Supplementary Information for

The Cost of Electrifying All Households in 40 sub-Saharan African countries by 2030

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Contains:

- Supplementary Figures S1 – S6
- Supplementary Tables S1 – S8

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Additional Figures

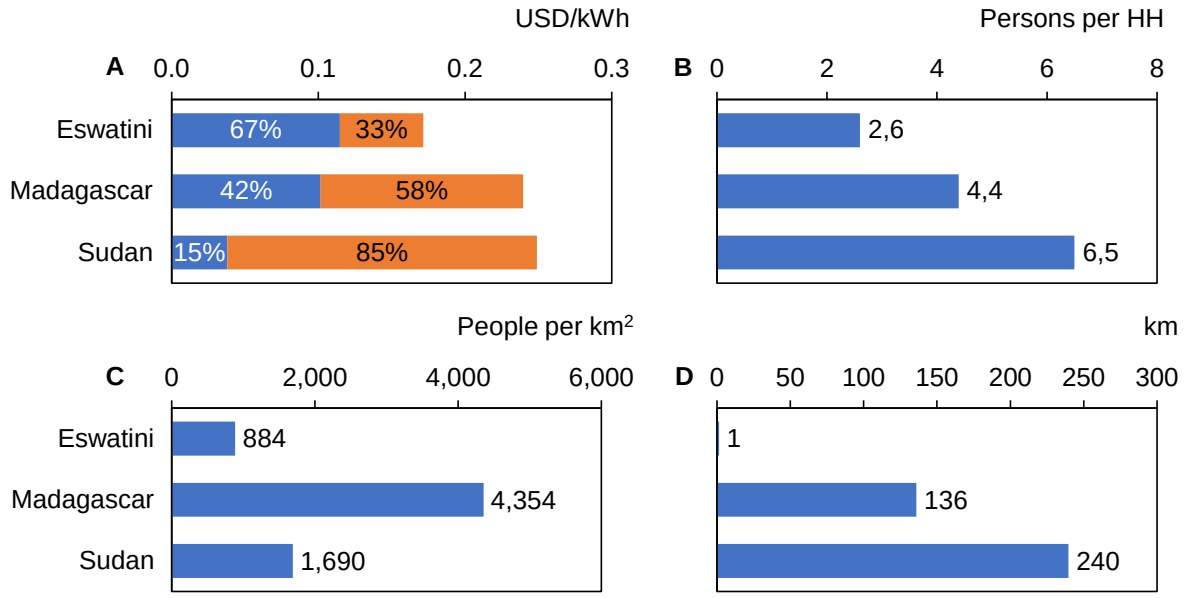

Figure S1: Extreme case country comparison. **A.** LCOE in USD/kWh where blue indicates the grid extension cost share and orange the SAS cost share. **B.** Average household size in person per household. **C.** Average cluster population density in people per km^2. Note that this shows the population density for clusters to be electrified – hence populated areas – and the average across clusters. The numbers therefore should not be compared to country-wide population density data. **D.** Average distance to closest medium voltage line in km. Numbers are always averages across areas to be electrified.

