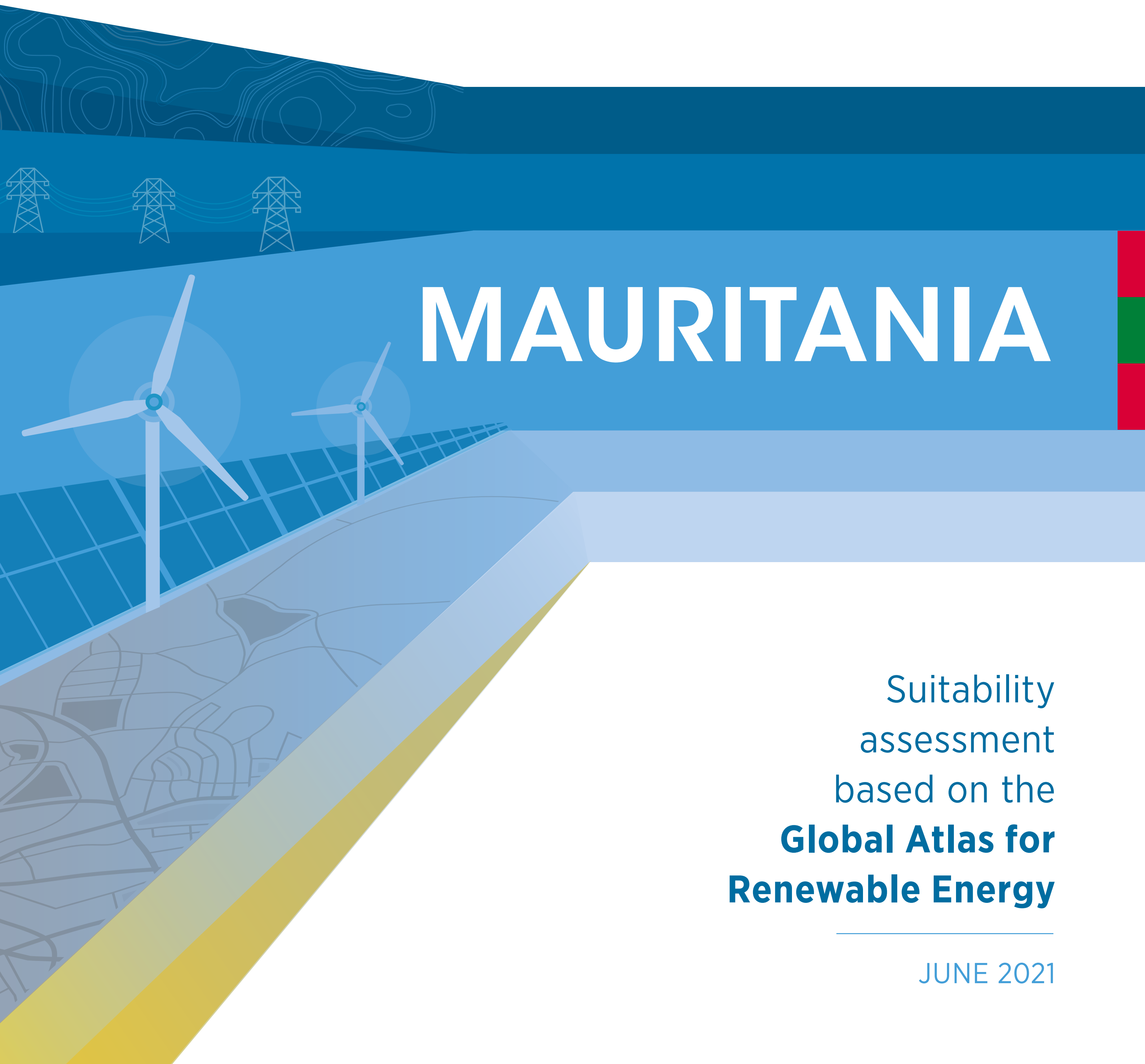
IRENA
International Renewable Energy Agency

UTILITY-SCALE SOLAR AND WIND AREAS



MAURITANIA

Suitability assessment based on the **Global Atlas for Renewable Energy**

JUNE 2021

IRENA
International Renewable Energy Agency

About IRENA

The International Renewable Energy Agency (IRENA) serves as the principal platform for international co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. An intergovernmental organisation established in 2011, IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. **www.irena.org**

ISBN 978-92-9260-248-2

Citation: IRENA (2021), Utility-scale solar and wind areas: Mauritania, International Renewable Energy Agency, Abu Dhabi.

