
7.1	Five priorities	26
7.2	Caveats and appropriate use	27

1. Introduction: Africa's Infrastructure System

Infrastructure determines how much of a country's economic geography becomes usable economic activity. The cost of moving goods shapes where firms and workers locate and how much they trade (Donaldson, 2018; Redding and Rossi-Hansberg, 2017; Krantz, 2024b); reliable electricity conditions what can be produced (Brown et al., 2018); and mobile connectivity increasingly gates access to markets, finance, and public services (Krantz et al., 2025; World Bank, 2023). These systems are almost always studied one at a time and one country at a time. This report does the opposite on both counts: it holds transport, power, and digital infrastructure in a single frame, and it compares that frame across all 54 African countries, so that a bottleneck in one country and one sector can be ranked against the others.

1.1 Four models, one frame

The evidence base is four pipelines, each applied to every country for which the required open data exist. *Transport* is analysed at two resolutions: a gridded spatial-equilibrium model over 0.25° cells that maps connectivity across the whole territory (Section 2), and a city-to-city network model that prices individual road works and solves for the welfare-maximising allocation of a fixed budget in general equilibrium (Section 3). *Power* is analysed from the supply side with a least-cost dispatch and capacity-expansion model of the national grid (Section 4), and from the demand side with a settlement-level map of who can physically reach electricity and connectivity (Section 5). Section 6 draws the four into a typology of binding constraints, and Section 7 states the resulting priorities.

1.2 Coverage

The power model runs for all 54 countries. The two transport models run for 52 (the exceptions are single small-island states with no inter-urban land network). The demand-side access analysis runs for the 45 sub-Saharan countries the settlement-level survey and continental causal-ML surface cover; it does not cover the five North African countries or a few small offshore islands, which therefore appear blank on the demand-side maps and are excluded from demand statistics rather than imputed. Every figure states its own coverage.

1.3 The continent at a glance

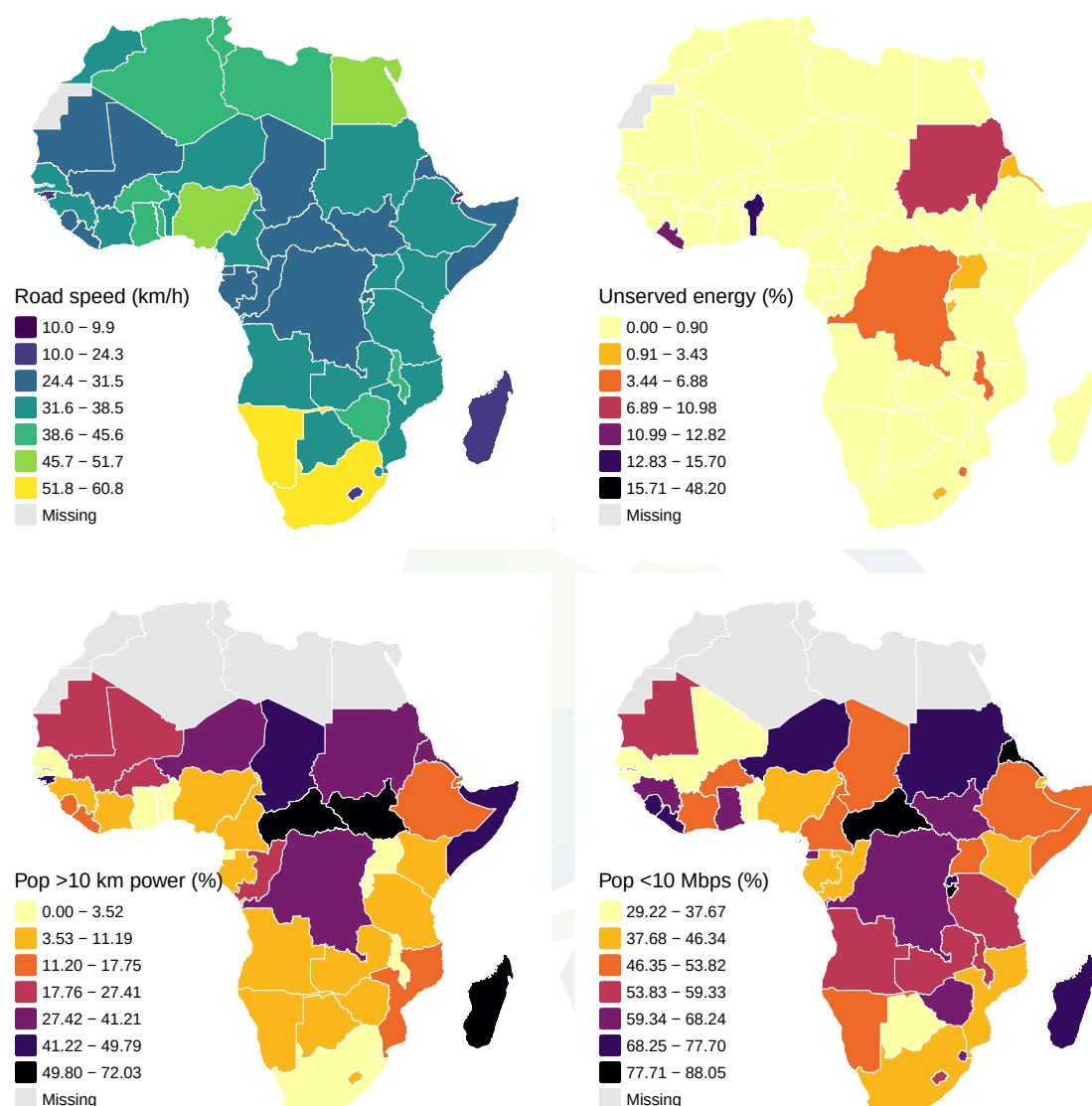
Table 1 collects the headline figures the four models produce for the whole sample. Each pipeline is calibrated to a different vintage and economic denominator, so these are cross-country *medians and totals under each model's own basis*, not a single reconciled account; the value is the pattern across systems, and the note makes each basis explicit. Figure 1 maps four of these indicators at once and previews the geography that recurs throughout: a fast, well-served North and South, and a Sahel-to-Central-Africa band that lags on roads, power, and connectivity together.

Table 1: Continental infrastructure system at a glance

<i>Coverage and economy</i>	
Countries analysed	54
Combined population, grid (millions)	1,350
Combined GDP (const. 2017 US\$, bn)	2,538
Combined 2025 electricity demand (GWh)	914,558
Combined modelled generation capacity (GW)	270
<i>Transport connectivity (grid)</i>	
Median inter-cell road speed (km/h)	35.4
Median own-trade (self-sufficiency) share	0.30
<i>Road network (cities)</i>	
Median network route efficiency	0.74
Median full-upgrade cost (% of GDP)	28
Median GE welfare gain, 30% budget (%)	0.34
<i>Power system (supply)</i>	
Median unserved energy (% of demand)	0.00
Median firm reserve margin (%)	20
Median firm-reported outages per month (observed)	4.6
Median renewable generation share (%)	33
Combined modelled CO ₂ (Mt/yr)	423.9
<i>Power & digital access (demand, 45 countries)</i>	
Median population beyond 10 km of power (%)	9.8
Median population below 10 Mbps mobile (%)	56
Median household wealth (IWI, 0–100)	42.9

Notes: Cross-country medians (or totals, for the coverage-and-economy block) computed by stacking the four pipelines' own per-country model outputs. Each row keeps its native basis: the transport grid counts all populated 0.25° cells and uses constant-2017 US dollars; the road network uses constant-2015 US dollars; the power model is a 2025 least-cost dispatch; the access indicators are settlement-level and cover 45 sub-Saharan countries only. Firm-reported outages are from the latest World Bank Enterprise Survey per country (48 countries, survey years 2006–2023). Route efficiency is straight-line over road distance (< 1). "Own-trade share" is the mean share of a cell's expenditure met from its own output (higher = more self-sufficient/fragmented). Medians are taken over the countries with data in each domain, so denominators differ by row.

Figure 1: Four infrastructure indicators across Africa



Notes: Country choropleths of, clockwise from top-left, median inter-cell road speed (km/h; higher is better, viridis), unserved energy as a share of demand (%), population below 10 Mbps mobile internet (%), and population beyond 10 km of mapped power (%). Grey (“Missing”) marks countries outside a given model’s coverage: the two island states without a road grid on the speed panel, and the five North African countries plus small islands on the two demand-side panels.

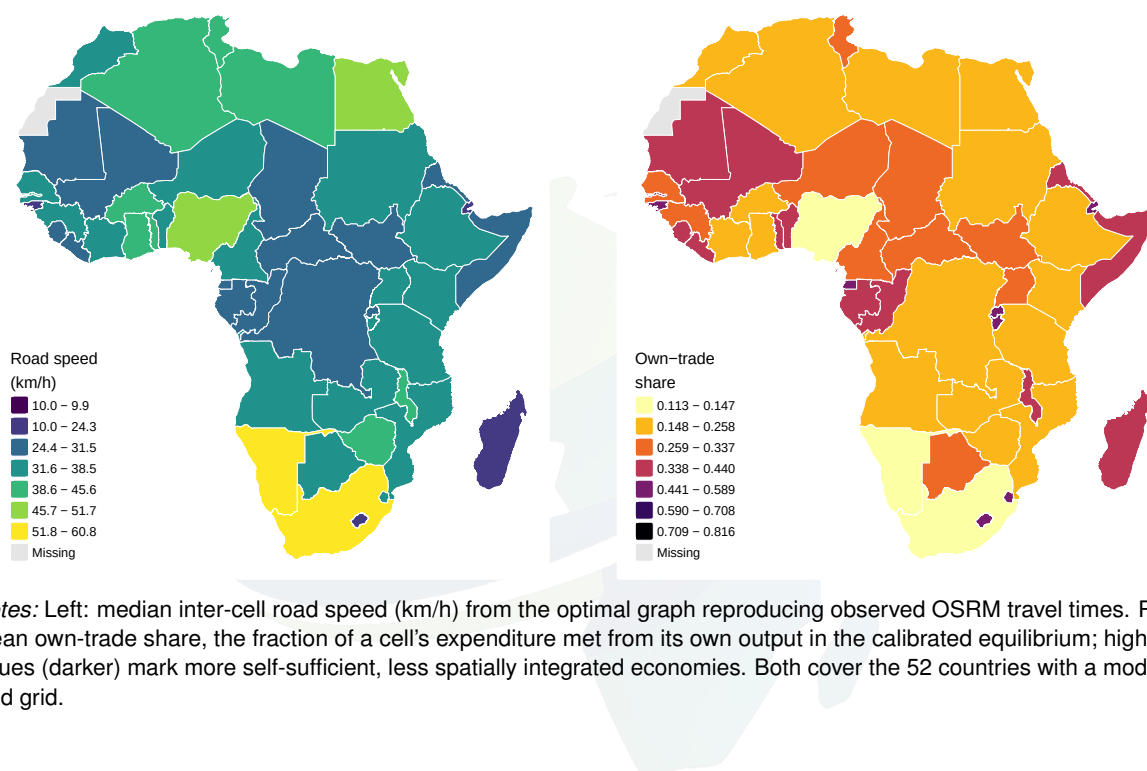
2. Transport Connectivity: Continental Patterns