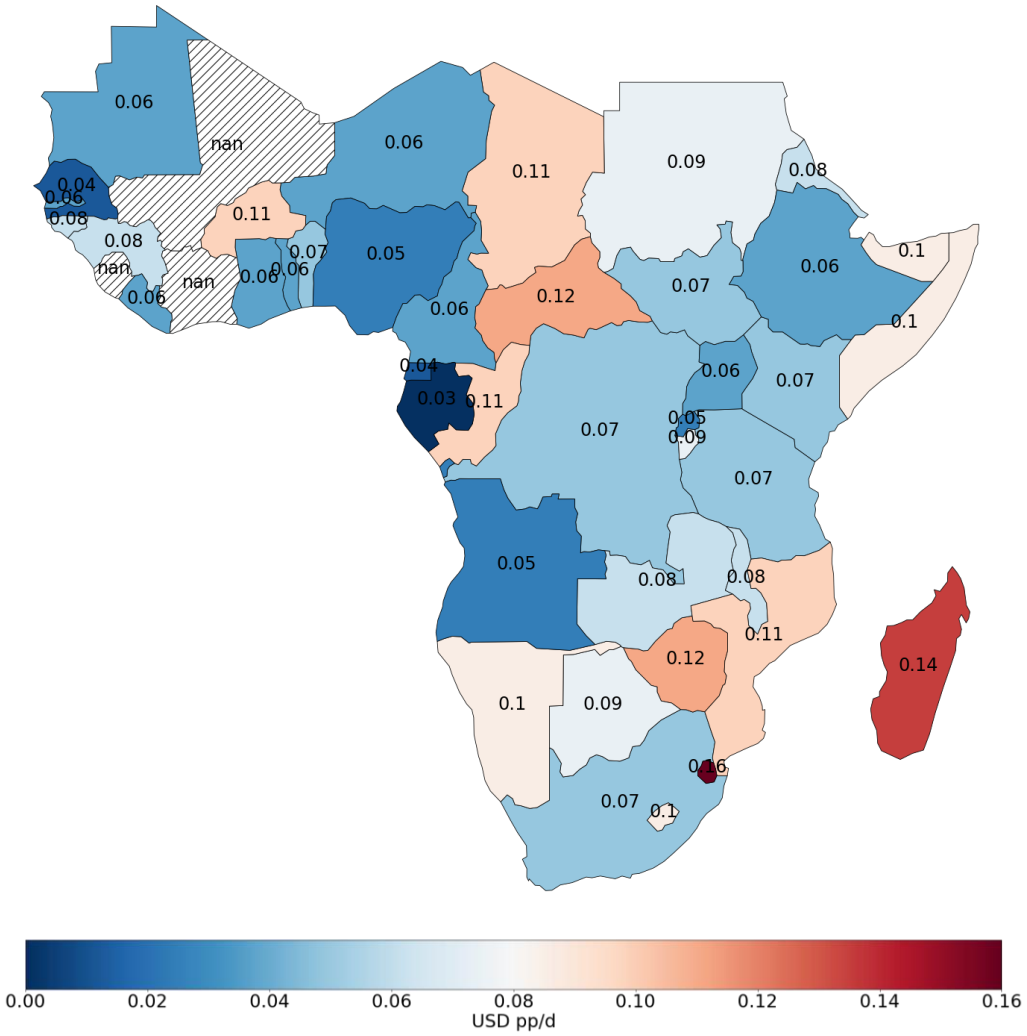

Figure S2: Least-cost electrification costs pp/d by country.

