# Multi-criteria Analysis for Planning Renewable Energy (MapRE)

# INTERACTIVE MAP | MALAWI

## Of Southern and Eastern Africa Renewable Energy Zones (SEAREZs)

This interactive PDF map contains locations of high quality wind, solar photovoltaic (PV), and concentrated solar power (CSP) zones and estimated zone attributes important to the site-selection process (e.g., levelized cost of electricity; distance to nearest transmission lines, roads, and load centers; and proximity to load centers). Locations of existing or planned renewable energy power plants, transmission lines, substations, and load centers are also indicated on the map, conditional on data availability. In order to access different data layers and their attributes, this map must be opened using Adobe PDF Readers, which are free to download. This interactive map can be used in conjunction with the SEAREZ Multi-Objective Zone Ranking Tool. Please refer to the accompanying report for methods, assumptions, and references for data sources. Spatial data used in this interactive map can be downloaded from the MapRE (http://mapre.lbl.gov/) or the Global Atlas (http://globalatlas.irena.org/) websites.

This map and its supporting study are the results of a collaboration between the International Renewable Energy Agency (IRENA), the Lawrence Berkeley National Laboratory (LBNL), and University of California at Berkeley (UCB) as part of the Africa Clean Energy Corridor Initiative © 2015.

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Acknowledgements:
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# HOW TO USE THIS MAP

## VIEWING LAYERS

a) On the left hand side menu, click on the layers icon.

b) Expand folders you wish to view. Individual layers are classified under three folders - INFRASTRUCTURE, RENEWABLE ENERGY ZONES, and DEVELOPMENT CONSTRAINTS.

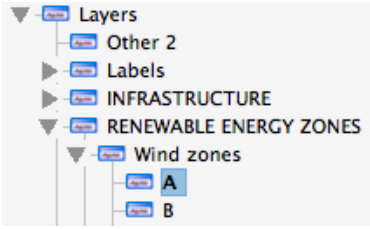
c) Each layer within a folder can be turned "on" or "off" by clicking on the "eye" icon. The legend on the right side of the map explains the symbology of each layer.

d) The renewable energy zones for each of the three technologies are colored by the estimated total levelized cost of energy (LCOE) for that technology. The legend on the right side of the map shows the corresponding LCOE costs (USD/MWh) for each color.

## VIEWING ATTRIBUTES

The detailed attributes of each SEAREZ are embedded in this map. These attributes are described on page 5 of this interactive PDF. Below are two ways to access these attributes:

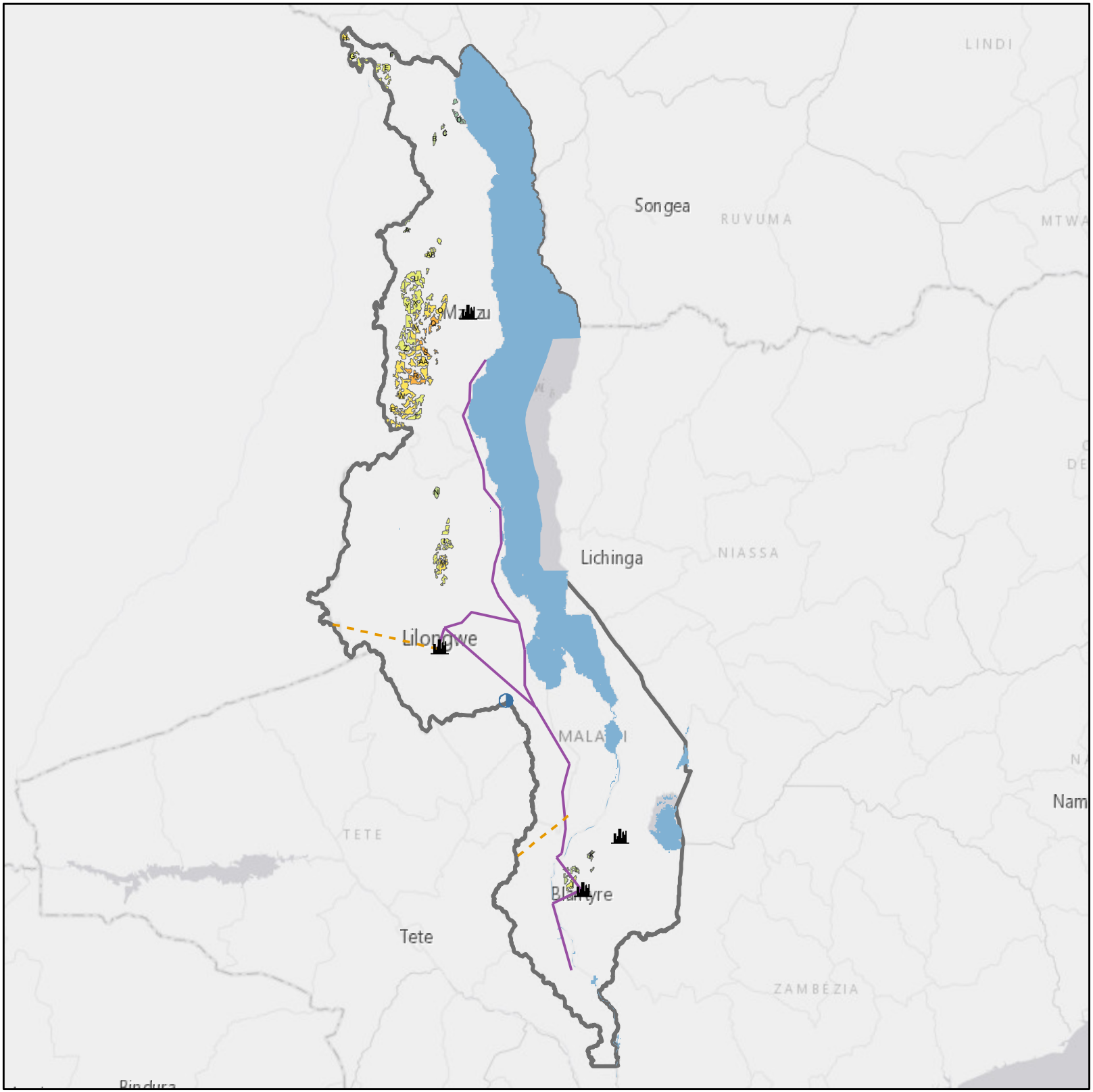
a**) Select Zone ID and retrieve attributes and location.**
The attribute table can be accessed for a zone by clicking on the Model Tree icon on the left menu. Within the Model Tree, expand the folders of the layers containing the zones and select a zone ID (e.g., "A"). An example Model Tree folder structure is shown here (right). The attributes (e.g. levelized cost of energy for generation, transmission and roads, distance to load centers) for each zone will be displayed on the bottom, left menu, beneath the Model Tree folder structure once you click on the zone ID. An example attribute table is shown here (lower right). You may also locate this zone on the map by right clicking on the zone ID-> Zoom to Selection. This feature is useful for locating zones identified through the Multi-Objective Zone Ranking Tool.




| Property | Value |
|---|---|
| OBJECTID | 90 |
| zone_identification | CL |
| electricity_generation_discounted_MWh | 1971990.258745 |
| area_km2 | 384.499998 |
| LCOE_total_transmission_USDperMWh | 65.125767 |

b) **Select location and retrieve attributes.**
Turn on the "Object Analysis Tool." In Adobe Acrobat Reader X, this tool is under Edit -> Analysis -> Object Data Tool. In Acrobat Pro X, this tool is under Tools -> Analyze -> Object Data Tool. For other versions of Adobe Reader, please refer to Adobe's documentation to find the Object Analysis Tool. The Model Tree icon will appear on the left menu if it not already available. Once the Object Analysis Tool has been activated, the cursor changes to a "cross". Move the cursor over a zone (or any other feature in the map), and click multiple times (giving at least a couple of seconds between each click). Each click opens a layer's folder in order to retrieve the final zone ID and its attributes. The map may highlight all selectable areas in red in between mouse clicks. Only the selected zone should be outlined in red once its attribute table has been retrieved. Please keep in mind that this way of assessing attributes may be slow.

c) If a map has been georeferenced, the latitude and longitude coordinates in decimal degrees can be displayed for any location on the map by accessing the "Geospatial Location Tool," found in the same menu as the "Object Analysis Tool."