Acknowledgements

IRENA would like to acknowledge the data providers for the Global Atlas for Renewable Energy, in particular the Energy Sector Management Assistance Program (ESMAP) of the World Bank, East View Geospatial, the OpenStreetMap Foundation, Solargis, the ESA GlobCover 2009 Project, the NASA Socioeconomic Data and Applications Center, and the United Nations Environment Programme. The methodology used in this study originated from prior IRENA studies in 2013 and 2016 and has been updated in 2020.

IRENA would like to thank the following reviewers: Xabier Nicuesa Chacon and Ivan Moya (National Renewable Energy Centre [CENER], Spain), Daniel Getman (National Renewable Energy Laboratory [NREL], USA), Hosni Ghedira (Khalifa University, UAE), Carsten Hoyer Klick, Christoph Schillings and Thomas Wanderer (German Aerospace Center [DLR]), Bart de Lathouwer (Open Geospatial Consortium), Lionel Menard and Lucien Wald (MINES ParisTech), Nicolas Fichaux (consultant), Dave Renne (International Solar Energy Society), Sandor Szabo (Joint Research Centre – European Commission), and David Villar and Jafaru Abdulrahman (ECOWAS Centre for Renewable Energy and Energy Efficiency [ECREEE]).

Background and country research was conducted by Zoheir Hamedi and Reem Korban.

The report was developed by Imen Gherboudj, Mohammed Sanusi Nababa, Abdulmalik Oricha Ali, and Jacinto Estima.

Report available for download: **www.irena.org/publications**

Feedback or new requests can be directed to: **GARE@irena.org**

CONTENTS

FIGURES

ABBREVIATIONS

AICD	Africa Infrastructure Country Diagnostic
GHI	global horizontal irradiation
GIS	geographic information system
IRENA	International Renewable Energy Agency
OSM	OpenStreetMap
PV	photovoltaic
RRA	Renewable Readiness Assessment
WDPA	World Database for Protected Areas

MEASUREMENTS

GW	gigawatt
km	kilometre
km^2	square kilometre
kWh	kilowatt hour
m^2	square metre
MW	megawatt

EXECUTIVE SUMMARY

This study seeks to map areas in Mauritania that are suitable for deploying utility-scale solar photovoltaic (PV) and wind power projects. It aims to i) provide insights into the country's potential to adopt solar PV and wind power; ii) inform national infrastructure planning across the electricity supply value chain, spanning generation, transmission and distribution; and iii) provide critical input for high-level policy models that aim to ensure universal electricity supply and support the long-term abatement of climate change.

The study combines high-quality resource data with ancillary factors, such as local population density, protected areas, topography, land use, electrical transmission lines and road network proximity, using a suitability assessment approach. This approach – developed by the International Renewable Energy Agency (IRENA) in 2013 and now updated based on accumulated global experience and heightened data collection capacity – has enabled the identification of areas in the country worthy of further investigation in the context of intensified renewable energy development.

The approach involves a spatial analysis procedure, whereby every square kilometre parcel of land is assessed on a scale of 0% to 100% to establish its suitability to host a solar PV or wind power project. To this end, a scoring system is assigned to a set of criteria (renewable resource data and ancillary information), with 0% representing the least favourable and 100% representing the most favourable. These criteria are aggregated using a weighted linear combination to establish the conditions for the feasibility of a solar PV or wind power plant, based on research and industry practice (IRENA, 2016c).

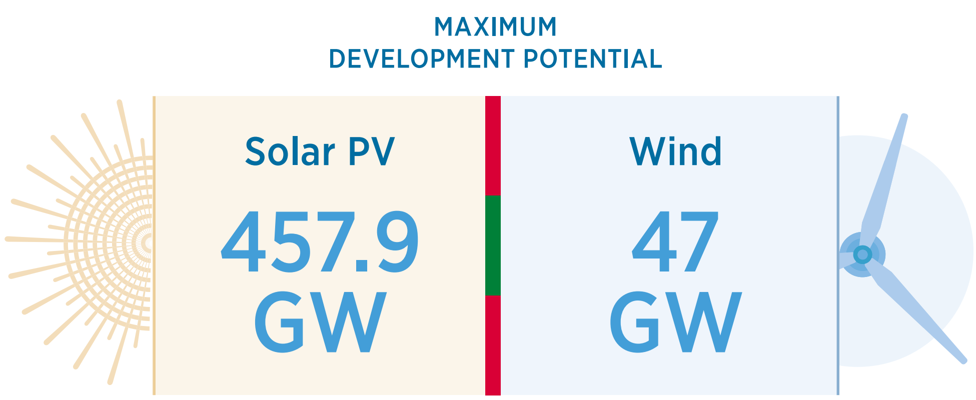
The criteria used to identify suitable areas for solar PV and wind project development are not of equal importance; thus, weights were assigned to the criteria based on an analytic hierarchical approach, where renewable energy planning experts from the country provided their independent opinion on the importance of each criterion considered for the assessment.