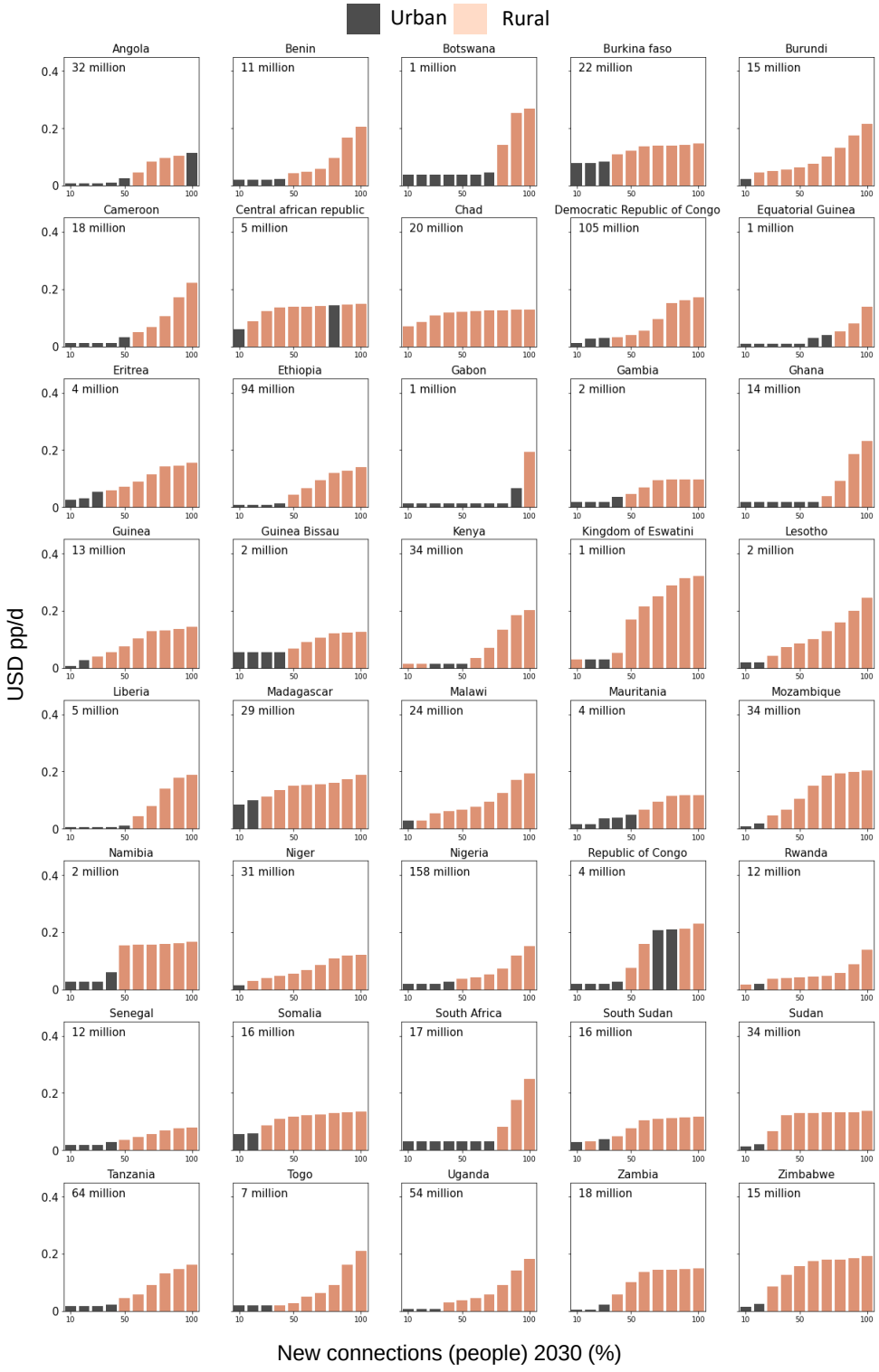

Figure S3: Electrification cost curves in pp/d for rural versus urban populations by country. Costs are in USD pp/d, each bar represents a decile of the population to be electrified by 2030 to reach 100% electrification. Based on an empirical threshold for urban population density by country[1], clusters are classified as urban or rural. Colours are assigned based on the classification of the majority of clusters per decile. Costs are shown for Tier 3 electrification.