2.1 Speed and market fragmentation

The gridded transport model calibrates a Redding-type spatial equilibrium (Redding, 2016; Redding and Rossi-Hansberg, 2017) on 0.25° cells, using an optimal sparse graph that reproduces observed road travel times (Luxen and Vetter, 2011) and then asking how welfare and market access would change if every cell’s links were upgraded to a common target speed. Read across countries, three regularities stand out. First, road speed is a development gradient in space: it is highest in North Africa (a regional median of 42 km/h) and lowest across Central Africa (29 km/h), with the slowest

territories being small islands and the forested interior (Figure 2, left). Second, low speed and economic *fragmentation* travel together: the cross-country correlation between low road speed and a high own-trade (self-sufficiency) share is 0.66, so the same places that move slowly also trade least with the rest of their own economy (Figure 2, right). Third, the modelled welfare return to upgrading roads is a mirror image of development: it is concentrated in the low-income, fragmented economies where the connectivity base is thinnest.

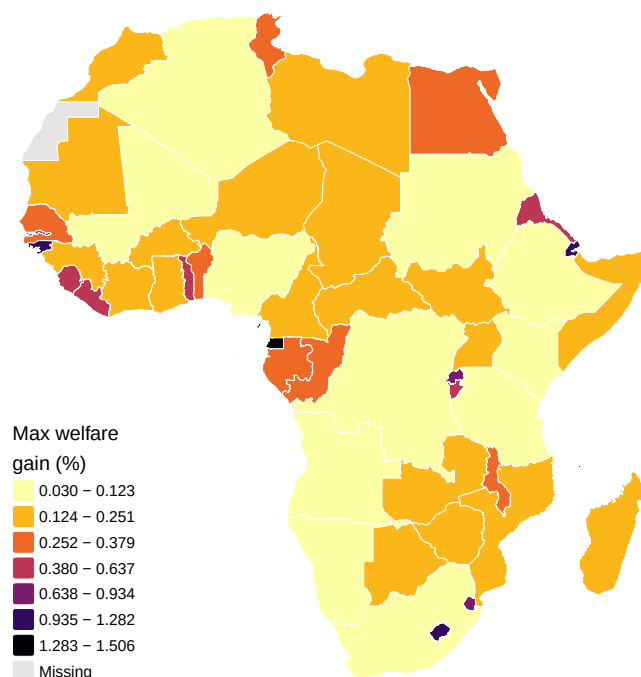
Figure 2: Road speed and economic self-sufficiency



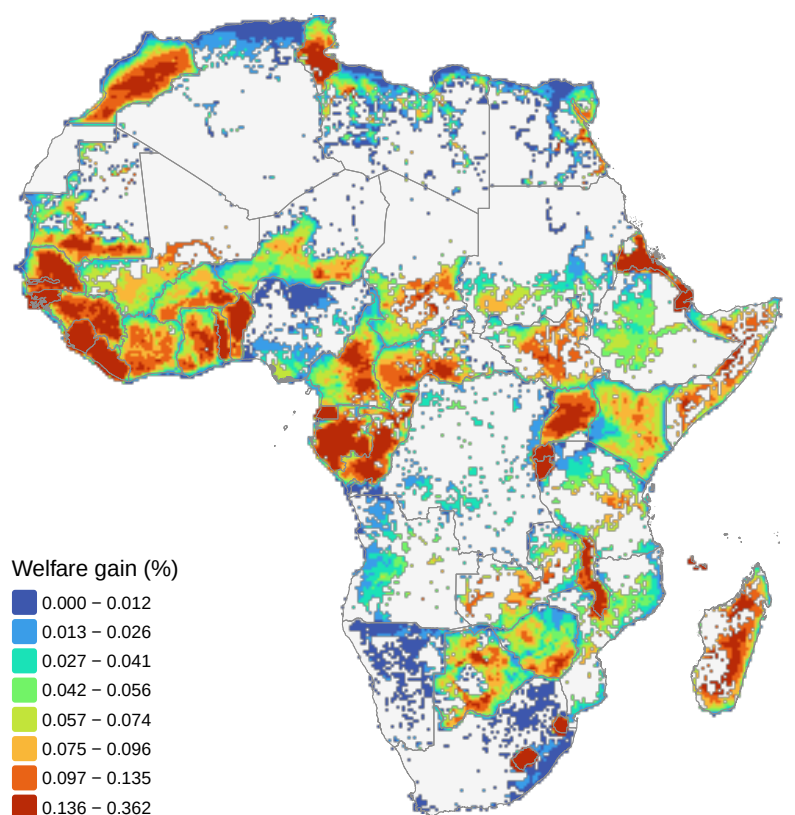
Notes: Left: median inter-cell road speed (km/h) from the optimal graph reproducing observed OSRM travel times. Right: mean own-trade share, the fraction of a cell's expenditure met from its own output in the calibrated equilibrium; higher values (darker) mark more self-sufficient, less spatially integrated economies. Both cover the 52 countries with a modelled land grid.

2.2 Where road upgrades pay off

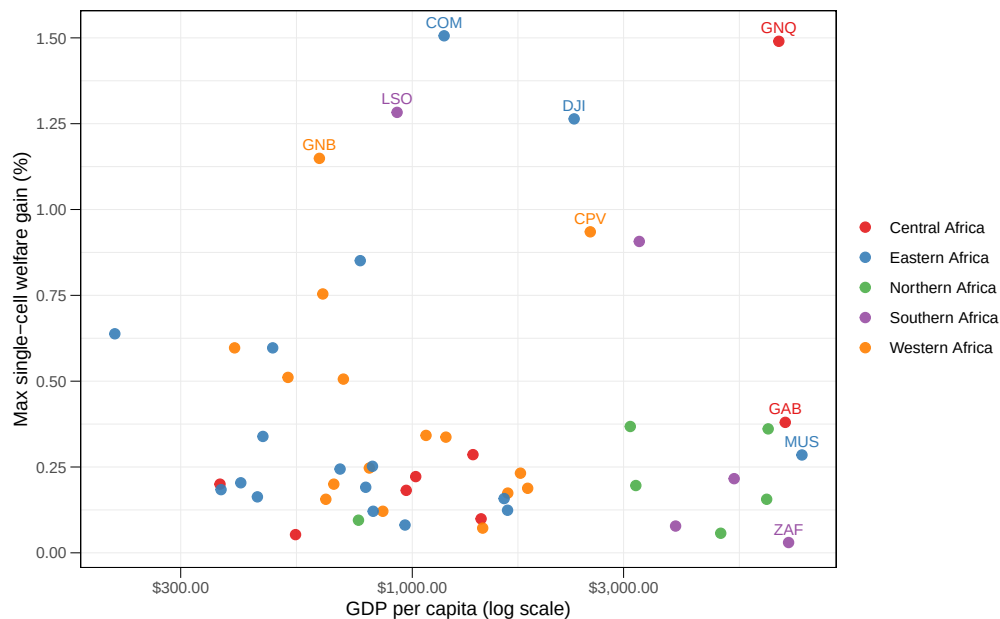
The welfare-potential map (Figure 3) makes the third point concrete: the largest single-cell short-run welfare gains from upgrading to target speed are found in Comoros, Equatorial Guinea, Lesotho, Djibouti, Cape Verde, and Guinea-Bissau (all small or geographically constrained economies where a thin network leaves large gains on the table), and the smallest in South Africa, Mauritius, and the North African economies whose networks are already dense. Figure 4 takes the same result to full spatial resolution, plotting the estimated welfare gain for each populated cell on the continent. The gains cluster along under-served corridors in the Sahel, the Ethiopian highlands, the Congo basin, and interior East Africa, rather than in the coastal metros, which is the spatial signature of a connectivity deficit rather than a congestion problem. Figure 5 plots each country's peak cell gain against income and confirms the gradient: welfare potential falls steeply with GDP per capita.

Figure 3: Welfare potential from road upgrades

Notes: Maximum single-cell short-run welfare gain (%) from upgrading a country's grid links to the common target speed, by country. Darker indicates a larger available gain; values rank within the sample and should be read ordinally, especially for very small economies where the market-access base is thin. Covers 52 countries.

Figure 4: Grid-cell welfare gain from road upgrades

Notes: Estimated short-run welfare gain (%) from upgrading local links to target speed, for each populated 0.25° cell in the 52-country grid ($\approx 20,000$ cells, each drawn at its full footprint; border cells shared by two country grids are averaged). Colours are within-sample quantiles of the gain (top 2% capped for legibility). Gains concentrate along under-served interior corridors rather than in the already-connected coastal metros.

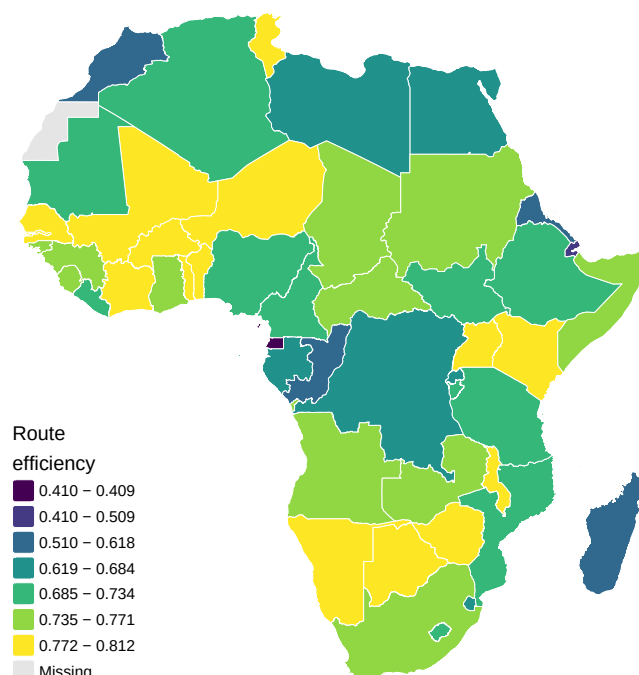
Figure 5: Welfare potential falls with income

Notes: Maximum single-cell welfare gain (%) against GDP per capita (log scale), by country, coloured by region. The downward pattern shows that the modelled returns to road upgrading are largest in the poorest, least-integrated economies. Labelled points are the highest-return and highest-income outliers.

