An all-Africa dataset of energy model "supply regions" for solar photovoltaic and wind power: Supplementary Material

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A. Full list of metadata provided with MSRs

A full list of the metadata provided for all MSRs in the data files is shown in Table 1 for solar PV and in Table 2 for wind power.

Table 1: Metadata provided for all solar PV MSRs

Parameter	Explanation	Unit
MSR_ID	ID assigned to each MSR	
Longitude	Longitude of MSR center	ºE
Latitude	Latitude of MSR center	ºN
AreakM2	MSR area	m^2
CapacityMW	Maximum deployable capacity in MSR	MW
RoadDist	Distance from road infrastructure	km
TD_Dist_gf	Distance from nearest transmission line	km
T_Dist_gf	Distance from nearest distribution line	km
D_Dist_gf	Distance from nearest transmission/distribution line	km
SubstnDist	Distance from nearest substation (from OpenStreetMap [1])	km
Load_dst	Distance from nearest urban area (based on World Urban Areas dataset [2])	km
City_name	Name of nearest urban area	
City_Pop	Population of nearest urban area	
CtLst100kM	Count of urban areas lying within 100 km radius of MSR center	
CtCnt100kM	Comma-separated name list of urban areas lying within 100 kms radius of MSR center. If >10, it displays “Above 10 cities”.	
PopIn100kM	Sum of population of all urban areas within 100 km	
CtryName	Name of country containing MSR	
GHIkWhm2d	Mean GHI according to Global Solar Atlas, spatially averaged across MSR	$kWh/m^2/day$
RawERAmean	Mean GHI extracted from ERA5 grid cell closest to MSR center	$kWh/m^2/day$
CorAdderWh	Additive bias-correction factor (added to each nonzero hourly GHI value in the nearest-neighbour ERA5 datapoint)	$kWh/m^2/day$
CF	Annual average capacity factor (including assumed 8% losses, consisting of 4% outage and 4% inverter and cable losses [3])	
Y_GWh	Yearly yield from maximum deployable capacity	GWh
sLCOE-MWh	LCOE of power plant assets	USD/MWh
tLCOE-MWh	LCOE of transmission/grid assets	USD/MWh
tCAPEX-kW	Transmission/grid asset CAPEX	USD/kW
rLCOE-MWh	LCOE of road assets	USD/MWh
rCAPEX-kW	Road asset CAPEX	USD/kW
LCOE-MWh	Full LCOE	USD/MWh
trCAPEX-kW	Transmission/grid + road asset CAPEX	USD/kW
H1...H8760	Hourly capacity factor (%) for one full year (not counting the losses reported under “CF”)	

Table 2: Metadata provided for all wind power MSRs

Parameter	**Explanation**	**Unit**
MSR_ID	ID assigned to each MSR	
Longitude	Longitude of MSR center	ºE
Latitude	Latitude of MSR center	ºN
AreakM2	MSR area	m^2
CapacityMW	Maximum deployable capacity in MSR	MW
RoadDist	Distance from road infrastructure	km
TD_Dist_gf	Distance from nearest transmission line	km
T_Dist_gf	Distance from nearest distribution line	km
D_Dist_gf	Distance from nearest transmission/distribution line	km
SubstnDist	Distance from nearest substation (from OpenStreetMap [1])	km
Load_dst	Distance from nearest urban area (based on World Urban Areas dataset [2])	
City_name	Name of nearest urban area	
City_Pop	Population of nearest urban area	
CtLst100kM	Count of urban areas lying within 100 km radius of MSR center	
CtCnt100kM	Comma-separated name list of urban areas lying within 100 kms radius of MSR center. If >10, it displays “Above 10 cities”.	
PopIn100kM	Sum of population of all urban areas within 100 km	
CtryName	Name of country containing MSR	
MeanSpeed	Mean wind speed according to Global Wind Atlas, spatially averaged across MSR	m/s
IEC_Class	Wind turbine class	
ERA_Wspeed	Mean wind speed (m/s) extracted from ERA5 grid cell closest to MSR center	m/s
CF100m	Annual average capacity factor (including assumed 17% losses, consisting of 2% outage and 15% array and wake losses [3]) for 100m-hub height turbine	
Y_GWh100m	Yearly yield from maximum deployable capacity (GWh)	GWh
sLCOE-MWh	LCOE of power plant assets (USD/MWh)	USD/MWh
tLCOE-MWh	LCOE of transmission/grid assets (USD/MWh)	USD/MWh
tCAPEX-kW	Transmission/grid asset CAPEX (USD/kW)	USD/kW
rLCOE-MWh	LCOE of road assets (USD/MWh)	USD/MWh
rCAPEX-kW	Road asset CAPEX (USD/kW)	USD/kW
LCOE-MWh	Full LCOE (USD/MWh)	USD/MWh
trCAPEX-kW	Transmission/grid + road asset CAPEX (USD/kW)	USD/kW
H1...H8760	Hourly capacity factor (%) for one full year (not counting the losses reported under “CF100m”)	

