

# Unleashing the solar potential in ECOWAS:

## Seeking areas of opportunity for grid-connected and decentralised PV applications

An opportunity-based approach



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Feedback: [potentials@irena.org](mailto:potentials@irena.org).

<sup>a</sup>ECOWAS Center for Renewable Energy and Energy Efficiency; <sup>b</sup>Centro Nacional de Energías Renovables; <sup>c</sup>National Renewable Energy Laboratory; <sup>d</sup>Deutschen Zentrums für Luft- und Raumfahrt; <sup>e</sup>Open Gospatial Consortium; <sup>f</sup>International Solar Energy Society; <sup>g</sup>Joint Research Center – European Commission.

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A fragment of the Earth with high relief, detailed surface, translucent ocean and atmosphere, illuminated by sunlight©Anton Balazh/Shutterstock

## CONTEXT

The Global Renewable Energy Atlas is the outcome of an international effort involving 39 countries. It was initiated under the Clean Energy Ministerial and is coordinated by the International Renewable Energy Agency (IRENA) based in Abu Dhabi. It is a contribution to the Sustainable Energy for All initiative (SE4All), initiated by the United Nations.

The Global Renewable Energy Atlas initiative builds on a strong international partnership involving national institutes, energy agencies, private companies and international organisations, who share data and expertise with the aim of promoting renewable energy. It started with solar and wind, and will progressively expand to include other resources: bioenergy, geothermal and hydropower in 2014, and marine energies in 2015.

The vision of the Global Renewable Energy Atlas initiative is to bridge the gap between countries that have access to the necessary data and expertise for assessing renewable energy potential, and those countries lacking such elements. The Global Renewable Energy Atlas provides access to the datasets and methods to enable a first screening of the areas of opportunity where further assessments can be targeted.

For solar and wind, a first version of the platform was released during IRENA's Assembly in January 2013. It includes an online Geographic Information System (GIS) to manipulate relevant solar and wind data and provide an estimate of the technical wind and solar potentials. Over time, the platform should include dedicated tools to perform calculations of energy production over areas of interest. The GIS can access a large library of datasets (through the data catalogue), which contains references to over 400 data layers – solar and wind maps, infrastructures, population density, and other information relevant to the assessment of technical potentials. The Atlas is a powerful instrument for countries willing to prospect their solar and wind resources.

The ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) is a partner of the Global Renewable Energy Atlas. Its mandate includes promoting *the provision of efficient, reliable and affordable energy services in West Africa through the common exploitation of its renewable energy resources and efficient energy use*. In the fulfilment

of its mandate, ECREEE has collected a large amount of geospatial data, and is making this information available through the ECOWAS Observatory for Renewable Energy and Energy Efficiency (ECOWREX). ECOWREX also provides other reliable information required to promote renewable energy and energy efficiency in the region. Through the partnership established between ECREEE and IRENA, the data collected by ECREEE are disseminated widely through the data catalogue of the Global Renewable Energy Atlas.

The data catalogue of the Global Atlas builds on the same data infrastructure as the Global Earth Observation System of Systems (GEOSS). GEOSS is a large international initiative involving 88 countries and the European Commission. It provides decision-support tools in several sectors (Societal Benefit Areas) and includes the energy sector. The Global Renewable Energy Atlas fulfils the objectives and standards of GEOSS, and has been identified as a possible candidate for the sixth round of demonstrations of GEOSS-related services (Sixth Architecture Implementation Pilot - AIP-6).