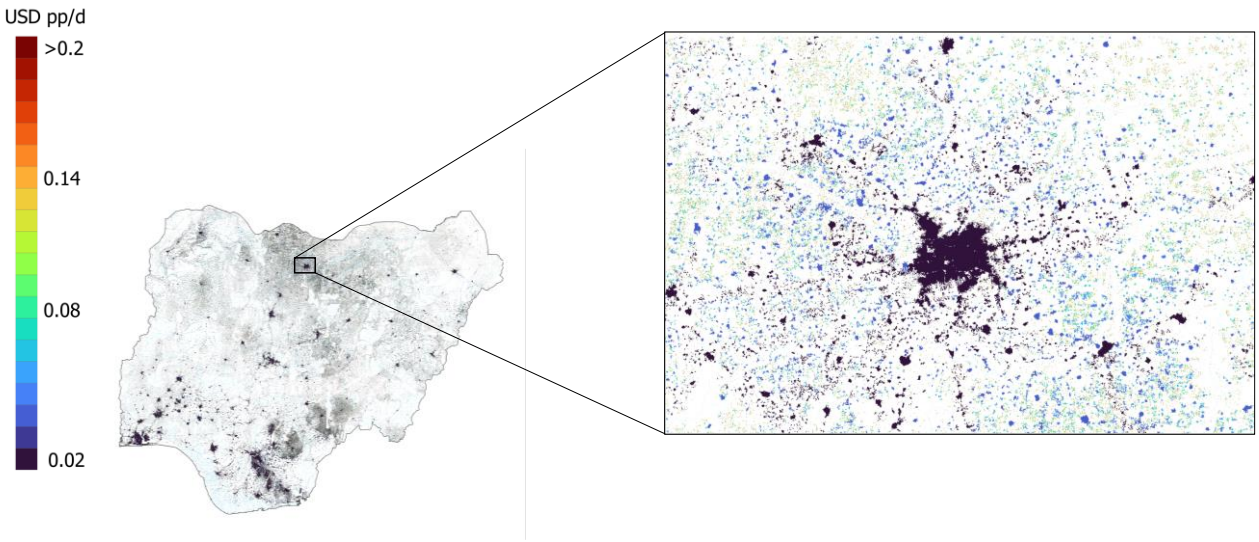

Figure S4: Illustration of spatially explicit cost per person per day for different clusters. The figure shows the example of Nigeria (left) and Kano city in the north of the country (inlay). The maps illustrate how costs are lowest in densely populated areas and along grid lines ("arteries" spreading from the city center). The maps are plotted using cluster data provided by the World Bank's Global Electrification Platform.

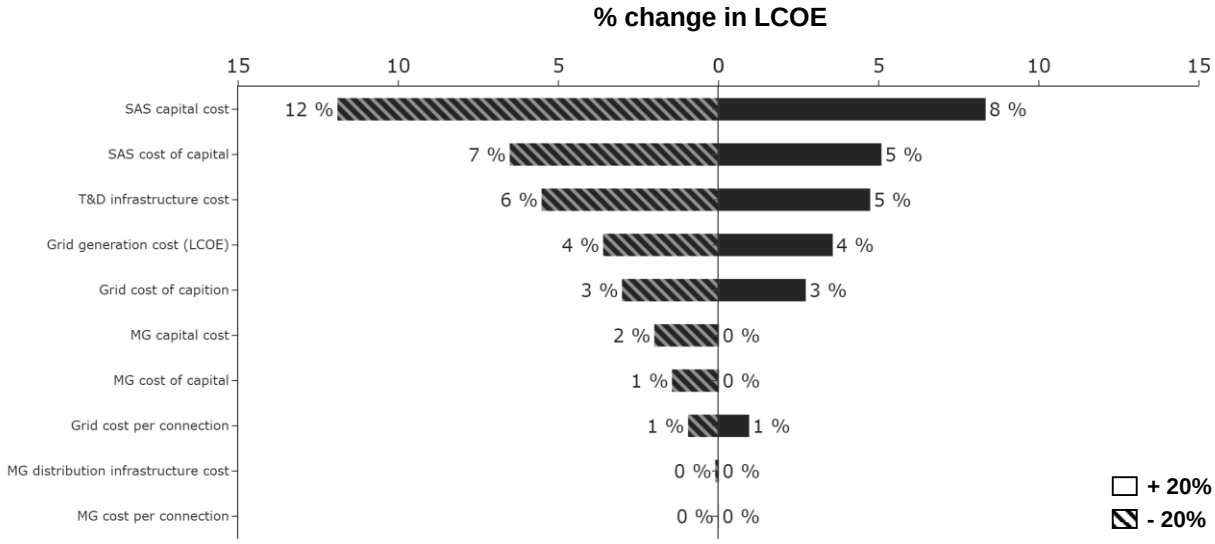

Figure S5: Sensitivity analysis for the reference scenario (Tier 3). Shows the percentage change in the weighted average LCOE for all of sub-Saharan Africa for a variation of ± 20% in each input parameter.