B. Costs used for LCOE calculations

The levelized cost of electricity (LCOE) of solar PV and wind power plants deployed in the identified MSRs is composed of three separate terms:

$$LCOE = LCOE_s + LCOE_t + LCOE_r,$$

Where $LCOE_s$ refers to the investment and operation & maintenance (O&M) costs of the power plant itself; $LCOE_t$ refers to the costs for transmission infrastructure, and $LCOE_r$ refers to the costs for road infrastructure. Each separate LCOE term is calculated as follows:

$$LCOE = \frac{\sum_y \frac{(I_y + M_y)}{(1+r)^y}}{\sum_y \frac{E_y}{(1+r)^y}},$$

where y represents the year of the asset's lifetime ($0 \leq y \leq Y$, with Y the plant's lifetime), I_y are the initial (overnight) costs related to construction of the asset in each year y, M_y are the operational and maintenance costs in each year y, E_y is the total electricity generated by the plant in each year y, and r is the discount rate.

Table 3: The parameters used in the calculation of the LCOE of solar PV and wind power plants deployed in the identified MSRs. All costs expressed in USD2019 (note that the cited source may have provided data in a different currency year).

Cost type	Value	Unit	Source	Notes
Solar PV investment costs	1070	USD/kW	[4]	
Solar PV O&M costs	53.5 (fixed) 4 (variable)	USD/kW/year USD/MWh	[3]	
Solar PV lifetime	25	years	[3]	
Wind power investment costs	1338 (Class-I) 1552 (Class-II) 1819 (Class-III)	USD/kW	[3]	
Wind power O&M costs	64.2	USD/kW/year	[3]	
Wind turbine lifetime	25	years	[3]	
Transmission line investment costs	1059.3	USD/MW evacuated/km	[3]	MW evacuated based on the maximum deployable capacity in each MSR
Transmission line O&M costs	0	USD/km/year	[3]	
Transmission line lifetime	40	years	[3]	
Road extension costs	435490	USD/km	[3]	
Road O&M costs	0	USD/km/year	[3]	
Road lifetime	25	years	[3]	
Substation costs	75970	USD/substation	[3]	One substation to be deployed at each plant for low- to high-voltage transformation; one substation to be deployed at transmission line end
Discount rate	10%	-	[5]	

C. LCOE versus capacity factor: full plots

Figure 1 and Figure 2 display the full scatterplots of MSR LCOE versus average capacity factor. Each point represents an MSR; point sizes are proportional to MSR sizes (area, or equivalently the maximum deployable capacity in MW in each MSR). Colours represent the "power pool" that the country in question belongs to; this classification is given in Table 4.