This demonstration illustrates the added value of the Global Atlas for initiating informed discussions on future solar and wind developments in a region. The demonstration covers the ECOWAS region, with datasets supplied by ECREEE and involves a grid connected and an off-grid scenario for solar photovoltaic, as a contribution to SE4All. The outcome of this demonstration will also be presented in the framework of the GEOSS AIP-6 and the results can be accessed as GIS layers at: <http://irena.masdar.ac.ae/?map=507>

## MAIN OBJECTIVE OF THIS DEMONSTRATION

Countries willing to deploy renewable energy technologies face a number of issues. For example, investments must be planned in advance, which requires an understanding of the share of energy mix that can be supplied by renewable energy sources, the energy costs, and identifying the technologies that can be most adapted to the local conditions. It is necessary to assess the volume of investments that are required, in terms of support schemes, human capacities and related infrastructures. Investors also prefer to have a long-term commitment on the market volumes, as well as a long-term perspective to create a supply chain.



Solar energy panels and wind turbine©Vaclav Volrab/Shutterstock

The information on the resource is required, but alone is not sufficient for the decision-making process, which requires an evaluation of the technical and economic potential. The potential accounts for the geospatial, engineering, economic, and social constraints to renewable energy development.

The precision of the potentials' estimate directly translates into a risk on the decision-making process and the decision to move on a national strategy.

Estimating the potentials requires large upfront investments in measurement campaigns, extensive consultations and a high level of technical knowledge to assess the resource and provide "bankable" information that supports the investments.

Over the ECOWAS region, very few countries have been through the exercise of mapping their solar and wind potential. However, thanks to the efforts of ECREEE, a large amount of data is readily available for the region, which can be complemented with data from the Global Renewable Energy Atlas. The data available does not allow for detailed site assessment, and is not therefore 'bankable'. However, this data can be used to perform a first screening for areas of opportunity for future solar projects. Such information is of great value to countries, providing a first overview of possible areas of interest, and raising awareness for further investigations into the available national resources.

The proposed project builds on the partnership between IRENA and ECREEE and provides a preliminary screening of sites of interest for solar developments in the ECOWAS region. Under this partnership, the consortium is able to demonstrate the value of GIS-based techniques using an opportunity-based approach to generate maps of suitability zones for solar photovoltaic developments.

The project outcome is a set of maps highlighting areas of opportunity for both grid connected and off-grid solar photovoltaic. A number of maps are produced, showing different results depending on the technical constraints (resource, distance to the grid, topography and land use). The purpose of these maps is not to provide a definitive assessment of the suitability of particular areas, as the final outcomes show different scenarios that are very sensitive to the input datasets and selected parameters.

Instead these maps are a first step towards initiating a dialogue with the ECOWAS countries, energy authorities and rural electrification agencies, and moving towards a coordinated promotion of solar energy in the region.

Therefore the purpose of this demonstration is to show the capabilities of spatial planning techniques and the small number of simplified assumptions that are taken. The next steps in such a process would involve organising a discussion with energy authorities, planners and rural electrification agencies, in order to review and amend the selected parameters, reconcile the outcomes with the reality, and converge towards a consensus on mapping the areas of opportunity.

The outcomes of this demonstration will also be disseminated through the IRENA Global Renewable Energy Atlas, and shared with ECREEE. The project outcomes will represent a contribution of the IRENA Global Renewable Energy Atlas to the GEOSS AIP-6, as a presentation of geospatial data use in the promotion of renewable energy.

## SELECTED APPROACH: A FLEXIBLE OPPORTUNITY-BASED STRATEGY

There is no identified standard or best practice to perform geospatial analysis for renewable energy developments, and each study is unique. Studies provide assessments that depend heavily on the selected approach and input data.

When dealing with geospatial analysis for assessing solar or wind potentials, most studies adopt an *exclusion-based* approach. A typical starting point in this approach, is to restrict the land available, and to define a realistic estimate of the maximum surface theoretically available for hypothetical developments. The land surface is restricted by superposing various constraints. The most common constraints are the distance to the grid, slope, protected areas, elevation, lakes and rivers. In some cases the distance to settlements, roads, load centres, protected areas, specific geological conditions, urban areas or military areas are also removed from the analysis.