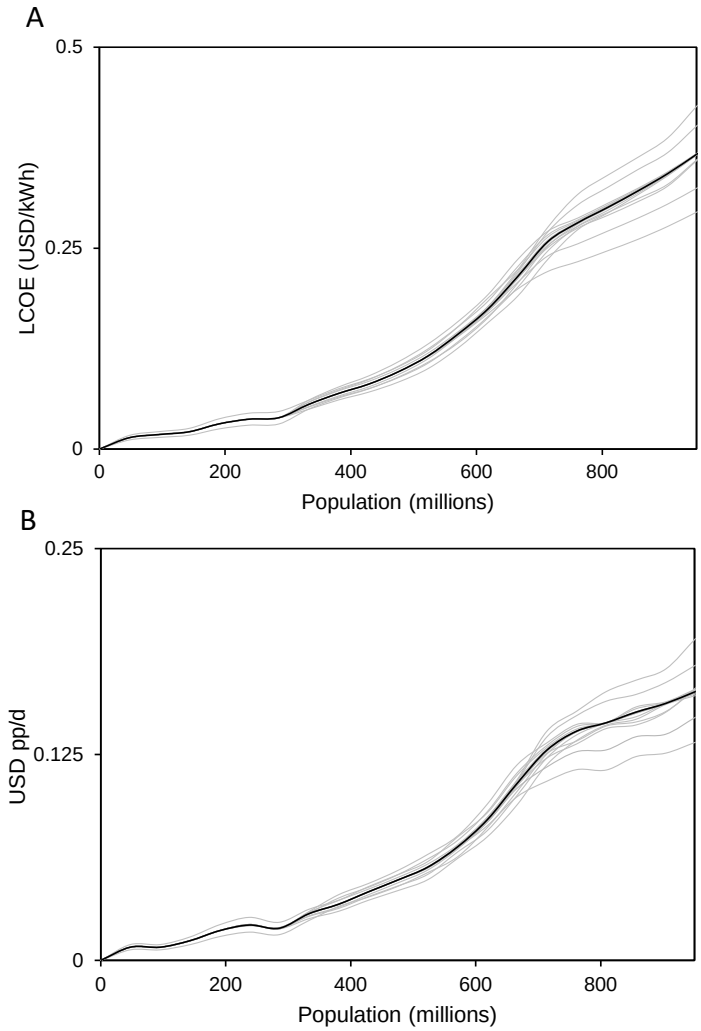

Figure S6: Sensitivities along the electrification cost curve. A. LCOE. B. Cost pp/d. Black line represents the baseline Tier 3 cost curve as shown in Figure 2 in the paper. Grey lines show the sensitivity for each ± 20% variation shown in Figure S4 (ten lines above and ten below the baseline).

Additional Tables

Table S1: Description of demand tiers used in analysis[2]

	Tier 2	Tier 3	Tier 4
Indicative annual per household demand (kWh)	ca. 73	ca. 365	ca. 1,241
Availability (minimum duration (hours))	4 – 8 hours	8 -16 hours	16 – 22 hours
Examples of typical energy services	Electrical lighting, phone charging & televisions	Tier 2 and mid-level powered appliances e.g., refrigerator/freezer, fans, water pump	Tier 3 highly powered appliances e.g., air conditioner/space heater, electric cooker, water heater

Table S2: Off-grid electrification assumptions (based on OnSSET and Table S3, see methods)

Parameter	CAPEX (USD/kW)	O&M (in % of CAPEX)	Asset lifetime (Years)	Capacity factor
Solar PV mini-grid (including batteries)	2,139	1.5% + 2% of T&D	20	Calculated using solar resource availability data
Hydro mini-grid	3,000	1.5% + 2% of T&D	30	0.5
Solar PV standalone system (including batteries)	<0.02 kW = 6,720 0.02 < kW < 0.05 = 6,133 0.05 < kW < 0.1 = 4,457 kW > 0.1 = 3,122	2%	15	Calculated using solar resource availability data