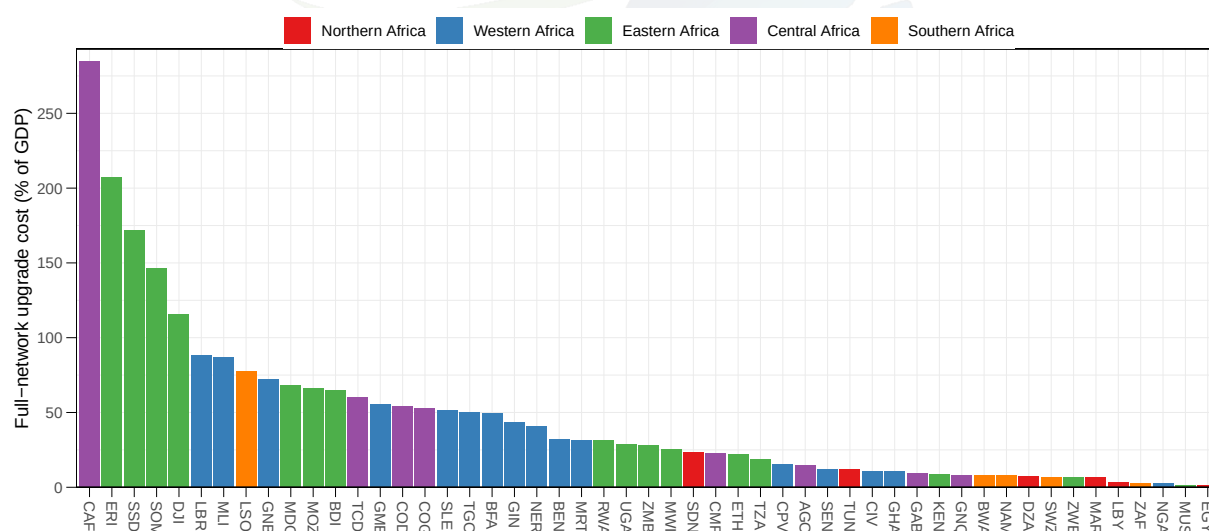
3. Road Networks and Investment Priorities

3.1 Circuity and the cost of catching up

The city-network model builds a realistic inter-urban road network from routed travel times, prices each link's construction and upgrade cost from terrain and land use (Collier et al., 2016; Nunn and Puga, 2012), and then solves two problems: which individual works give the most market access per dollar, and how a fixed budget should be spent to maximise welfare in general equilibrium (Fajgelbaum and Schaal, 2020; Allen and Arkolakis, 2022). Two cross-country facts frame the investment case. The median network is only 0.74 as direct as the straight line (roads run about 35% longer than straight-line distance), and route efficiency is lowest in exactly the fragmented, low-income economies the grid model already flagged (Figure 6). And the bill to remove that inefficiency is large relative to the economies that carry it: bringing every modelled link to target speed costs a median of 28% of national GDP, and exceeds half of GDP in several small, rugged, or landlocked countries (Figure 7).

Figure 6: Network route efficiency


Notes: Network route efficiency (straight-line over road distance; higher = more direct) for the inter-urban network, by country. Values near 0.6–0.7 imply roads 40–65% longer than straight-line; values near 0.9 imply near-direct networks. Covers 52 countries.

Figure 7: Cost of a full network upgrade, relative to GDP


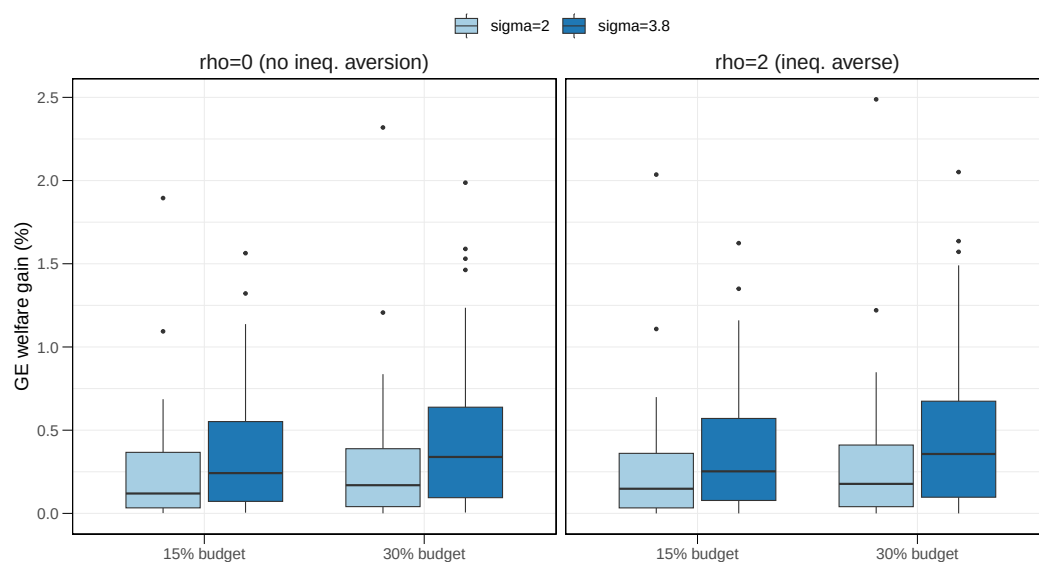
Notes: Cost of upgrading every modelled inter-urban link to target speed, as a share of national GDP (constant-2017 US\$), by country, coloured by region. The full-upgrade programme is a screening bound, not a recommended plan; the budget-constrained optimisation below allocates a small fraction of it.

3.2 Returns to a constrained budget

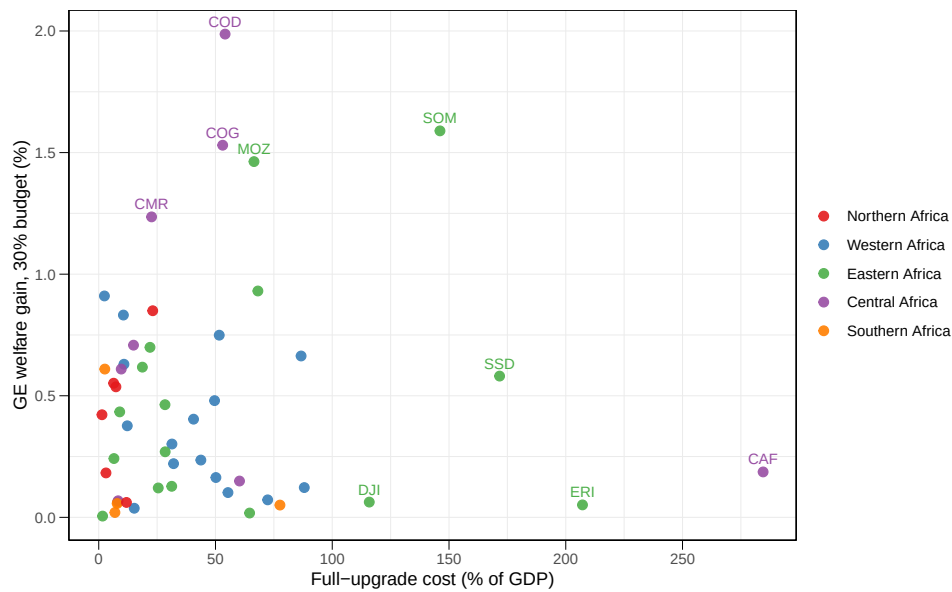
Because the full programme is unaffordable, the question that matters is where a *constrained* budget earns the most. The general-equilibrium optimisation allocates a fixed share of the upgrade budget

across the network under different trade elasticities and degrees of inequality aversion. Welfare gains scale with the budget and are larger under the lower elasticity, but the more informative pattern is cross-country (Figure 8): the median 30%-budget welfare gain is 0.34%, but the distribution has a long upper tail of small, poorly-connected economies where the same budget share earns several times the median. Figure 9 shows that this return is only weakly related to how expensive a country's full upgrade is (high cost-to-GDP does not preclude a high return), so affordability and payoff must be judged jointly rather than either alone. For the subset of countries with a macroeconomic cost-benefit calibration, Figure 10 expresses the same trade-off as the one-off increase in the growth rate that would repay the upgrade, which is modest for large economies and demanding for the smallest.

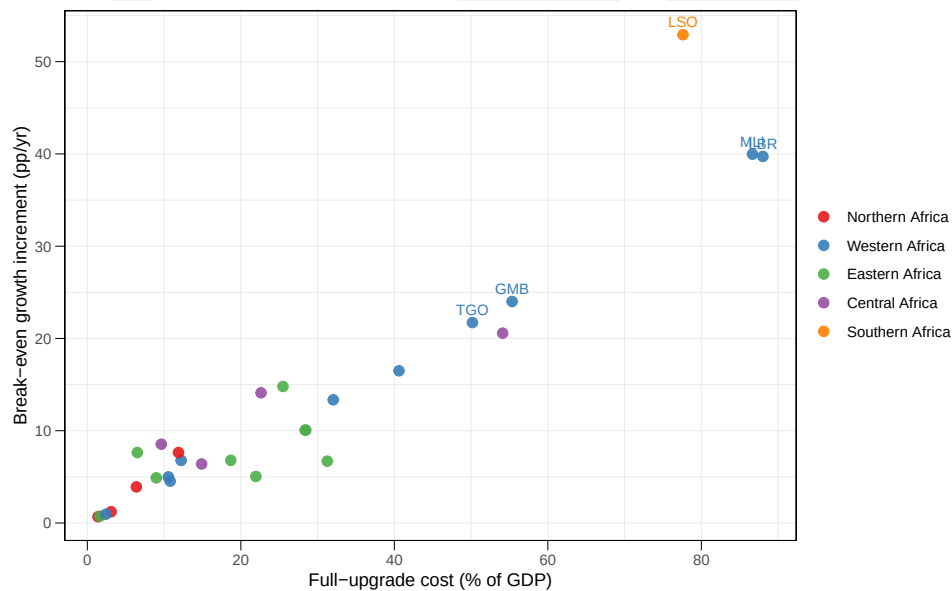
Figure 8: General-equilibrium welfare gains by scenario



Notes: Distribution across countries of the general-equilibrium welfare gain (%) from optimally allocating a constrained road budget, by budget share (15% vs 30% of the full-upgrade cost) and trade elasticity σ , split by inequality aversion ρ . Boxes span the interquartile range across the 52 networked countries; gains rise with the budget and with lower σ .