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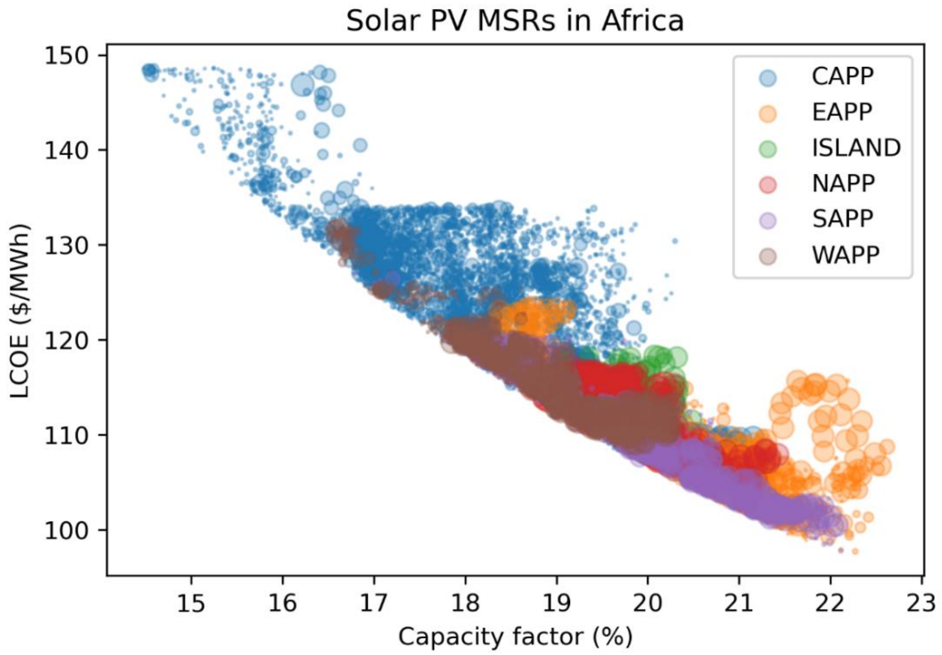

Figure 1: Full set of solar PV MSR LCOE values versus average capacity factor. Point sizes are proportional to MSR area.

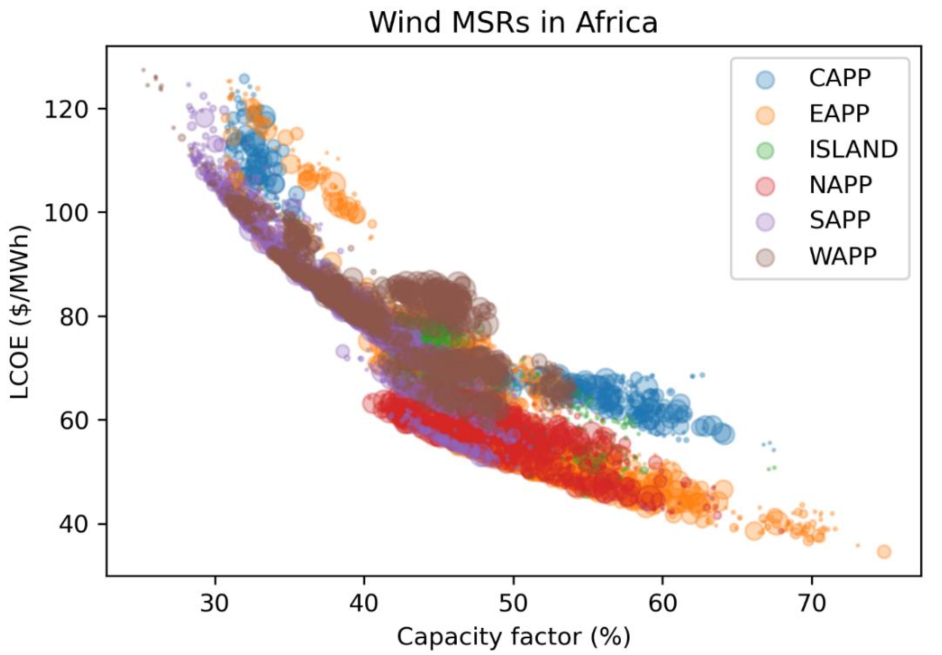

Figure 2: Full set of wind MSR LCOE values versus average capacity factor. Point sizes are proportional to MSR area.