The next step is to multiply the available surface by a density of installations (in Megawatts per square

kilometre - MW/km<sup>2</sup>). An assumed power curve or load factor of a typical installation is then combined with the resource available at each point in order to calculate a value in kilowatt-hours (kWh). This value is called a technical potential. Often, values of the technical potential are summed up in order to assume a value at the level of a region or a country.

Exclusion-based approaches have limitations, since they do not discriminate locations where developments are legally prohibited, or technically impossible, from those where developments are unlikely to happen. Often, maps based on exclusion criteria can be challenged on the basis of the uncertainty of the input data, or where one or more aspects of the analysis could not be considered. Sensitivity analyses for such an approach also show large variations in the final value of technical potential.

The increasingly large diffusion of Geographic Information Systems (GIS), and the tremendous increase in computer performances currently enable the adoption of more nuanced approaches, consequently *opportunity-based* approaches are being increasingly developed. These approaches rank the quality of sites by assigning a score to each dimensioning parameter. The combination of the

scores provides the final ranking of the site. The maps created with such approaches display suitability scores for each site. The maps do not show go and no-go areas, but areas where the developments are likely to be possible, and others where they are unlikely. The advantage is that it provides a nuanced vision of the situation for the selected values.

The messages carried by such maps are not anymore: *'this is the value of the energy you can produce at that point, under the assumptions which were presented', but instead 'in this area, it appears that most of the considered parameters combined together seem to indicate an area of significant interest for future developments, and would justify further exploration'.*

With opportunity-based approaches, a number of maps are computed. Each map illustrates a specific set of assumptions- or a scenario. The maps are not used to calculate a value of technical potential. Instead, the maps are used to initiate a discussion with the stakeholders and authorities of the region in order to understand which set of assumption is closer to the local situation. During these discussions specific areas are identified as promising, where more detailed investigations can be conducted. These options can include considering more detailed assumptions, and



Figure 1: Example Outcome of an Opportunity-based Approach for off-grid applications further than 20 km from the Electricity Grid. The map displays scores between 0 - 100% showing the result of a combination of hypothesis. See the figure in full at: <http://irena.masdar.ac.ae/?map=507>



running more detailed models to converge towards realistic estimates of the technical potentials.

The strategy taken towards providing a valuation of technical potentials could be seen as a ‘zooming’ approach (or multi-resolution approach). The closer the zoom and the greater the number of parameters that can be taken into account, the more realistic the estimates of technical potential. At such high level of details, cost models can be progressively introduced into the analysis.

## CONTENT OF THE DEMONSTRATION

In the best-case scenario, the decision makers and planners themselves would have the tools at hand to define their entry parameters, and perform the analysis. The development of such interactive tools is part of the development plans of the Global Renewable Energy Atlas, but these are not yet available.

Therefore, for this demonstration, a limited set of dimensioning parameters were selected for

the following two reasons: the demonstration was carried over a short period of time and therefore involved datasets already available through the IRENA Global Renewable Energy Atlas or ECOWREX; and for such a large area it was advisable to initiate discussions on the basis of few relevant parameters, instead of attempting to capture local effects. In a second stage, a more detailed analysis would need to be conducted on those areas of interest.

For each parameter, a range of values were selected. When several values are selected for a single parameter (several scenarios are available), one map is calculated for each value. The proposed parameters, values and scenarios are on the basis of the best knowledge available from the participating entities. The participants to this demonstration have a large experience in developing such GIS-based analysis. The parameters and input datasets are presented and discussed hereafter.