Figure 9: Return versus cost of road investment


Notes: General-equilibrium welfare gain at a 30% budget (%) against the full-upgrade cost as a share of GDP, by country, coloured by region. A weak relationship means high relative cost does not rule out a high welfare return; the two must be weighed together.

Figure 10: Break-even growth for a full upgrade


Notes: For the countries with a macroeconomic cost-benefit calibration (29), the one-off increase in the annual real growth rate (percentage points) that would repay the full-upgrade cost, against that cost as a share of GDP. Larger economies break even on a small growth increment; the smallest require a demanding one.

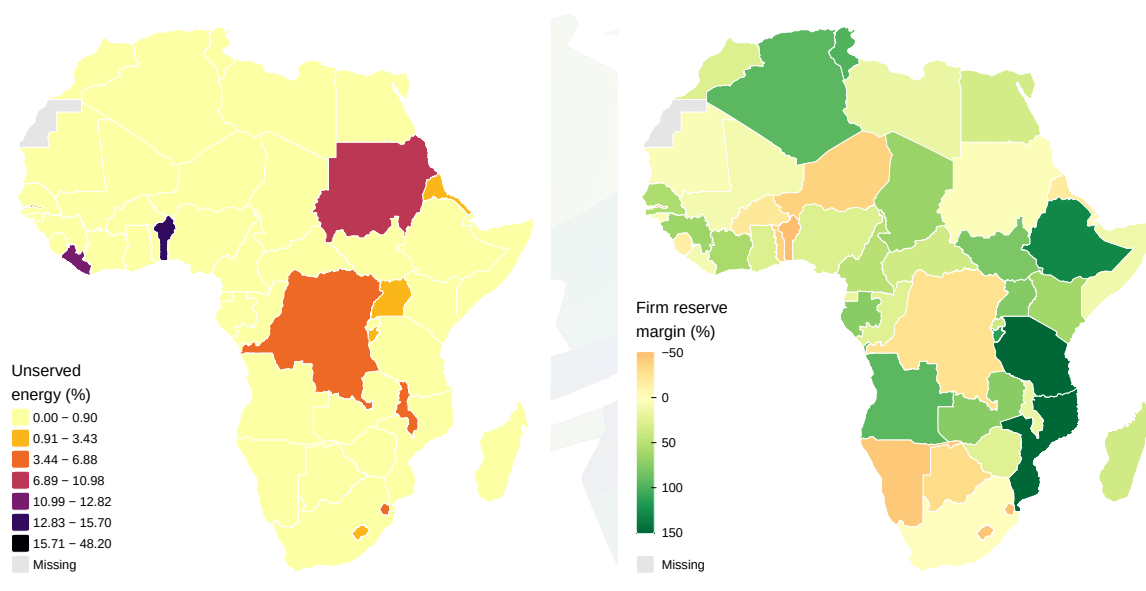
4. Power Systems: Supply-Side Adequacy

Each national power system is modelled as a single-period 2025 least-cost dispatch on a nodal network synthesised from open data, with a least-cost capacity-expansion overlay (Brown et al., 2018; Parzen et al., 2023; Mattsson et al., 2021; Gotzens et al., 2019).

4.1 Adequacy: unserved energy and reserve margins

The headline continental result is that supply is adequate in the median but fails in a definite tail. Half of the countries leave essentially no demand unserved, but 13 lose more than 1% of annual demand, reaching tens of percent in a handful of fragile states (Figure 11, left). Firm reserve margins tell a compatible story with a wider spread: the median is 20%, but 16 systems are negative against their modelled peak, concentrated in Southern Africa and in small import-dependent states such as the Gambia, Eswatini, and the Comoros (Figure 11, right). These are the results of a cost-minimising planner with a typical weather year; Section 4.4 confronts them with the reliability firms and households actually experience.

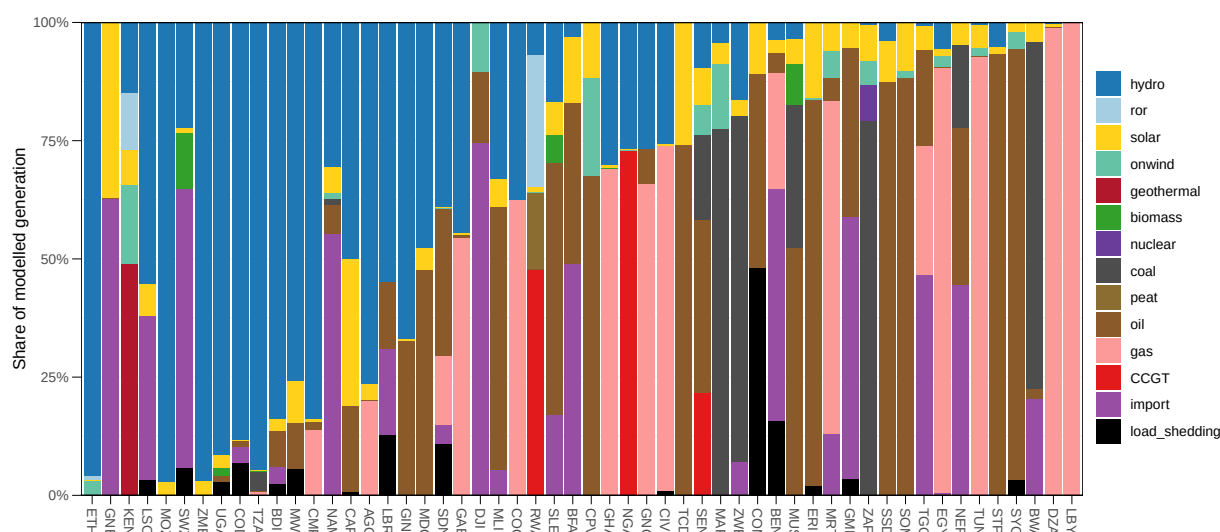
Figure 11: Generation adequacy: unserved energy and reserve margin



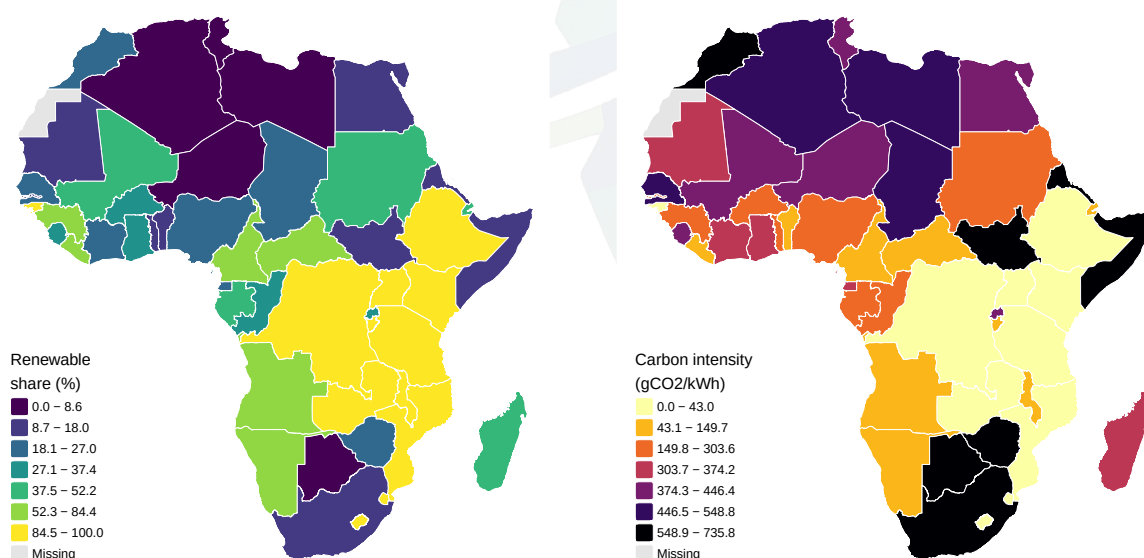
Notes: Left: modelled unserved energy as a share of annual demand (%); yellow is adequate, dark is a large shortfall. Right: firm (dispatchable) reserve margin against the modelled peak (%), a diverging scale centred on zero (green a surplus, orange/red a deficit); values are capped to $[-50, 150]$ for display. Both cover all 54 countries; grey marks territory outside the modelled set.

4.2 Generation mix and least-cost expansion

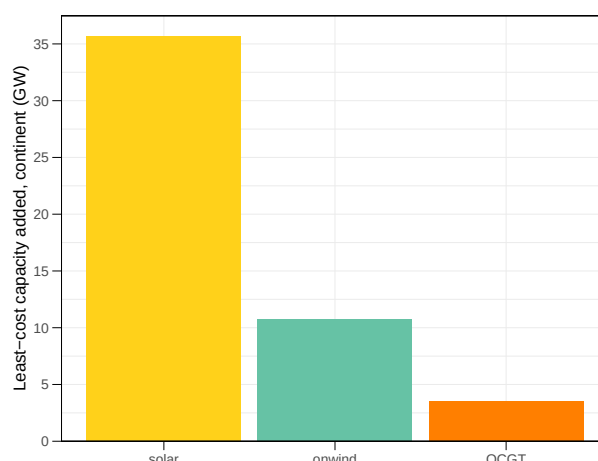
The generation mix (Figure 12) is more renewable than the continent's reputation suggests. Ordered from most to least renewable, the left of the panel is dominated by hydro, geothermal, and increasingly solar and wind (eleven systems exceed 90% renewable generation), while the fossil-heavy right is the gas systems of North Africa and the coal system of South Africa. The median renewable share is 33%, and the carbon intensity of generation follows the mix directly (Figure 13). The model's own least-cost answer to future load points the same way: the capacity it would add is **71% solar** and 22% onshore wind, with only a small residual of flexible gas (Figure 14), so renewables are the cheaper option as well as the cleaner one at generic costs across most of the continent.

Figure 12: Modelled generation mix, 54 countries


Notes: Share of modelled 2025 generation by carrier, one bar per country, ordered from the most to the least renewable system. “import” is energy served from interconnectors; “load_shedding” (black) is unserved energy and flags the adequacy tail. Hydro, run-of-river, solar, wind, geothermal, and biomass are renewable; coal, peat, oil, gas, and the gas turbines (CCGT/OCGT) are fossil.