Table 4: Countries/regions considered in this study, including their alpha-2 country code and the Power Pool to which they were assigned (by the authors; note that these designations are meant to represent geographical regions, and do not correspond 100% to the legal entities known as "power pools", as e.g. some countries are legally not a member of any, and others are members of multiple). NAPP = North African Power Pool, CAPP = Central African Power Pool, EAPP = Eastern Africa Power Pool, SAPP = Southern African Power Pool, WAPP = West African Power Pool.

Country/region	Alpha-2 code	Power Pool
Algeria	DZ	NAPP
Angola	AO	CAPP
Benin	BJ	WAPP
Botswana	BW	SAPP
Burkina Faso	BF	WAPP
Burundi	BI	CAPP
Cameroon	CM	CAPP
Central African Republic	CF	CAPP
Chad	TD	CAPP
Congo	CG	CAPP
Democratic Republic of the Congo	CD	CAPP
Djibouti	DJ	EAPP
Egypt	EG	EAPP
Equatorial Guinea	GQ	CAPP
Eritrea	ER	EAPP
Eswatini	SZ	SAPP
Ethiopia	ET	EAPP
Gabon	GA	CAPP
Gambia	GM	WAPP
Ghana	GH	WAPP
Guinea	GN	WAPP
Guinea-Bissau	GW	WAPP
Côte d'Ivoire	CI	WAPP
Kenya	KE	EAPP
Lesotho	LS	SAPP
Liberia	LR	WAPP
Libya	LY	NAPP
Madagascar	MG	n/a (ISLAND)
Malawi	MW	SAPP
Mali	ML	WAPP
Mauritania	MR	NAPP
Morocco (see note on EH)	MA	NAPP
Mozambique	MZ	SAPP
Namibia	NA	SAPP
Niger	NE	WAPP
Nigeria	NG	WAPP
Rwanda	RW	CAPP
Senegal	SN	WAPP
Sierra Leone	SL	WAPP
Somalia	SO	EAPP
South Africa	ZA	SAPP
South Sudan	SS	EAPP

Sudan	SD	EAPP
Togo	TG	WAPP
Tunisia	TN	NAPP
Uganda	UG	EAPP
United Republic of Tanzania	TZ	EAPP
Western Sahara (analysed as separate region for the purposes of this study)	EH	NAPP
Zambia	ZM	SAPP
Zimbabwe	ZW	SAPP

D. Effect of future CAPEX and OPEX reductions

Given the substantial reductions in capital and operational expenses (CAPEX and OPEX) for solar PV and wind power expected over the coming years, the results of this study—in particular, the compromise between exploiting good resources and paying the "remoteness premium" when attempting to screen the lowest-cost sites—may shift in the future. Assuming no changes in infrastructure costs for transmission lines, substations, and road construction, a reduction in CAPEX and OPEX of VRE would theoretically tend to shift the most favourable MSRs (in LCOE terms) somewhat closer to grid infrastructures, with the avoided remoteness premium making up for losses in average yield. The question is whether this effect is substantial, marginal, or non-existent.

A sensitivity test was run on the basis of predicted CAPEX and OPEX values for 2040 for solar PV and wind. Based on historical learning rates observed for these sources [4], for this test, CAPEX were assumed to drop by 50% between the present-day and 2040 for both solar PV and wind, and OPEX were assumed to drop by 50% for solar PV and by 60% for wind. The results are summarised in Table 5, which shows the average gains in grid closeness of MSRs (when passing from present-day cost assumptions to 2040 cost assumptions), alongside the corresponding average compromises in CFs. This is done both for the African average, as well as for the three countries with the strongest geographical shift in MSRs when passing from present-day to 2040 costs.

Table 5: Changes in geographical location of MSRs (expressed in average reduction in distance from the grid) and yield of these MSRs (expressed in compromise in average CF) when changing from present-day to 2040 assumptions on the CAPEX and OPEX of solar PV and wind power.