High voltage transmission towers in the desert©Philip Lange/Shutterstock

## SELECTED PARAMETERS

Parameter	Grid connected	Off-grid	Datasets and limitations
Yearly global irradiation (kWh/m <sup>2</sup> )	Yes.	Yes.	<p>Solar dataset supplied by ECOWREX presenting the Global horizontal solar irradiance at 3 km resolution. Map developed from the dataset of the private company 3TIER, with an annual temporal resolution, for the entire ECOWAS region. The data was funded by US Agency for International Development (USAID) through its implementing partner Nexant in collaboration with ECREEE.</p> <p><u>LIMITATIONS:</u> the map does not capture the high resolution (below 1 km) effects. The map is the outcome of a simulation, and requires ground validation. The average annual values do not provide indications of the inter-annual variability. However, the average value is built on a multi-decadal data archive and inherently captures the past inter-annual variability. It however cannot anticipate the values which may appear in the future.</p>
Grid distance (km)	Yes. Up to a maximum distance.	Yes. From a minimum distance.	<p>Transmission lines from ECOWREX. Only the existing transmission lines were considered in this demonstration.</p> <p><u>LIMITATIONS:</u> Connecting to the grid is not solely dependent on the distance between the grid and new connection point, as the local situation on the ground can be far more complex.</p> <p>Distance to the (current and future) connection points would be closer to reality. The distance is an imperfect indicator of the technical feasibility of a connection. In reality, the feasibility to connect to the grid depends on the share of the grid connection costs on the overall project cost. Large projects may allow for dedicated lines to be deployed. The planned extensions of the grid were not considered in this demonstration, which only provides a snapshot of the current situation. The possibility to connect to the line does not guarantee that any capacity will be available to transport additional energy. For off-grid applications, the presence of a transmission line in the vicinity of a population centre does not guarantee that the centre will be connected to that grid.</p>
Population density (persons/km <sup>2</sup> )	Yes. Favour less densely populated areas.	Yes. Favour populated areas (no minimum level).	<p>Dataset available from the Global Atlas. The LandScan 2011 Global Population Database was developed by Oak Ridge National Laboratory (ORNL) for the United States Department of Defense (DoD).</p> <p><u>LIMITATIONS:</u> recent conflicts in the region may have created movements of populations, not captured by this dataset.</p>
Slope (%)	Yes. A higher value is considered.	No.	<p>Dataset available from the Global Atlas. Terrain maps show the elevation above sea level on the land and depth of the ocean and sea bottom. The slope inclination and azimuth are calculated on-the-fly. The map is developed from Shuttle Radar Topography Mission (SRTM) and SRTM Water Body Dataset (SWBD).</p> <p>The detailed SRTM3 data with grid resolution of 3 arcsec (~90 m at the equator) are available between the latitudes 60°N and 50°S, which represents most of the emerged land on Earth. For ECOWAS regions north from 60°N and south from 50°S, only the elevation data from GTOPO30 (SRTM30) are available. The original grid resolution of the GTOPO30 dataset is 30 arcsec (~1000 m at the equator).</p> <p><u>LIMITATIONS:</u> the actual resolution of the dataset used for the analysis is 1 km. Terrain features smaller than 1 km are averaged.</p>

Table 1: selected parameters for the demonstration, input datasets and limitations.

Parameter	Grid connected	Off-grid	Datasets and limitations
Land cover	Yes. Forests and water bodies.	Yes. Forests and water bodies.	<p>Dataset available from ECOWREX and the Global Atlas. Regional component of the Global Land Cover 2000 (GLC2000) exercise, conceived and coordinated by the European Commission's Joint Research Centre. The GLC2000 maps are based on daily observations made from 1st November 1999 to 31st December 2000 by the VEGETATION sensor on the SPOT 4 satellite.</p> <p><u>LIMITATIONS:</u> since 2000, the land occupation may have changed significantly. In particular the presence of forests and their density can alter significantly over 13 years. For this analysis, the class 'forest' aggregates several sub-classes with several types of forests, which is a coarse approximation of the reality. Forests of low height or low density may allow for developments.</p>
Protected area	Yes.	Yes.	<p>Dataset available from the Global Atlas. The World Database on Protected Areas (WDPA) is the most comprehensive spatial dataset on the world's marine and terrestrial protected areas, produced through a joint initiative of the International Union for the Conservation of Nature (IUCN) and the United Nations Environment Programme (UNEP). The WDPA contains the UN List of protected areas (official national data), as well as authoritative information sourced by non-governmental organisations, academic institutions, international convention secretariats and many others. The WDPA is used to report on global indicators and trends, ecological gap analysis, environmental impact analysis and is increasingly used for private sector decision-making. The WDPA is hosted and managed at the UNEP World Conservation Monitoring Centre.</p> <p><u>LIMITATIONS:</u> some of the larger protected areas appearing on the map may contain several smaller areas. The protection level varies with the protection convention, and some classification levels may allow for developments. It was unfortunately not possible to take into account the individual status of each protected area, nor the exceptions. Protected areas were considered for off-grid applications in order to indicate the special status of such areas. However, when populations are living in such protected zone, off-grid applications may be possible.</p>