Figure 13: Renewable generation share


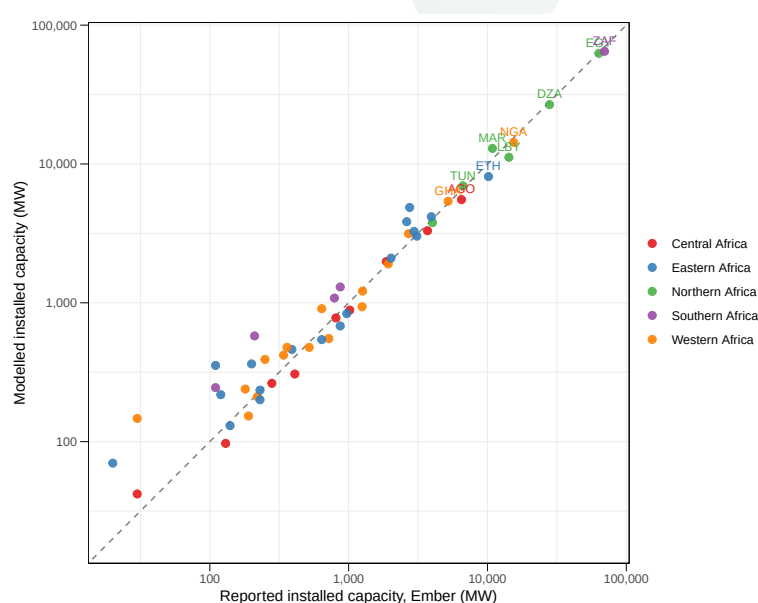
Notes: Left: renewable share of modelled generation (%; higher is greener). Right: carbon intensity of generation (gCO_2/kWh), driven directly by the fossil share. Gas-based North Africa and coal-based South Africa carry the highest intensities; hydro-, geothermal-, and solar-led systems the lowest. Both cover all 54 countries.

Figure 14: Least-cost capacity additions, by technology

Notes: Total capacity the least-cost expansion adds across all countries, by technology (GW). At generic costs the model builds almost entirely solar and onshore wind, with a small flexible-gas residual; it adds no new transmission. Covers the 44 countries with cost-effective additions.

4.3 Validation and the role of the grid

Two checks complete the supply picture. Figure 15 compares the modelled fleet against an independent reference: modelled installed capacity tracks Ember's reported national totals closely across three orders of magnitude (Ember, 2025), which is the main external check that the synthesised networks are the right size. And where systems are short, the constraint is overwhelmingly generation rather than the wires: transmission corridors rarely bind, so adequacy, not congestion, is the near-term problem for the deficit countries.

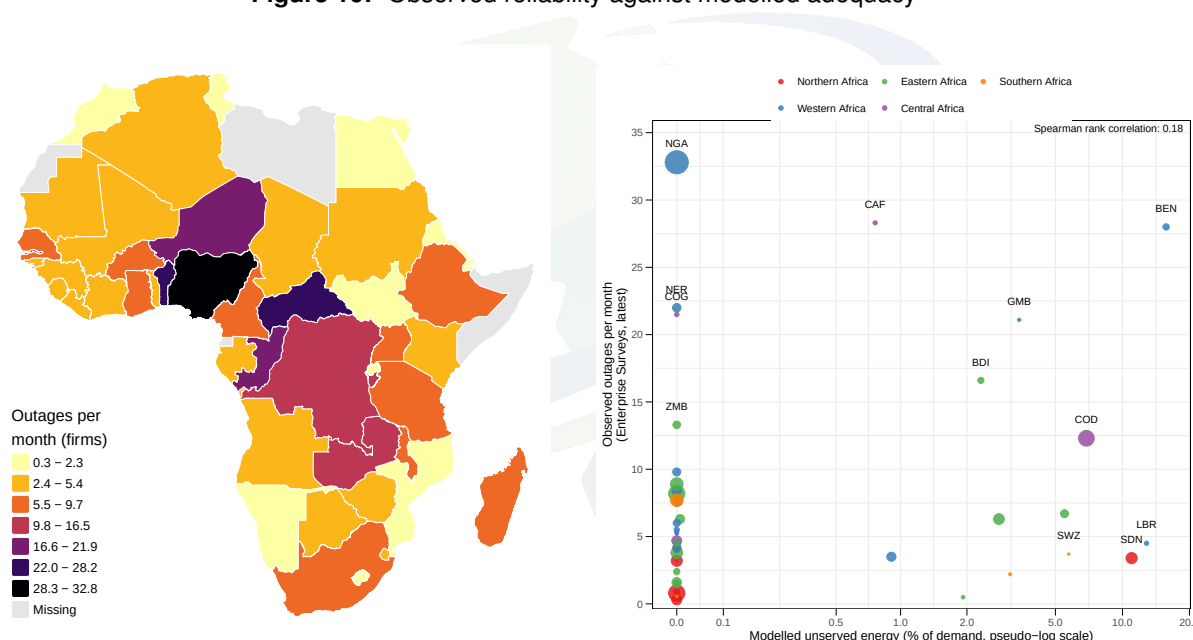
Figure 15: Modelled versus reported installed capacity

Notes: Modelled total installed capacity (MW) against Ember's reported national total (MW), log-log, with the 45° line of exact agreement. Points hugging the line indicate the synthesised fleets are correctly scaled; the largest systems (South Africa, Egypt, Algeria, Nigeria, Morocco) are labelled.

4.4 Modelled adequacy is not delivered reliability

The adequacy results above describe what a fully financed, well-maintained, cost-minimising system could deliver in a typical weather year. Delivered reliability across Africa is far worse. In the latest World Bank Enterprise Survey for each of 48 countries, firms report a median of 4.6 power outages in a typical month, and the average outage lasts about five hours; in 65% of these countries firms face at least one outage a month even though the model leaves under 0.1% of demand unserved. The rank correlation between observed outage frequency and modelled unserved energy is only 0.18 (Figure 16): the model's adequacy tail (Sudan, Liberia, Benin, the Gambia, the DRC) does report frequent outages, but so do countries the model rates fully adequate, most prominently Nigeria, where firms report 33 outages a month against a modelled shortfall of zero.

Figure 16: Observed reliability against modelled adequacy



Notes: Left: firm-reported electrical outages in a typical month, from the latest World Bank Enterprise Survey per country (48 countries, survey years 2006–2023; grey = never surveyed). Right: the same outage frequency against modelled unserved energy (pseudo-log scale), sized by population and coloured by region. The flat relationship (Spearman rank correlation 0.18) shows that modelled adequacy is a poor guide to the reliability firms experience. South Africa's most recent survey (2020, 7.7 outages per month) predates the 2023 peak of its load-shedding crisis.

Recent load-shedding crises make the same point at national scale. South Africa shed load on a record 335 days of 2023, roughly 16,000 GWh, at an estimated cost of about 1.8 percentage points of GDP growth (South African Reserve Bank, 2023), before a sustained recovery left 2024–25 nearly shedding-free. Zambia and Zimbabwe, which depend on the Kariba reservoir for over 80% and roughly half of their generation respectively, faced cuts of up to 21 hours a day when the 2024 drought reduced the lake to under 8% of usable storage. Nigeria's grid delivers 4–6 GW from roughly 13 GW installed, and firms and households have responded with an estimated 14–20 GW of private generator capacity, more than the grid itself delivers; 71% of Nigerian firms own or share a generator (African Development Bank, 2026). Egypt rationed household electricity in the summers of 2023 and 2024 to free natural gas for export earnings, and Sudan's grid has lost more than a third of its capacity to war damage.

Firm-level studies put the cost of such unreliability at several percent of sales for affected firms and on the order of 1–5% of GDP for the region (Andersen and Dalgaard, 2013; Cole et al., 2018; Rentschler et al., 2019).

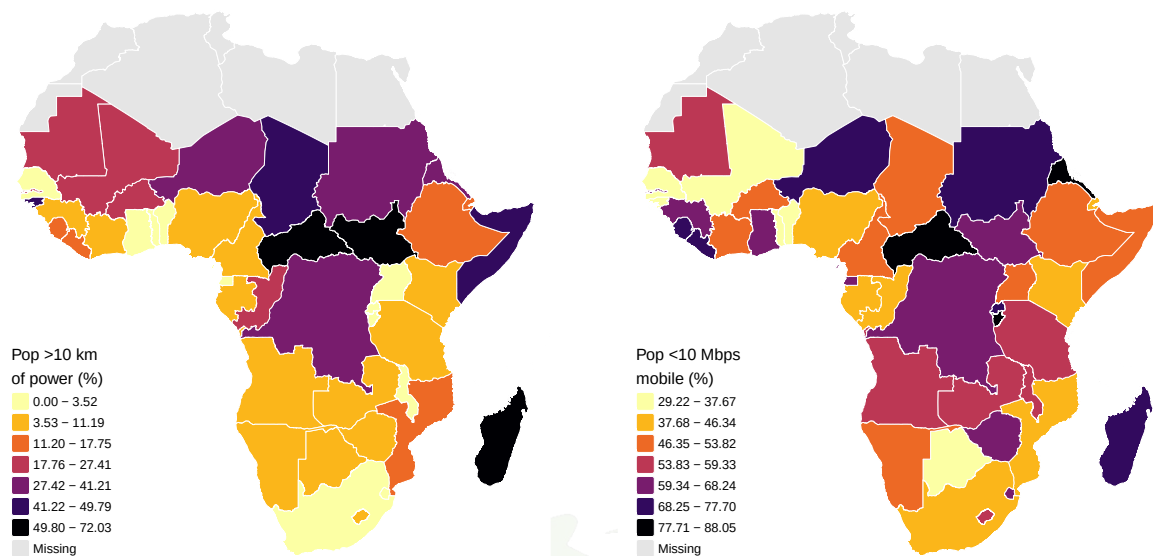
The gap has a systematic anatomy, and each element sits outside a least-cost model. The model treats planned capacity as financed, built, fuelled, and maintained, whereas most African utilities cannot fund maintenance or fuel from their own revenues: electricity sectors in Sub-Saharan Africa ran quasi-fiscal deficits averaging 1.5% of GDP, and only two of 39 were financially viable at existing tariffs and performance (Trimble et al., 2016). The model sees a single typical weather year, whereas hydro-dominated systems (Zambia, Zimbabwe, Malawi, Ethiopia) fail in consecutive drought years. And it optimises generation and transmission adequacy, whereas much of the observed burden arises in system operation and distribution, as in Nigeria's dozen grid collapses of 2024 or Kenya's three nationwide blackouts the same year. Modelled unserved energy should therefore be read as a structural lower bound on the reliability problem: where even this optimistic bound flags a shortfall, the deficit is severe; where it does not, reliable supply still depends on utility finances, fuel logistics, hydrology, and grid operation (Blimpo and Cosgrove-Davies, 2019; Eberhard et al., 2011).