# MALAWI

## RENEWABLE ENERGY ZONES

Total Levelized Cost of Electricity (USD/MWh)

| Wind | Solar PV | Solar CSP |
|---|---|---|
| < 50 | < 120 | < 200 |
| 51 - 60 | 121 - 125 | 201 - 205 |
| 61 - 70 | 126 - 130 | 206 - 210 |
| 71 - 80 | 131 - 135 | 211 - 215 |
| 81 - 90 | 136 - 140 | 216 - 220 |
| 91 - 100 | 141 - 145 | 221 - 225 |
| 101 - 110 | 146 - 150 | 226 - 230 |
| 111 - 120 | 151 - 155 | 231 - 235 |
| 121 - 130 | 156 - 160 | 236 - 240 |
| > 131 | > 161 | > 241 |

## INFRASTRUCTURE

Major cities — Roads

### Renewable energy power plants

| Operational | Potential/proposed |
|---|---|
| Wind | Wind |
| Solar PV | Solar PV |
| Solar CSP | Solar CSP |
| Geothermal | Geothermal |

### Transmission lines

| Existing | Planned | Existing | Planned |
|---|---|---|---|
| | > 500 kV | | 101 - 200 |
| | 401 - 500 kV | | 66 - 100 |
| | 301 - 400 kV | | Unknown |
| | 201 - 300 kV | | |

### Substations

Maximum rating (kV)

| | |
|---|---|
| > 400 | 101 - 200 |
| 301 - 400 | 66 - 100 |
| 201 - 300 | Not specified |

## DEVELOPMENT CONSTRAINTS

- Elevation
- Slope (solar)
- Slope (wind)
- Population (>100 persons/km2)
- Land use\land cover (solar)
- Land use\land cover (wind)
- Protected areas
- Water bodies

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# ATTRIBUTE TABLE DESCRIPTIONS

The attribute table, once retrieved, will be displayed on the bottom, left-hand side of the Model Tree menu. Blue highlighted cells indicate attributes that are specific to wind zones, orange highlighted cells indicate attributes specific to solar CSP zones, and yellow highlighted cells indicate attributes specific to solar PV. All other attributes are common between technologies.