Table 1: selected parameters for the demonstration, input datasets and limitations.



Power plant using renewable solar energy©Gencho Petkov/Shutterstock



Solar power plant - Sunset over solar power station©Pecold/Shutterstock

## SCORING SYSTEM

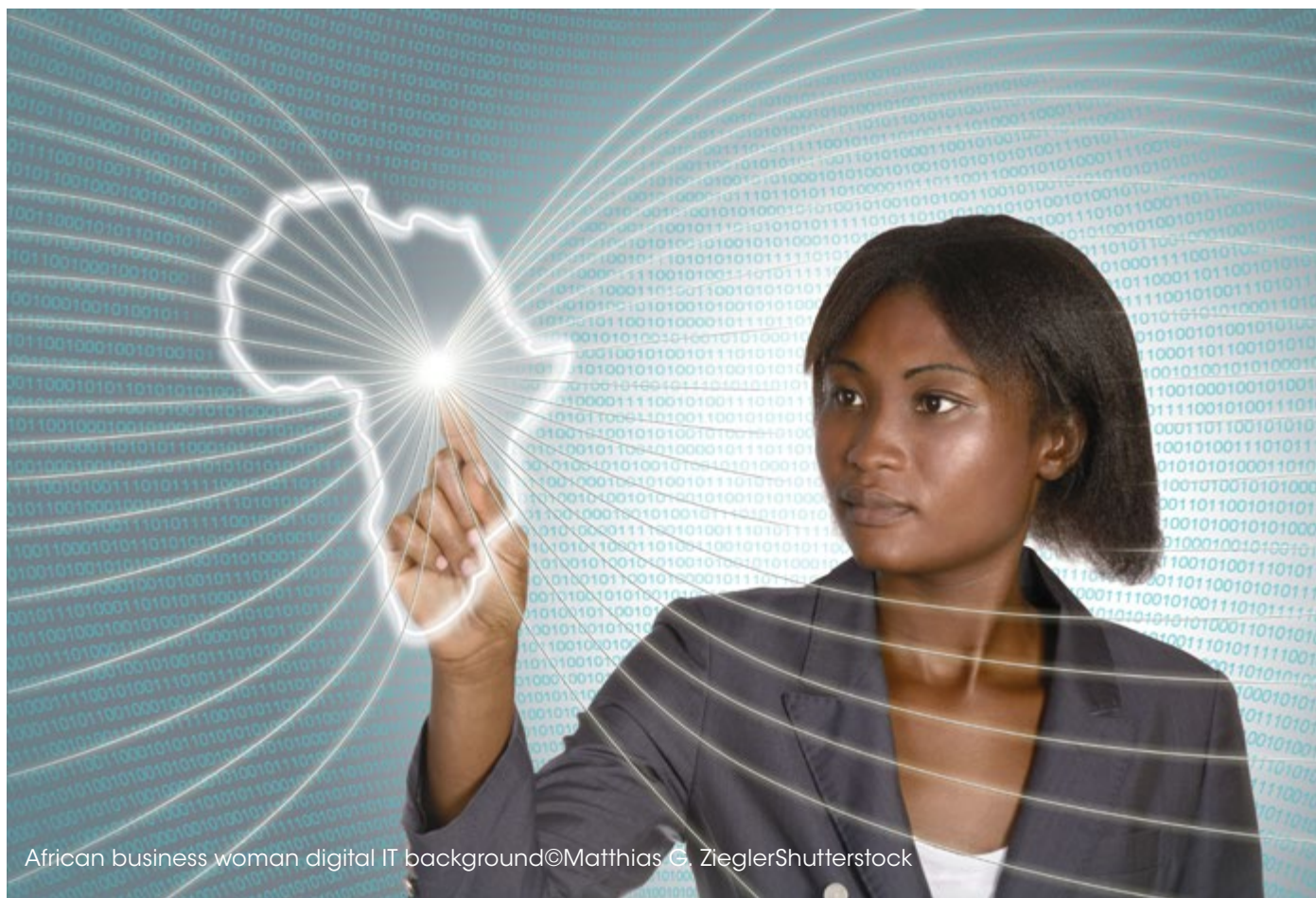
For each parameter listed in Table 1, a range of values needed to be specified, in order to allocate a progressively cumulative score. The scores are allocated as follows: the minimum score for a parameter starts at 0, with the minimum acceptable value. It increases linearly to 1 (100%), when a suitable value is reached and maintained at 100% beyond this value. In our demonstration, the final score for a location is the average of the scores for each parameter. A high score means that the majority of the parameters fulfil optimal conditions, while a low score indicates that most elements studied by the analysis do not show optimal conditions.