Table S3: Annual cost reduction factors by component and system

Parameter	Annual cost reduction factor
Components	
PV Modules	5%
Li-ion Battery	12%
Inverter, charge controllers & BOS	5%
System (total CAPEX)	
Mini-grid	4%
Standalone system	5%

Table S4: MG and SAS future cost triangulation

Approach	Source	Region	Capital cost (USD/kW)	Year
Mini-grid	National Renewable Energy Lab[3]	Sub-Saharan Africa	3,356	2020
	UNDP Cambodia[4]	Cambodia	2,566	2025
	The World Bank/Energy Sector Management Assistance Program[5]	Global	2,500	2030 (best in class)
Standalone system	Rockefeller Foundation[6]	Global, focus Sub-Saharan Africa	7,580	2020 (0.05 kW system)
	UNDP Cambodia[4]	Cambodia	3,360	2025 (0.1 kW system)

Table S5: Cost increase due to misguided planning. The second column shows the population weighted average LCOE across SSA as shown in the paper (optimal electrification approach choice). The third column shows the population weighted average LCOE across SSA if the electrification approach is chosen according to the previous column but electrification demand is only Tier 2. Technically, we show the LCOE of the Tier 2 model run for the (often suboptimal) electrification approach from the first column. Note that OnSSET only calculates the grid LCOE if the optimal technology choice is grid. Hence, most clusters that are electrified via the grid in Tier 3 or Tier 4 but via and off grid approach in Tier 2 are excluded because we do not have a Tier 2 grid electrification cost. We report the according population coverage for both cases in the first column.

	Share of population covered	Weighted average LCOE; expected demand (USD/kWh)	Weighted average LCOE; T2 demand (USD/kWh)	Relative increase in LCOE
Tier 3	81%	0.13	0.17	32%
Tier 4	72%	0.09	0.17	86%

Table S6: Cost increase due to oversizing. We choose two representative clusters at the median of the Tier 3 LCOE distribution by electrification approach. Survey data from an electrification program evaluation in Rwanda show that newly grid connected households consumed 11 kWh/month on average (median = 6 kWh/month) and official data for the same country reporting that more than half of newly grid connected households consume less than 15 kWh/month[7]. 15 kWh/month is roughly half of the assumed Tier 3 demand in OnSSET (51% for the representative MG cluster, 53% for SAS respectively). We therefore contrast the LCOE for Tier 3 electrification with a case where demand is reduced to 50%. Note that Tier 3 demand is country specific.

	Country specific Tier 3 demand per household (kWh/yr)	LCOE for Tier 3 demand (USD/kWh)	LCOE for 50% of Tier 3 demand (USD/kWh)	Relative increase in LCOE
Representative MG	353	0.35	0.79	128%
Representative SAS	339	0.31	0.68	121%