5. Power and Digital Access: The Demand Side

The supply models above ask whether a country *generates* enough energy; the demand-side analysis asks whether people can actually *reach* electricity and connectivity, using settlement-level distances to infrastructure and a continental causal-ML surface (Krantz et al., 2025; Krantz, 2024a; GSMA Intelligence, 2024). It covers the 45 sub-Saharan countries the underlying survey reaches, the region that holds 565 million of the world's people without electricity access (IEA et al., 2025).

5.1 Two gaps with different shapes

The two gaps have very different shapes. The electricity-access gap is localised: a median 9.8% of the population lives beyond 10 km of mapped power, but that share exceeds half the population in the sparsely-settled interiors of South Sudan, the Central African Republic, Madagascar, Somalia, and Chad (Figure 17, left). The digital-quality gap is pervasive: a *median* 56% of the population has mobile internet below 10 Mbps, rising above 80% in the Central African Republic, Eritrea, Burundi, Madagascar, and Sudan (Figure 17, right).

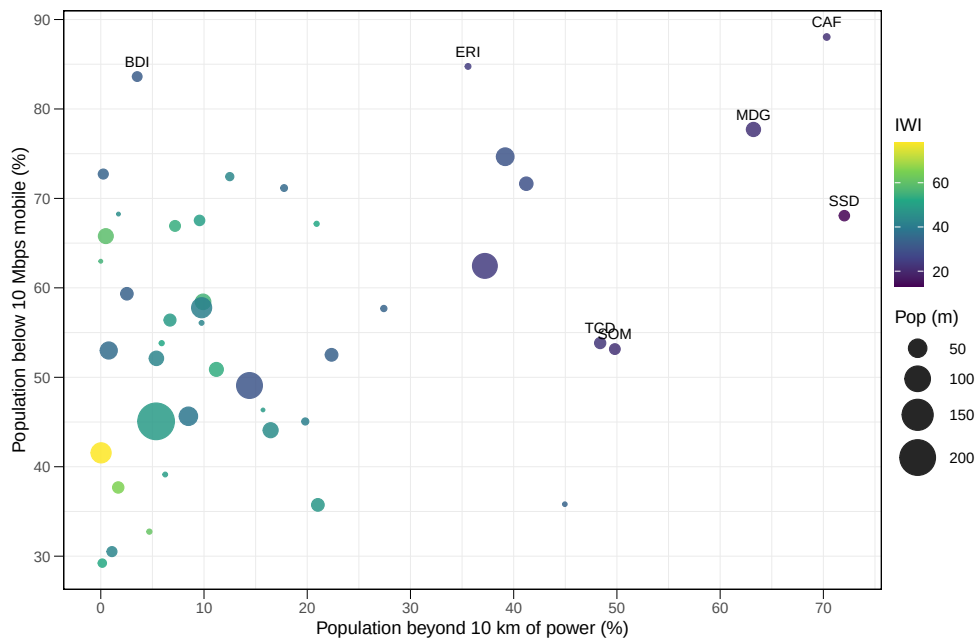
Figure 17: Power-access and digital-quality gaps

Notes: Left: population beyond 10 km of mapped power infrastructure (%). Right: population with mobile internet below 10 Mbps (%). Both cover 45 sub-Saharan countries; the five North African countries and small offshore islands (grey) are outside the settlement-level dataset and are not imputed.

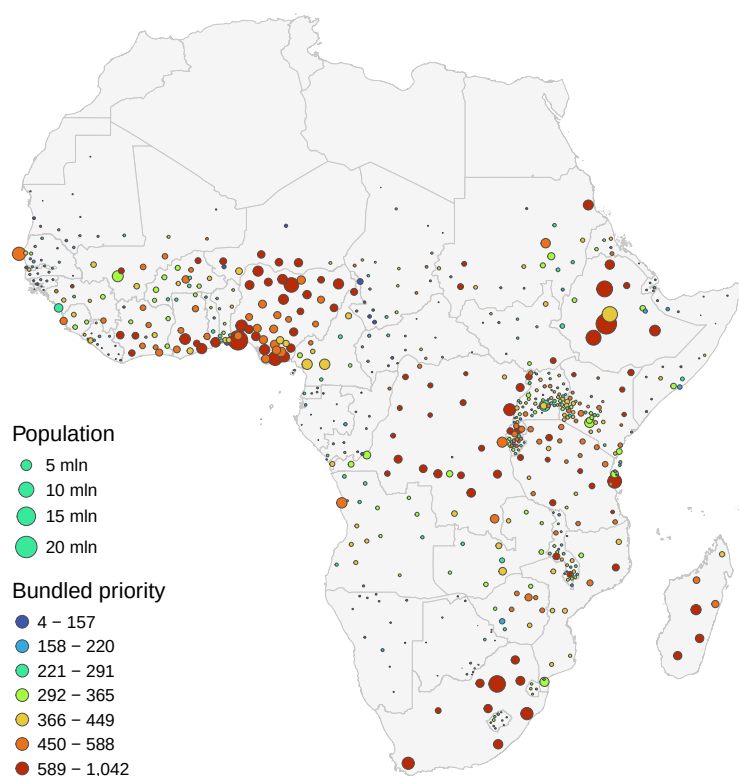
5.2 Complementarity and bundled priorities

Where the two gaps coincide, the case for coordinated investment is strongest, because power and digital infrastructure raise each other's returns (Krantz et al., 2025). Two pieces of evidence support treating them together. First, the country-level power and digital gaps are positively correlated (0.38) and both are worst in the same low-wealth economies (Figure 18). Second, at the sub-national level the estimated marginal effect of proximity to power and to digital infrastructure on household wealth is consistently signed across countries (Figure 20). Mapping the bundled-priority score to the sub-national level (Figure 19) localises the frontier: after restricting to genuinely under-served regions, the highest population-weighted bundled priorities fall in a compact set of places listed in Table 2: the Sudanese Red Sea state, the Ethiopian highlands (Oromia, Amhara, Somali), the Sahelian north of Nigeria (Borno, Sokoto), northern Kenya, southern Madagascar, and the eastern DRC.

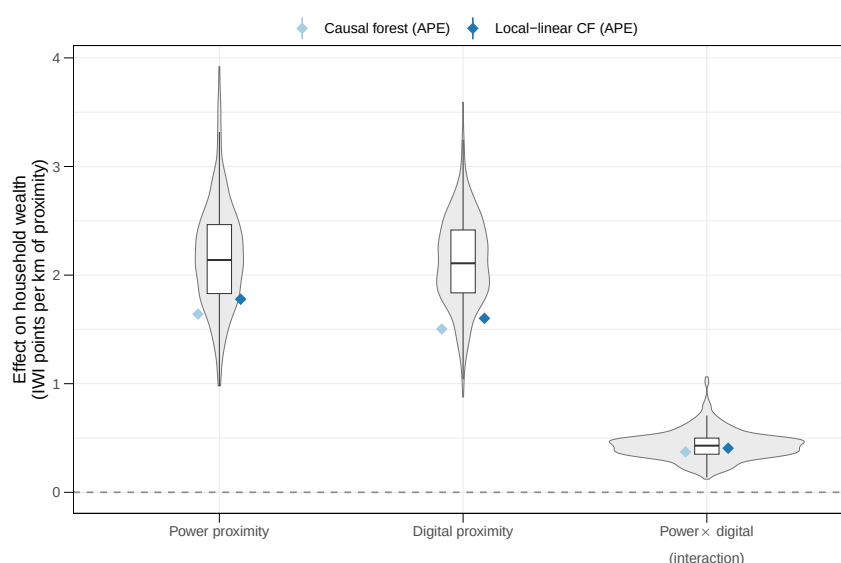
Figure 18: Power gap against digital gap



Notes: Population below 10 Mbps mobile (%) against population beyond 10 km of power (%), by country, sized by population and coloured by average household wealth (IWI). The upward drift and the low-wealth colouring of the upper-right show power and digital deprivation concentrating in the same, poorest economies.

Figure 19: Sub-national bundled-investment hotspots

Notes: Admin-1 regions across 45 countries, sized by population and coloured by the bundled power-plus-digital priority score (darker = higher). The score combines population, gap severity, and the local complementarity between power and digital returns; North Africa is outside the dataset. High-priority clusters fall in the Sahel, the Horn, the Ethiopian highlands, the eastern DRC, and Madagascar.

Figure 20: Marginal effect of infrastructure proximity on wealth

Notes: Violins: distribution across 641 admin-1 regions of the estimated conditional effect (CATE, local-linear causal forest, averaged over settlements within each region) of proximity to power, proximity to digital infrastructure, and their interaction on the International Wealth Index; inner boxes span the interquartile range. Diamonds: the continental average partial effect from two causal-machine-learning estimators, with 95% confidence intervals narrower than the plotted markers. Every region's interaction effect is positive, which is the empirical basis for treating power and digital access as complements.

Table 2: Leading sub-national regions for bundled power–digital investment

Region (country)	Main place	Pop. (m)	Power gap (%)	Digital gap (%)
Red Sea (SDN)	Red Sea	4.36	58	90
Oromia (ETH)	Oromia	18.10	24	85
Amhara (ETH)	Amhara	10.99	33	89
Somali (ETH)	Somali	5.02	71	90
Mandera (KEN)	Lafey	1.72	65	85
Borno (NGA)	Kukawa	4.51	64	84
Sokoto (NGA)	Sokoto	4.50	32	68
Eastern Cape (ZAF)	Mthatha	3.84	1	42
Fianarantsoa (MDG)	Ikalamavony	3.12	94	92
Southern Nations, Nat. (ETH)	Southern Nation.	9.76	10	83
Toliary (MDG)	Ambovombe	3.07	96	95
South Darfur (SDN)	South Darfur	1.53	99	98
Rivers (NGA)	Choba	8.48	2	32
Haut-Lomami (COD)	Haut-Lomami	3.27	53	94
Wajir (KEN)	Wajir	1.17	66	69

Notes: The 15 admin-1 regions with the highest population-weighted bundled power-plus-digital priority, among regions with a genuine access gap (at least 30% under-served on power or digital). “Power gap” and “digital gap” are the shares of regional population under-served on each dimension. Ranked by the bundled-priority score; restricting to under-served regions removes well-served metros that would otherwise rank high on population alone.