The method is sensitive to several assumptions:

- » The minimum and the suitable values are based on expert knowledge. For the purpose of this demonstration the number of cases was limited to a minimum number. In an ideal situation, energy authorities and planners would be in the position to modify such parameters and carry sensitivity analyses on the final results. Such features are part of the development plans for the Global Renewable

Energy Atlas, but not yet available.

- » A linear increment was selected for this demonstration, but other mathematical functions can be proposed to model the incremental suitability of a parameter. A commonly used mathematical function is the sigmoid (S-shape function). Changing the function would affect the results.
- » The final score is the average of all the individual scores. Some methods (not used in this demonstration) may propose to weight some of the scores in order to increase the influence of a particularly important parameter. Weighting the result may significantly change the final outcomes.
- » Some parameters did not allow for a scoring system to be designed, i.e. the protected areas and land cover. In such cases the parameter is set to 0 if in a forested, water or protected area and 100% for all other areas outside. Those parameters act as exclusions and were considered only in the last stage of the calculations. The intermediate calculation layers were made available without such limitations, in order to provide a complete overview for the other dimensioning parameters, some of which were considered to be inside the exclusion zones.



African business woman digital IT background©Matthias G. ZieglerShutterstock

## DEMONSTRATION FOR THE ECOWAS REGION-SOLAR PHOTOVOLTAIC-GRID CONNECTED

For grid connected photovoltaic, four scenarios are proposed in order to visualise the influence of the distance to the grid on the final parameters. The analysis presents a higher score to areas with

lower population densities, where more space can be available for large renewable energy installations. Forest and water bodies were not deemed suitable for installations. Protected areas are considered as part of the last step of the analysis, in order to highlight areas where specific regulations apply.