Table S7: Table showing the LCOE, cost pp/d and population per country

		Tier 2		Tier 3		Tier 4	
Country	**Population to be electrified**	**LCOE (USD/kWh)**	**cost pp/d**	**LCOE (USD/kWh)**	**cost pp/d**	**LCOE (USD/kWh)**	**cost pp/d**
Angola	31,787,200	0.16	0.02	0.13	0.05	0.11	0.10
Benin	10,689,460	0.15	0.03	0.10	0.07	0.07	0.13
Botswana	1,345,063	0.09	0.03	0.08	0.09	0.07	0.20
Burkina Faso	22,444,490	0.26	0.03	0.25	0.11	0.23	0.28
Burundi	14,789,410	0.27	0.04	0.15	0.09	0.10	0.15
Cameroon	17,926,060	0.15	0.03	0.09	0.06	0.06	0.11
Central African Republic	4,702,520	0.31	0.04	0.29	0.12	0.27	0.29
Chad	19,919,067	0.29	0.03	0.26	0.11	0.24	0.26
Democratic Republic of Congo	104,877,598	0.22	0.03	0.15	0.07	0.12	0.15
Republic of Congo	3,754,890	0.21	0.03	0.19	0.11	0.16	0.25
Equatorial Guinea	990,840	0.16	0.02	0.09	0.04	0.05	0.06
Eritrea	4,227,450	0.26	0.03	0.19	0.08	0.15	0.17
Kingdom of Eswatini	637,100	0.21	0.05	0.17	0.16	0.10	0.25
Ethiopia	93,697,777	0.17	0.02	0.13	0.06	0.09	0.11
Gabon	764,454	0.08	0.01	0.06	0.03	0.05	0.07
Gambia	1,788,830	0.21	0.02	0.18	0.06	0.16	0.13
Ghana	14,017,460	0.13	0.02	0.10	0.06	0.07	0.12
Guinea	13,062,830	0.28	0.03	0.21	0.08	0.17	0.16
Guinea Bissau	1,996,760	0.22	0.02	0.20	0.08	0.18	0.19
Kenya	34,351,350	0.13	0.02	0.10	0.07	0.07	0.13
Lesotho	1,838,540	0.22	0.05	0.13	0.10	0.08	0.16
Liberia	5,476,040	0.19	0.02	0.14	0.06	0.10	0.11
Madagascar	29,288,820	0.28	0.04	0.25	0.14	0.23	0.32
Malawi	24,086,800	0.23	0.04	0.14	0.08	0.10	0.16
Mauritania	4,198,292	0.26	0.02	0.18	0.06	0.14	0.12
Mozambique	34,195,870	0.26	0.04	0.20	0.11	0.15	0.21
Namibia	1,882,080	0.15	0.03	0.15	0.10	0.13	0.24
Niger	30,531,340	0.26	0.03	0.18	0.06	0.13	0.12
Nigeria	158,295,030	0.16	0.02	0.10	0.05	0.08	0.10
Rwanda	11,773,910	0.22	0.03	0.12	0.05	0.08	0.09
Senegal	12,020,950	0.19	0.01	0.15	0.04	0.12	0.09
Somalia	16,313,682	0.30	0.03	0.29	0.10	0.26	0.25
South Africa	16,666,174	0.10	0.02	0.08	0.07	0.06	0.14
South Sudan	16,130,098	0.27	0.03	0.21	0.07	0.17	0.16
Sudan	33,740,812	0.30	0.03	0.26	0.09	0.23	0.23
Tanzania	64,202,020	0.17	0.02	0.13	0.07	0.09	0.13
Togo	6,640,742	0.16	0.03	0.10	0.06	0.07	0.12
Uganda	54,102,740	0.17	0.03	0.09	0.06	0.06	0.09
Zambia	17,815,780	0.22	0.03	0.19	0.08	0.15	0.18
Zimbabwe	14,761,660	0.26	0.04	0.22	0.12	0.16	0.23
Total / overall	**951,731,988**	**0.20**	**0.03**	**0.14**	**0.07**	**0.11**	**0.15**

Table S8: country specific inputs for households, grid costs and the cost of capital used for analysis.