| ATTRIBUTE NAME | DESCRIPTION |
|---|---|
| zone_identification | This is the unique alphabetical identifier for the zones. Zones are labeled on the map using this identifier. |
| Electricity generation attributes: | Estimated annual average electricity generation in MWh for the following: |
| A) Electricity_generation_discounted_MWhPerYr | **Solar PV**, assuming a 90% land use discount factor. |
| B) Electricity_generation_discounted_chosenTurbine_MWhPerYr | **Wind** using the optimally selected IEC turbine class, assuming a 75% land use discount factor. |
| C) Electricity_generation_discounted_classIIturbine_MWhPerYr | **Wind** using IEC Class II turbines, assuming a 75% land use discount factor. |
| D) Electricity_generation_discounted_noStorage_MWhPerYr | **Solar CSP** without storage, assuming a 90% land use discount factor. |
| E) Electricity_generation_discounted_6hrsStorage_MWhPerYr | **Solar CSP** with 6 hours of storage, assuming a 90% land use discount factor. |
| Potential installed capacity attributes: | Potential capacity (MW) that could be installed within a zone for the following: |
| installedCapacity_MW | **Solar PV or wind**, assuming a 90% and 75% land use discount factor, respectively. |
| installedCapacity_noStorage_MW | **Solar CSP** without storage, assuming a 90% land use discount factor. |
| installedCapacity_6hrsStorage_MW | **Solar CSP** with 6 hours of storage, assuming a 90% land use discount factor. |
| area_km2 | Total area of the zone in units of square kilometers |
| Levelized cost of electricity (LCOE) of non-generation components attributes: | Average levelized cost of electricity (in USD/MWh) for the non-generation components of the following (values are only reported if transmission or substation data could be procured): |
| A) LCOE_transmission_USDperMWh | **Solar PV**, estimated using distance to the nearest transmission line, if available. |
| B) LCOE_substation_USDperMWh | **Solar PV**, estimated using distance to the nearest substation, if available. |
| C) LCOE_road_USDperMWh | **Solar PV**, estimated using distance to the nearest road. |
| D) LCOE_transmission_chosenTurbine_USDperMWh | **Wind** using the optimally selected IEC turbine, estimated using nearest transmission line. |
| E) LCOE_substation_chosenTurbine_USDperMWh | **Wind** using the optimally selected IEC turbine, estimated using nearest substation. |
| F) LCOE_road_chosenTurbine_USDperMWh | **Wind** using the optimally selected IEC turbine, estimated using nearest road. |
| G) LCOE_transmission_6hrsStorage_USDperMWh | **Solar CSP** with 6 hours of storage, estimated using nearest transmission line. |
| H) LCOE_substation_6hrsStorage_USDperMWh | **Solar CSP** with 6 hours of storage, estimated using nearest substation. |
| I) LCOE_road_6hrsStorage_USDperMWh | **Solar CSP** with 6 hours of storage, estimated using nearest road. |
| Levelized cost of electricity (LCOE) of generation component attributes: | Average levelized cost of electricity (in USD/MWh) for generation component of the following technologies (values were estimated using the location's capacity factor and efficiencies specific to the technology): |
| A) LCOE_generation_USDperMWh | **Solar PV** |
| B) LCOE_generation_chosenTurbine_USDperMWh | **Wind** using the optimally selected IEC turbine class. |
| C) LCOE_generation_classIIturbine_USDperMWh | **Wind** using IEC Class II turbine. |
| D) LCOE_generation_noStorage_USDperMWh | **Solar CSP** without storage. |
| E) LCOE_generation_6hrsStorage_USDperMWh | **Solar CSP** with 6 hours of storage. |

| | |
|---|---|
| Total levelized cost of electricity (LCOE) attributes: | Average total levelized cost of electricity estimated by summing the individual component LCOEs for generation, transmission line or substation (values are only available if data could be procured), and road for the following: |
| A) LCOE_total_transmission_USDperMWh | **Solar PV**, estimated using the transmission component. |
| B) LCOE_total_substation_USDperMWh | **Solar PV**, estimated using the substation component. |
| C) LCOE_total_transmission_chosenTurbine_USDperMWh | **Wind** using the optimally selected IEC turbine class, estimated using transmission |
| D) LCOE_total_transmission_classIIturbine_USDperMWh | **Wind** using IEC Class II turbine, estimated using transmission |
| E) LCOE_total_substation_chosenTurbine_USDperMWh | **Wind** using the optimally selected IEC turbine class, estimated using substation |
| F) LCOE_total_substation_classIIturbine_USDperMWh | **Wind** using IEC Class II turbine, estimated using substation |
| G) LCOE_total_transmission_noStorage_USDperMWh | **Solar CSP** without storage, estimated using transmission |
| H) LCOE_total_transmission_6hrsStorage_USDperMWh | **Solar CSP** with 6 hours of storage, estimated using transmission |
| I) LCOE_total_substation_noStorage_USDperMWh | **Solar CSP** without storage, estimated using substation |
| J) LCOE_total_substation_6hrsStorage_USDperMWh | **Solar CSP** with 6 hours of storage, estimated using substation |
| mean_slope_percent | Mean slope of the zone in units of percent rise. |
| mean_populationDensity_personsPerKm2 | Mean population density of the zone in units of persons per square kilometer. |
| mean_HumanFootprint_0to100 | Mean human footprint metric (0 – least human impact; 100 – most human impact) |
| mean_LULC_score | Mean score for land use/land cover categories in the zone. Scores range from 1 to 5, with 1 being most compatible for energy development and 5 being least compatible. |
| Mean_colocation_score | Mean score for the suitability of the zone for other renewable energy technologies. For example, the attribute table of a solar PV zone would display the colocation score calculated using the zone's overlap with wind and CSP potential. The score ranges from 0 to 1, with 0 being no overlap and 1 being overlap with both renewable technologies. |
| Num_projectsWithWaterAccess | Number of project opportunity areas within the zone that is within 10 km of surface water. |
| mean_resourceQuality_Wperm2 | Mean resource quality in terms of wind power density or solar irradiance of the zone in units of watts per $m^2$. |
| mean_resourceQuality_kWhPerm2Day | Mean solar resource quality of the zone in units of annual average kWh per $m^2$ per day. |
| Capacity factor attributes: | Mean capacity factor of the zone for the following (values range from 0 to 1): |
| A) mean_capacityFactor | **Solar PV** |
| B) mean_capacityFactor_chosenTurbine | **Wind** using the optimally selected IEC turbine class. |
| C) mean_capacityFactor_classIIturbine | **Wind** using IEC Class II turbine. |
| D) mean_capacityFactor_noStorage | **Solar CSP** without storage. |
| E) mean_capacityFactor_6hrsStorage | **Solar CSP** with 6 hours of storage. |
| area_chosenTurbine_classIII_km2 | Area (in $km^2$) within the zone for which IEC class III turbines would be most suitable |
| area_chosenTurbine_classII_km2 | Area (in $km^2$) within the zone for which IEC class II turbines would be most suitable |
| area_chosenTurbine_classI_km2 | Area (in $km^2$) within the zone for which IEC class I turbines would be most suitable |
| Distance attributes: | Distance to the nearest following locations (in units of kilometers): |
| A) distance_nearest_transmission_km | Transmission line |
| B) distance_nearest_substation_km | Substation |
| C) distance_nearest_road_km | Road |