Parameter	Min score (0) at	Max score (1) at
Yearly global irradiation (kWh/m <sup>2</sup> )	1500	2100 and more
Grid distance – centralised (km)	20, 75, 100 and 150	0
Population density – centralised (persons/km <sup>2</sup> )	500	0
Slope (%)	45	0
Land cover (exclusion)	Forests + water bodies and water bodies only	Other categories
Protected areas (exclusion)	0 for protected areas	1 outside

## FINAL SCORE CALCULATION EXAMPLE

Parameter	Value	Score
Yearly global irradiation (kWh/m <sup>2</sup> )	2000	$(2000-1500)/(2100-1500) = 0.75$
Grid distance [range 0 – 150] (km)	50	$1 - (50 / 150) = 0.66$
Population density (persons/km <sup>2</sup> )	100	$1 - (100/500) = 0.8$
Slope (%)	5	$1 - (5/45) = 0.89$
Land cover	Grassland	1
Protected area	No	1
Final score		$((0.75+0.66+0.8+0.89)/4) \times 1 \times 1 = 77\%$

## RESULTS

The final calculations, base data and intermediate results are presented by the Global Renewable Energy Atlas, and accessible at: <http://irena.masdar.ac.ae/?map=507>. The maps are illustrated for the solar photovoltaic grid connected scenarios.

Grid Connected Solar Photovoltaic Scenarios for the ECOWAS Region at Four Grid Distances. The higher scores (green colours) are closer to the grids. However, even remote areas (light green) have a score above 70% (red). See the results in full size at: <http://irena.masdar.ac.ae/?map=507>



Figure 2: Final Scores for a Grid Distance up to 20 km.



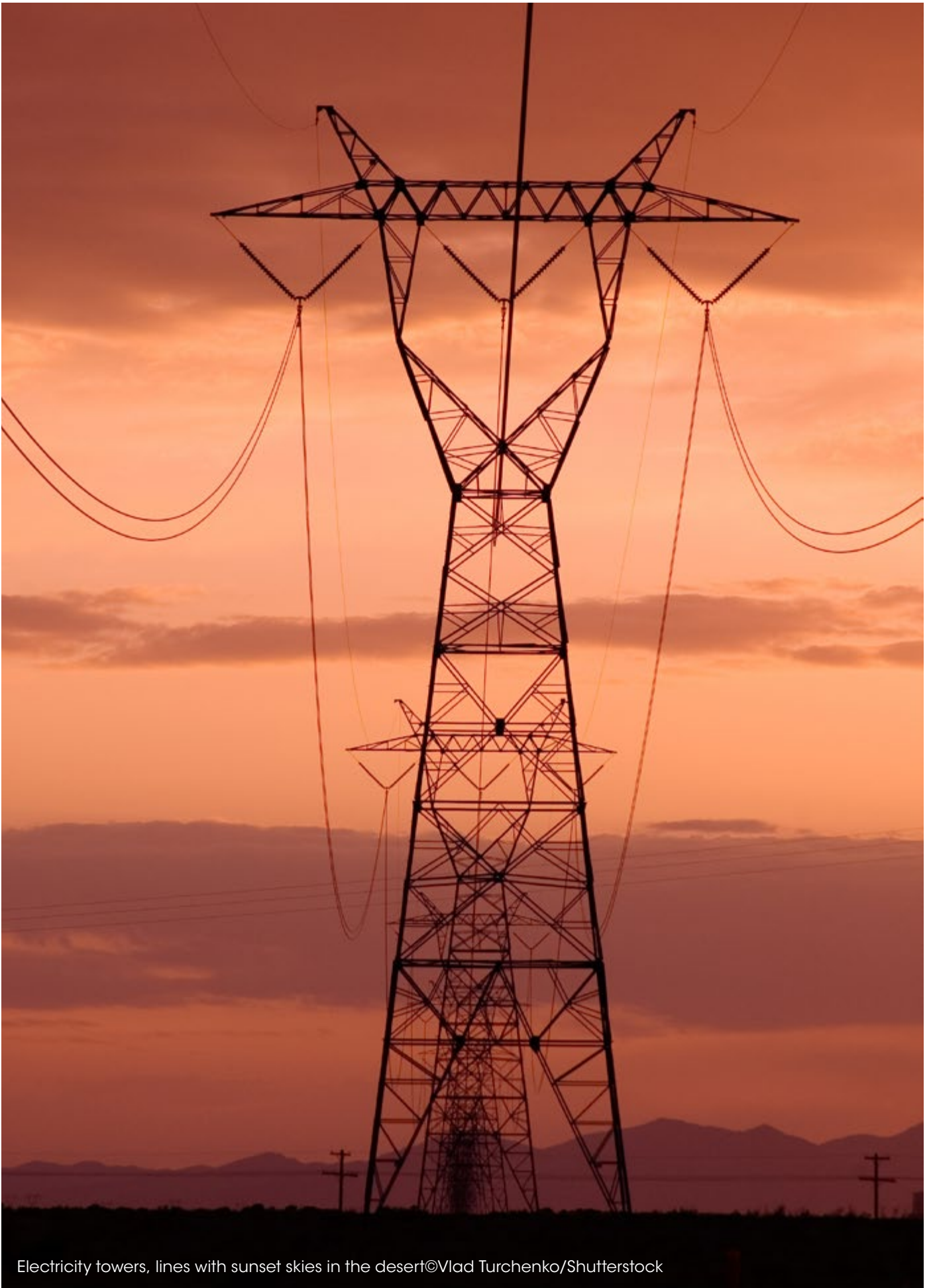
Figure 3: Final Scores for a Grid Distance up to 75 km.