		MSR shift towards grid infrastructure	**Compromise in average MSR capacity factor**
Solar PV	**Africa-wide**	**0.8 km**	**-0.1 pp**
	Malawi (strongest shift)	20.9 km	-0.3 pp
	Gabon (2nd strongest)	20.6 km	-0.4 pp
	DRC (3rd strongest)	13.1 km	-0.2 pp
Wind	**Africa-wide**	**50.2 km**	**-0.9 pp**
	Mali (strongest shift)	299.4 km	-5.1 pp
	Chad (2nd strongest)	179.2 km	-3.9 pp
	Niger (3rd strongest)	137.3 km	-1.9 pp

It can be concluded that the effect, on average, is relatively small for solar PV, whose MSRs already tend to cluster around grid infrastructure even under present-day costs, an effect which would be only slightly strengthened by further cost drops. The effect is more important for wind, although strongly diverging on a country-by-country basis, with some countries seeing nearly no geographical shift of MSRs and others seeing substantial changes. A few clear outliers can be identified for wind power: these are countries straddling the Sahelian belt, which has excellent wind resources but mostly at several hundreds of kilometres from existing grid infrastructure.

E. Clustering approach

The clustering approach developed to complement the MSR identification algorithm is described in Methods. In Figure 3, we show an example of the results of the clustering in a geographical sense. We use the example of Mali, which had 145 separate MSRs for solar PV and 131 separate MSRs for wind (based on the screening criterion of maximum 5% coverage of a country area mentioned in the main text). Here, the MSRs were grouped into five clusters for both solar PV and wind, each with their own maximum deployable capacity, weighted average cost parameters and weighted average capacity factor time series.

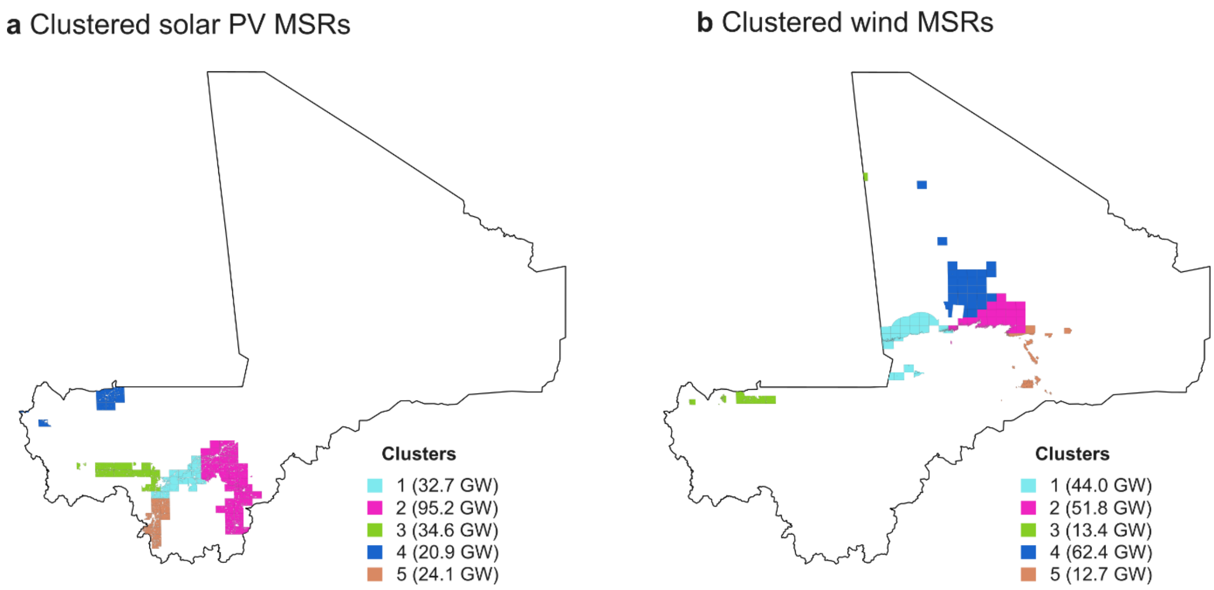

Figure 3: A geographical view of the clusters developed for Mali for solar PV (a) and wind power (b). MSRs were clustered into five clusters in both cases. Numbers in brackets indicate the maximum deployable capacity across each cluster (GW).

Bibliography

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