The findings of this study indicate that a significant portion of Mauritania's land area is highly suitable for solar PV and wind development. It suggests a maximum development potential of approximately 457.9 and 47 gigawatts (GW) for solar PV and wind projects, respectively, taking into consideration an installation density of 50 megawatts (MW) per square kilometre for solar PV, 5 MW per square kilometre for wind and a land utilisation factor of 1%. The utilisation factor was determined based on the premise that not all the suitable area is eligible for power production due to competing land uses such as agriculture and heritage protection, among others; this is explored in section 4.

The results of the study reveal that several areas within four key cities in Mauritania – namely Nouakchott (population, 661 400), Nouadhibou (population, 72 337), Kiffa (population, 40 281) and Zouérate (population, 38 000) (World Population Review, 2020) – are satisfactory and can be further explored for solar PV and wind project development

These findings intend to prompt further action to identify specific sites for in-depth assessment using high resolution spatial and temporal data. However, the limitations of this study must be considered – specifically in terms of the sensitivity of the result to the assumptions made in setting thresholds for each criterion and the underlying quality of datasets. Non-technical issues, such as land ownership, may also influence the selection of areas to consider for further evaluation.

Potential sites within these areas will benefit from IRENA's Site Assessment service. This comprises a pre-feasibility assessment that determines the technical and financial viability of sites for solar photovoltaic and wind project development using downscaled time series resource data, site specific characteristics and technology specific parameters.



1

INTRODUCTION

This study is carried out at the request of the Government of Mauritania. The request follows the conclusion of a Renewable Energy Readiness Assessment (RRA) conducted in co-operation with the International Renewable Energy Agency (IRENA) in 2017.

The RRA constitutes a wide-ranging tool to assess national conditions for the deployment of renewable energy and, more specifically, the actions required to improve those conditions. Mauritania's RRA process, initiated at the government's request in September 2015, was carried out by IRENA in collaboration with the United Nations Development Programme Country Office and the Ministry of Petroleum, Energy and Mines of Mauritania.

The Mauritania RRA identifies challenges that may restrict the government's ability to deploy renewable energy technologies for accelerated economic growth in the country. The assessment provides a set of recommendations developed in consultation with public and private sector stakeholders to assist Mauritania in maximising the use of its vast renewable energy resources.

In line with the post-RRA process, Mauritania's Ministry of Petroleum, Energy and Mines requested IRENA's support in May 2019 to undertake a suitability assessment to map potential areas for utility-scale solar photovoltaic (PV) and wind projects.

This support, according to the Ministry, will assist in the introduction of additional solar PV and wind projects to the transmission grid, as well as contribute to meeting the national targets to achieve 50% of overall electricity generation from renewable sources by 2020 and 100% by 2050.

The suitability assessment can assist the Ministry in the selection of areas for new development and enable the creation of least-cost master plans from its analysis. This will allow the energy sector to conduct more detailed evaluations that take into account the investment and operating costs of prospective plants in the areas that are deemed most suitable.

The first section describes the methodology used to achieve the underlying assumptions for the suitability assessment criteria and the requirements to conduct the assessment. The seven criteria considered (resource quality; transmission line network; road network; topography; protected areas; population density; and land use) are explained in detail in terms of their effect on the planning of solar PV and wind power projects.

The second section of this report explains the data sources for each criterion. It includes specific details such as spatial and temporal resolutions, the extent of validation and the recommended use for each dataset given their strength.

The results of this study are included in the third section and comprise land suitability maps for solar PV and wind, as well as estimates of the country's maximum development potential. Results also include the development potential of four cities – Nouakchott, Nouadhibou, Kiffa and Zouheirat.