Figure 4: Final Scores for a Grid Distance up to 100 km.



Figure 5: Final Scores for a Grid Distance up to 150 km.



Electricity towers, lines with sunset skies in the desert©Vlad Turchenko/Shutterstock



## PROPOSAL FOR THE ECOWAS REGION-SOLAR PHOTOVOLTAIC OFF GRID

For off-grid applications, five scenarios are proposed – distinguished by the relative distances of sites from the grid, to which they might eventually be connected.

However, as discussed in the parameter section, the proximity of a transmission line to a population centre does not guarantee any grid connection for residents or businesses there, especially given the disparity, for example, between a 220V household

connection and a high-voltage, 400,000V power line. Off-grid applications can also be eligible if they are close to transmission lines.

Given the objective of SE4All is to provide universal access to energy, no minimum threshold was considered for the population density for off-grid applications. Protected areas although not directly relevant, since communities may be located in such areas, still appear on the final maps to highlight that in such areas specific or different legislation may apply.

Parameter	Min score (0) at	Max score (1) at
Yearly global irradiation (kWh/m <sup>2</sup> )	1500	2100 and more
Grid distance – decentralised (km)	0	20, 50, 75, 100 and 150 km and maximum above those distances
Population density – decentralised (persons/km <sup>2</sup> )	0	Maximum above 0
Land cover (exclusion)	Forests + water bodies and water bodies only	Other categories
Protected areas (exclusion)	0 for protected areas	1 outside



## RESULTS

The final calculations, base data and intermediate results are presented by the Global Atlas, and accessible at: <http://irena.masdar.ac.ae/?map=507>. The maps illustrate the solar photovoltaic off-grid scenarios.

Off-grid scenarios for a grid distance from 20 km, 50 km, 75 km, 100 km and 150 km. The higher scores (red colours) represent areas in general far from the grids. However, even areas close to the grid (light green) have a score above 80%. See the information in full size at <http://irena.masdar.ac.ae/?map=507>



Figure 6: Final Scores for a Grid Distance from 20 km.



Figure 7: Final Scores for a Grid Distance from 50 km.



Figure 8: Final Scores for a Grid Distance from 75 km.



Figure 9: Final Scores for a Grid Distance from 100 km.



Figure 10: Final Scores for a Grid Distance from 150 km.



Green wheat field against the sun with photovoltaic panel©ldambies/Shutterstock



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[Potentials@irena.org](mailto:Potentials@irena.org)



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IRENA Headquarters  
CI Tower, Khalidiyah  
P.O. Box 236, Abu Dhabi  
United Arab Emirates

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