6. Synthesis: A Typology of Binding Constraints

Bringing the four domains together, two questions organise the continent: *which* constraint binds in each country, and *whether* the constraints coincide in the same places. To answer the first, each

domain's gap is converted to a within-sample percentile (road connectivity from low speed, high circuitry, and high welfare potential; power supply from unserved energy, low or negative reserve, and import dependence; demand-side access from distance to power, slow mobile speeds, and dark cells), and the domains are ranked against each other for every country.

6.1 Regional patterns

Regional medians (Table 3) already show the coarse structure: North Africa leads on roads and power but not on the demand-side quality gap; Central and Eastern Africa lag on access; Southern Africa runs the tightest reserve margins.

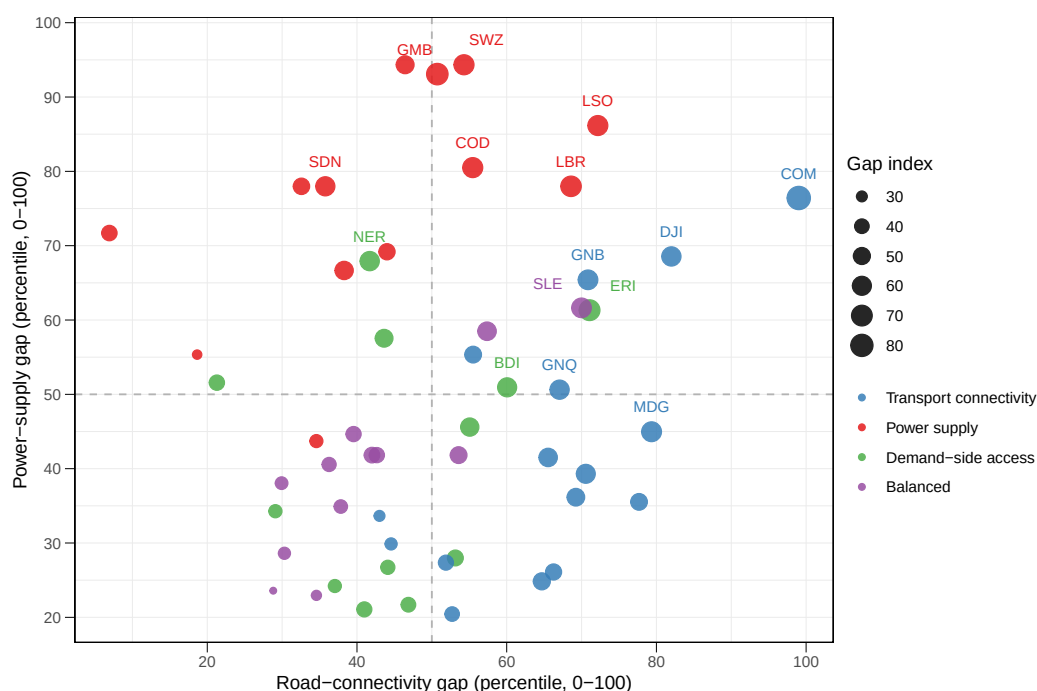
Table 3: Infrastructure indicators by region

Region	<i>N</i>	Speed (km/h)	Route eff.	Unserved (%)	Reserve (%)	Renew. (%)	Pwr. gap (%)	Mobile (%)
Northern Africa	6	42.1	0.70	0.00	30	8	39.2	75
Western Africa	16	35.2	0.78	0.00	7	29	12.5	53
Eastern Africa	18	35.1	0.72	0.00	36	47	9.8	58
Central Africa	9	29.2	0.71	0.00	35	45	15.5	56
Southern Africa	5	35.2	0.76	0.01	-42	84	4.7	54

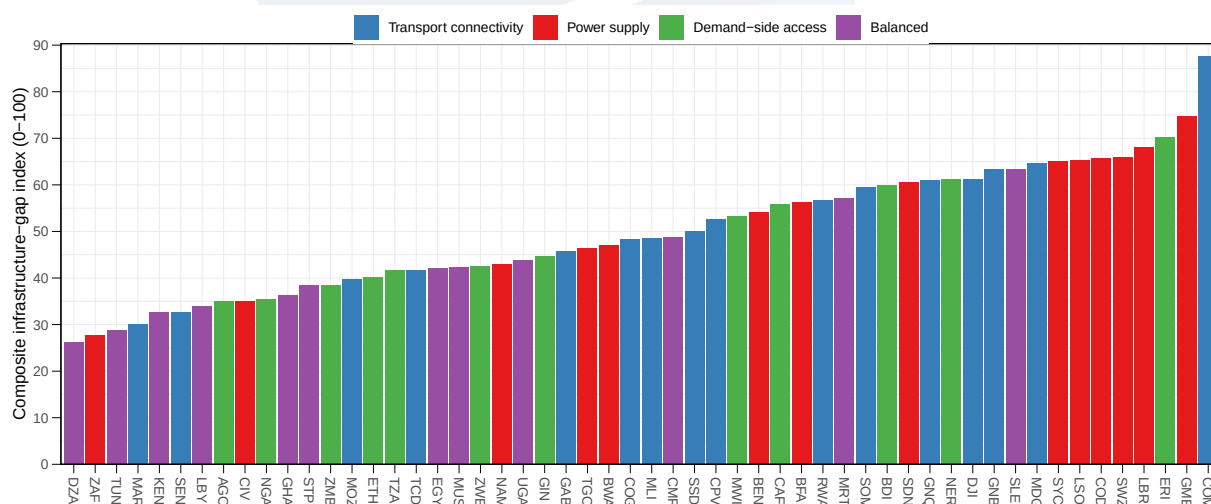
Notes: Regional medians (five UN macro-regions). Columns: number of countries; median inter-cell road speed; network route efficiency; unserved energy; firm reserve margin; renewable generation share; population beyond 10 km of power; population below 10 Mbps mobile. A dash marks a domain with no covered country in the region; the North-African access figures reflect Sudan alone, the only demand-covered country there.

6.2 A country typology and composite index

The country-level typology (Figure 21) places each country in the space of its road-connectivity and power-supply gaps, coloured by which of the three domains binds hardest. The corners are informative: economies in the lower-left (low gaps on both, such as Algeria, Tunisia, and South Africa) are constrained, if at all, by demand-side quality rather than by the physical backbone; the upper-right (Comoros, the DRC, Liberia, Lesotho) face compounding deficits across domains at once. Aggregating the domains into a single composite index and ranking all 54 countries (Figure 22) yields a clear ordering: the North African economies and South Africa sit lowest, and the small and fragile states (Comoros, the Gambia, Eritrea, Liberia, Eswatini, the DRC, Lesotho) sit highest, with the colour of each bar showing that the binding domain shifts along the ranking. The classification splits the continent into **16 transport-constrained**, **14 power-supply-constrained**, **12 access-constrained**, and 12 balanced economies (Table 4).

Figure 21: Typology of binding constraints


Notes: Each country in the space of its road-connectivity gap (x) and power-supply gap (y), both as within-sample percentiles (0–100), sized by the composite gap index and coloured by which domain binds hardest (including demand-side access, which is not an axis here). Dashed lines mark the sample midpoints. Labels are the highest-gap countries.

Figure 22: Composite infrastructure-gap index


Notes: Composite infrastructure-gap index (0–100), the mean of the available domain-gap percentiles, ranked from lowest (left) to highest (right) and coloured by binding constraint. The index is a relative screening measure across this 54-country sample, not an absolute standard; countries missing the demand-side domain are scored on the domains they have.

6.3 Do the gaps coincide?

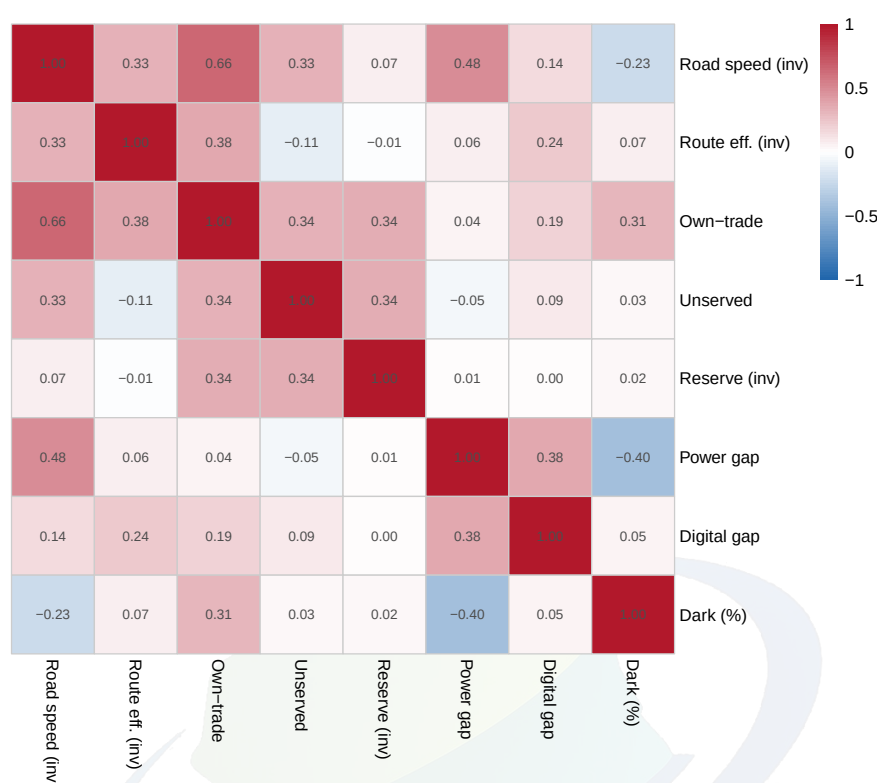
Partly, and in a policy-relevant way (Figure 23). Slow roads and economic self-sufficiency move together strongly (0.66), so the transport-connectivity gap is internally coherent. Power-supply adequacy is largely *orthogonal* to the other gaps (a country can generate enough and still leave its people far from

the grid), which is why supply and access must be diagnosed separately. But the two demand-side gaps, distance-to-power and slow-mobile, are positively correlated (0.38), and that overlap is the empirical basis for spatially bundling power and digital investment where both are severe.