| | |
|---|---|
| D) distance_nearest_existingPlanned_wind_km (or distance_nearest_existingPlanned_PV_km, distance_nearest_existingPlaned_CSP_km) | Operational or planned wind (or solar PV, solar CSP) power plant. |
| E) distance_nearest_geothermalLocation_km | Operational or planned geothermal power plant. |
| F) distance_nearest_anyRenewableEnergyLocation_km | Operational or planned renewable energy (wind, solar PV, solar CSP, geothermal) power plant. |
| G) distance_nearest_majorCity_km | Major city or load center. |
| H) distance_nearest_waterSource_km | Surface water (lake or river) source. |
| GroupVal | Identifier that is used to assign a project opportunity area to a zone. |
| Capacity value attributes: | |
| A) distance_nearest_3TierWindLocation_km | From the centroid of the zone, distance in km to the nearest location where simulated wind speed time series data were acquired from 3Tier. Hourly time series were used to estimate capacity value ratios. |
| B) capacityValueRatio_10percentPeakHours | The ratio of the capacity factor for the top 10% of hours with the largest electricity demand within a year (876 hrs) to the capacity factor of all hours within the same year (8760 hrs). |
| C) capacityValueRatio_chosen3peakHours | The ratio of the capacity factor for the daily top 3 hours with the largest electricity demand across an entire year (1095 hrs) to the capacity factor of all hours within the same year (8760 hrs). |
| D) capacityValueRatio_chosen3peakHours_multiyear | The ratio of the capacity factor for the daily top 3 hours with the largest electricity demand across an entire year, extrapolated to 10 years (10,950 hrs), to the capacity factor of all hours within the same 10 years (87,600 hrs). 3Tier provided 10 years of hourly time series data for each point location. |
| E) adjustedCF_top10percent | The capacity factor of the top 10% of hours with the largest electricity demand within a year (876 hrs). This value was estimated by multiplying the capacityValueRatio_10percentPeakHours with the mean_capacityFactor_chosenTurbine. |
| F) adjustedCF_top3hrs | The capacity factor of the daily top 3 hours with the largest electricity demand across an entire year (1095 hrs). This value was estimated by multiplying the capacityValueRatio_chosen3peakHours with the mean_capacityFactor_chosenTurbine. |