Country	Population 2030	NumPeoplePerHH (Urban)	NumPeoplePerHH (Rural)	Grid Capacity Investment Cost (USD/kW)	Grid Losses	GridGenerationCost (USD/kWh)	Cost of capital		
							Grid	Mini-grid	Standalone system
Angola	44,427,789	5.6	6.7	1,160	0.11	0.019	8.1%	21.2%	15.3%
Benin	15,648,264	3.1	3.6	1,810.7	0.24	0.031	7.6%	21.0%	14.9%
Botswana	2,749,922	1.7	2.1	1,505.2	0.11	0.032	2.6%	15.7%	9.8%
Burkina Faso	27,259,037	4.4	5.1	1,998	0.17	0.169	10.0%	23.2%	17.2%
Burundi	15,783,471	3.5	4.1	973	0.24	0.033	13.2%	26.4%	20.4%
Cameroon	3,283,193	3	3.3	1,980.1	0.11	0.017	9.1%	22.3%	16.3%
Central Africa Republic	6,031,242	5	5.6	2,228	0.14	0.134	11.9%	25.0%	19.1%
Chad	21,450,533	5.1	5.6	1,924.1	0.31	0.108	11.2%	24.3%	18.4%
Republic of Congo	7,262,400	3.5	3.9	1,782	0.45	0.034	10.6%	23.8%	17.8%
Democratic Republic of Congo	119,763,914	4.4	4.9	1,713	0.21	0.02	10.5%	23.7%	17.7%
Equatorial Guinea	1,853,489	5.2	5.7	2,188	0.25	0.02	9.8%	23.2%	17.1%
Eritrea	6,751,715	4.5	5.4	1,448.4	0.13	0.06	14.7%	27.9%	21.9%
Eswatini	1,673,865	2.2	2.6	1,693.1	0.61	0.032	8.4%	21.3%	15.5%
Ethiopia	139,578,721	4.4	5.2	2,248	0.19	0.018	7.7%	20.9%	14.9%
Gabon	2,632,143	4	4.4	2,184.4	0.28	0.024	8.8%	21.9%	16.0%
Gambia	3,028,782	6.6	7.6	1,207.5	0.4	0.062	9.8%	23.3%	17.2%
Ghana	37,413,133	3.3	3.8	1,801	0.23	0.03	10.2%	23.4%	17.4%
Guinea	17,618,044	5.6	6.5	1,985.8	0.58	0.015	14.6%	28.3%	22.1%
Guinea-Bissau	2,466,973	5	5.8	1,307.8	0.4	0.137	8.8%	22.3%	16.2%
Kenya	67,000,459	3	3.5	1,906	0.18	0.022	8.0%	21.2%	15.2%
Lesotho	2,653,958	2.6	3.1	2,181.1	0.22	0.026	10.6%	24.0%	17.9%
Liberia	6,513,217	4.6	5.4	2,180.8	0.25	0.012	14.2%	27.8%	21.6%
Madagascar	35,370,576	3.7	4.4	2,353	0.33	0.1355	8.2%	21.6%	15.5%
Malawi	26,433,006	3.5	4.1	1,362.9	0.23	0.047	11.3%	24.9%	18.7%
Mauritania	5,981,526	6.1	7	1,628	0.27	0.042	15.1%	28.5%	22.4%
Mozambique	41,989,931	3.7	4.4	1,737	0.15	0.017	13.0%	26.2%	20.2%
Namibia	3,258,844	2.9	3.4	1,067.3	0.36	0.038	4.6%	17.8%	11.8%
Niger	34,887,762	5.7	6.6	1,785	0.42	0.039	14.2%	27.8%	21.6%
Nigeria	263,463,721	4	4.6	1,864.3	0.16	0.039	8.0%	21.1%	15.2%
Rwanda	16,040,538	4.7	5.6	1,240.5	0.19	0.042	8.8%	22.0%	16.0%
Senegal	22,179,714	7.2	8.4	1,303.4	0.13	0.066	7.3%	20.4%	14.5%
Somalia	21,420,425	5.6	6.6	1,759	0.25	0.155	15.5%	29.2%	23.0%
South Africa	64,679,757	2.3	2.7	2,356.9	0.08	0.036	4.2%	17.4%	11.4%
South Sudan	17,147,041	5.7	6.8	2,941.1	0.06	0.036	10.5%	24.2%	18.0%
Sudan	54,519,982	5.5	6.5	1,183	0.14	0.036	18.5%	32.2%	26.0%
Tanzania	83,285,995	3.9	4.6	1,345.5	0.18	0.032	8.4%	21.9%	15.8%
Togo	10,509,876	3.3	3.8	2,020.4	0.37	0.03	9.7%	23.2%	17.1%
Uganda	63,901,008	3.4	4	2,300	0.17	0.012	8.5%	21.7%	15.7%
Zambia	24,802,597	4.5	5.3	1,441.1	0.15	0.013	10.2%	23.4%	17.4%
Zimbabwe	21,433,286	3.7	4.3	1,884.3	0.16	0.025	12.3%	25.9%	19.7%

Supplementary information references

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