Table 4: Highest composite-gap countries and their binding constraint

Country	Region	Index	Conn.	Supply	Access	Binding constraint
Comoros	Eastern	87.7	99	76	–	Transport connectivity
Gambia	Western	74.8	51	93	81	Power supply
Eritrea	Eastern	70.3	71	61	79	Demand-side access
Liberia	Western	68.2	69	78	58	Power supply
Eswatini	Southern	65.9	54	94	49	Power supply
DR Congo	Central	65.6	55	81	61	Power supply
Lesotho	Southern	65.4	72	86	38	Power supply
Seychelles	Eastern	65.1	–	65	–	Power supply
Madagascar	Eastern	64.6	79	45	70	Transport connectivity
Sierra Leone	Western	63.4	70	62	59	Balanced
Guinea-Bissau	Western	63.3	71	65	54	Transport connectivity
Djibouti	Eastern	61.3	82	69	33	Transport connectivity
Niger	Western	61.2	42	68	74	Demand-side access
Equatorial Guinea	Central	60.9	67	51	65	Transport connectivity
Sudan	Northern	60.6	36	78	68	Power supply
Burundi	Eastern	60.0	60	51	69	Demand-side access
Somalia	Eastern	59.4	71	39	68	Transport connectivity
Mauritania	Western	57.1	57	58	56	Balanced
Rwanda	Eastern	56.6	66	42	63	Transport connectivity
Burkina Faso	Western	56.2	38	67	64	Power supply

Notes: The 20 countries with the highest composite gap index. “Conn.”, “Supply”, and “Access” are the within-sample percentiles (0–100) of the road-connectivity, power-supply, and demand-side-access gaps; a dash marks a domain the country does not have. “Binding constraint” is the domain with the highest percentile (“Balanced” when the domains are within 12 points of each other).

Figure 23: Do the infrastructure gaps coincide?


Notes: Cross-country correlations among the underlying gap indicators (metrics oriented so that higher always means a worse gap). Red is positive, blue negative. Slow roads and self-sufficiency co-move strongly; power and digital access gaps co-move moderately; power-supply adequacy is largely independent of the rest.

7. Policy Priorities and Conclusion

The continental diagnostic does not prescribe projects; it ranks where the returns to attention are highest and in which sector. Five priorities follow from the patterns above.

7.1 Five priorities

1. **Sequence by the binding constraint, not by sector uniformly.** The typology assigns each country a first-order domain: roads for the 16 fragmented, low-route-efficiency economies where a constrained budget earns the highest general-equilibrium return; generation for the 14 supply-short systems, most of them in Southern Africa or small and import-dependent; and household access for the 12 economies where energy is produced but not reached. A continent-wide programme that treats every country as a road problem, or every country as a generation problem, misallocates against this map.
2. **Build the next generation of power capacity as renewables.** The least-cost expansion is 71% solar and 22% wind at generic costs, and the deficit systems are constrained by generation rather than transmission. For the 16 systems running negative reserve margins, the cheapest path to adequacy is firm-able renewable capacity plus flexibility, not new fossil baseload; for the import-

dependent small states, domestic renewable build also reduces exposure to interconnector risk. Hydro-dominated systems should diversify: the deepest recent crises (Zambia, Zimbabwe, Malawi) came from single-reservoir drought exposure, and solar is the natural hedge because it does not share hydrology with the existing fleet.

3. **Treat reliability as a delivery problem, not only a capacity problem.** Observed outages bear little relation to modelled adequacy (Section 4.4): most of the burden firms face arises from utility finances, fuel and foreign exchange, and grid operation, not from a shortage of least-cost capacity on paper. Capacity programmes therefore need to travel with cost-recovery reform and maintenance funding (Trimble et al., 2016); without them, new plant decays into the same unreliability, as three decades of the continent's utility record show (Eberhard et al., 2011).
4. **Bundle power and digital investment where the gaps coincide.** The demand-side gaps overlap (correlation 0.38) and the marginal return to each rises with the other, so coordinated power-plus-digital investment pays off most in the compact set of under-served, high-population regions in Table 2: the Sudanese Red Sea, the Ethiopian highlands, Sahelian Nigeria, southern Madagascar, and the eastern DRC. These are screening priorities that a project pipeline can target directly.
5. **Match the road programme to affordability and return jointly.** Full network upgrades cost a median 28% of GDP and far more in the smallest economies, so the realistic instrument is the budget-constrained optimisation, which concentrates gains in the fragmented economies where circuitry is worst. Return and relative cost are only weakly related, so neither should be used alone to rank road spending.

7.2 Caveats and appropriate use

These results are a spatial screening exercise, not project appraisals. Each pipeline rests on proxies (night-lights for electrification, routed times for road quality, a single modelled weather and demand year for the power system) and on differing GDP vintages and population denominators, which are reconciled here by keeping each indicator on its own basis rather than forcing a single national account. The power model is a single-period least-cost dispatch: its near-zero unserved energy is a planner's optimum, not a forecast of delivered reliability, and Section 4.4 quantifies how far the two diverge. The transport optimisation abstracts from financing, maintenance, and political-economy constraints, and the demand-side analysis covers only the 45 sub-Saharan countries in the settlement survey. The value of the exercise is comparative: it is a consistent, reproducible ranking of where each kind of infrastructure return is likely to be highest, and the country diagnostics should be consulted before any of these priorities is turned into a plan.

References

- African Development Bank (2026). African economic outlook 2026. Technical report, African Development Bank, Abidjan.
- Allen, T. and Arkolakis, C. (2022). The welfare effects of transportation infrastructure improvements. *The Review of Economic Studies*, 89(6):2911–2957.
- Andersen, T. B. and Dalgaard, C.-J. (2013). Power outages and economic growth in africa. *Energy Economics*, 38:19–23.
- Blimpo, M. P. and Cosgrove-Davies, M. (2019). *Electricity Access in Sub-Saharan Africa: Uptake, Reliability, and Complementary Factors for Economic Impact*. Africa Development Forum. World Bank, Washington, DC.
- Brown, T., Hörsch, J., and Schlachtberger, D. (2018). PyPSA: Python for Power System Analysis. *Journal of Open Research Software*, 6(1):4.
- Cole, M. A., Elliott, R. J. R., Occhiali, G., and Strobl, E. (2018). Power outages and firm performance in sub-saharan africa. *Journal of Development Economics*, 134:150–159.
- Collier, P., Kirchberger, M., and Söderbom, M. (2016). The cost of road infrastructure in low- and middle-income countries. *The World Bank Economic Review*, 30(3):522–548.
- Donaldson, D. (2018). Railroads of the Raj: Estimating the impact of transportation infrastructure. *American Economic Review*, 108(4-5):899–934.
- Eberhard, A., Rosnes, O., Shkaratan, M., and Vennemo, H. (2011). *Africa's Power Infrastructure: Investment, Integration, Efficiency*. Directions in Development. World Bank, Washington, DC.
- Ember (2025). Yearly Electricity Data. Technical report, Ember.
- Fajgelbaum, P. D. and Schaal, E. (2020). Optimal transport networks in spatial equilibrium. *Econometrica*, 88(4):1411–1452.
- Gotzens, F., Heinrichs, H., Hörsch, J., and Hofmann, F. (2019). Performing energy modelling exercises in a transparent way — The issue of data quality in power plant databases. *Energy Strategy Reviews*, 23:1–12.
- GSMA Intelligence (2024). The state of mobile internet connectivity 2024. Technical report, GSMA, London. Documents that 83% of LDC populations are covered by 3G+ but only 36% are online; identifies electricity as a key barrier to converting coverage into connectivity.
- IEA, IRENA, UNSD, World Bank, and WHO (2025). Tracking SDG 7: The energy progress report 2025. Technical report, World Bank, Washington, DC.
- Krantz, S. (2024a). Mapping Africa's infrastructure potential with geospatial big data and causal ML. *Kiel Working Paper*, (2276).
- Krantz, S. (2024b). Optimal investments in Africa's road network. Policy Research Working Paper 099223509042435445, The World Bank Group, Washington, DC.
- Krantz, S., Srinivasan, S., and Begazo, T. (2025). Complementarities between energy and digital infrastructure in Africa. Technical report, Kiel Institute for the World Economy and World Bank. Settlement-level evidence that the development returns to power and digital infrastructure are mutually reinforcing, with a stable positive interaction of about 1.5 International Wealth Index points and a Local-Linear Causal Forest confirming complementarity as the strongest predictor of treatment-effect heterogeneity.

- Luxen, D. and Vetter, C. (2011). Open source routing machine (OSRM). <http://project-osrm.org>.
- Mattsson, N., Verendel, V., Hedenus, F., and Reichenberg, L. (2021). An autopilot for energy models – automatic generation of renewable supply curves, hourly capacity factors and hourly synthetic electricity demand for arbitrary world regions. *Energy Strategy Reviews*, 33:100606.
- Nunn, N. and Puga, D. (2012). Ruggedness: The blessing of bad geography in Africa. *Review of Economics and Statistics*, 94(1):20–36.
- Parzen, M., Abdel-Khalek, H., Fedotova, E., Mahmood, M., Frysztacki, M. M., Hampp, J., Franken, L., Schumm, L., Neumann, F., Poli, D., Kiprakis, A., and Fioriti, D. (2023). PyPSA-Earth. A new global open energy system optimization model demonstrated in Africa. *Applied Energy*, 341:121096.
- Redding, S. J. (2016). Goods trade, factor mobility and welfare. *Journal of International Economics*, 101:148–167.
- Redding, S. J. and Rossi-Hansberg, E. (2017). Quantitative spatial economics. *Annual Review of Economics*, 9:21–58.
- Rentschler, J., Kornejew, M., Hallegatte, S., Braese, J., and Obolensky, M. (2019). Underutilized potential: The business costs of unreliable infrastructure in developing countries. Policy Research Working Paper 8899, World Bank, Washington, DC.
- South African Reserve Bank (2023). Reflections on load-shedding and potential GDP. Occasional bulletin of economic notes, South African Reserve Bank, Pretoria.
- Trimble, C., Kojima, M., Perez Arroyo, I., and Mohammadzadeh, F. (2016). Financial viability of electricity sectors in sub-saharan africa: Quasi-fiscal deficits and hidden costs. Policy Research Working Paper 7788, World Bank, Washington, DC.
- World Bank (2023). Digital Africa: Technological transformation for jobs. Technical report, World Bank Group, Washington, DC. Argues that digital technology and electricity are mutual complements for firm and household production; calls for coordinated investment in both.