The report concludes with a summary of the key findings of the assessment and presents recommendations for use by local authorities.

16.6 MW solar PV facility for Mauritania's Rural Electrification Programme

Photograph: Masdar and SOMELEC (Societe Mauritanienne de l'electricite / Mauritanian Electricity Company)

2

THE SUITABILITY ASSESSMENT

The suitability assessment is predominantly a GIS-based multi criteria decision making analysis that enables the objective mapping of the renewable energy potential in a country or a region.

The resource data – such as solar irradiance or wind speed at a specific height – is the most important criterion in evaluating the potential of an area for solar and wind energy project development. Such evaluation requires a representative mapping of the renewable resources.

The solar irradiance component affecting photovoltaic (PV) output is global horizontal irradiance (GHI). This component is commonly calculated using either physical-based or statistical-based approaches that also require satellite or ground measurements. Datasets, such as the World Bank's Global Solar Atlas and Transvalor's SODA solar maps, cover more than 20 years of hourly historical data at 1 km grid cell resolution; they allow the calculation of a representative long-term average annual global horizontal irradiation (see section 3.1).

Wind speed data are commonly derived using weather research and forecasting models and data assimilation techniques to achieve the most realistic description of weather occurrences – Reanalysis data. Datasets, such as DTU's global wind atlas, and Vortex's wind maps, cover long-term hourly historical datasets at 1 km grid cell resolution and allow for the calculation of a representative annual average wind speed at different heights (see section 3.1).

Technical (slope and elevation), financial (proximity to transmission line and road networks), and socio-environmental (protected areas, land use and population growth) criteria are of great importance when selecting an area for solar or wind farm construction. Areas with steep slopes and high elevation pose challenges in terms of site access for construction, while the distances to transmission line and road networks determine the final cost of infrastructure and installation. The land feature is less significant, as it is concerned with national legislation. The related datasets for these criteria are generated using different techniques and technologies, such as satellite imagery and GIS data (see section 3.1).

Combining renewable resource (solar or wind) potential with technical, financial and socio-environmental criteria using weighted linear combination (section 2.4) allows the calculation of the suitability index for each grid cell; this identifies the feasibility (or opportunity) for each area to host a solar or wind project. Such assessment requires a feasibility scoring system for each criterion (see sections 2.1 and 2.2) and the assignment of weights for each criterion using the analytic hierarchy process (section 2.3). The final score scale of 0–100% corresponds to the worst and best areas, respectively. Obviously, suitable areas exhibit high resource potential and low technical, financial and socio-environmental impacts (IRENA, 2016c).

For instance, an ideal location for a 50–100 megawatt (MW) utility-scale wind farm will score highly when the site has a high annual average wind speed, is a reasonable distance away from the transmission line and road networks, features relatively flat terrain, is significantly competitive in terms of land use and is outside environmentally sensitive areas.

On the other hand, an area may have high resource potential but be situated far from transmission line or road networks. Such locations will feature within the analysis but with lower scores than the ideal site, which implies that the location presents an opportunity for development should additional investments in the grid or road network be considered.

The suitability assessment approach for solar PV and wind projects has been deployed across Latin America,[1] the Gulf Cooperation Council (GCC) states,[2] Southeast Asia, Southeast Europe and parts of Africa. This approach involves the following steps (Figure 1).

Figure 1. Suitability assessment method

2.1 Defining the thresholds for each criterion

Lower and upper thresholds are set for each of the above criteria to establish whether a grid cell is marginal or favourable for project development (Table 1).

For solar PV, locations with an annual GHI of less than 1 000 kWh/m^2 are deemed to be not suitable and are assigned a 0% score, while areas with an annual GHI of 2 200 kWh/m^2 or more are considered highly favourable and are assigned a score of 100%.

As for wind, areas with annual average wind speeds below 6 m/s may not be worth considering for project development and are assigned to 0% score (Höfer et al., 2016), while areas with wind speeds above 8 m/s are considered highly favourable and are assigned a 100% score. The assumption behind the lower threshold is supported by the results of IRENA's site assessment methodology conducted on 36 wind project sites characterised by different wind regimes, layouts and terrain types. These assessments demonstrated that sites with an annual average wind speed of 5.4 m/s and below have capacity factors of less than 23%.

Favourable areas for the development of solar PV and wind projects should have slope values that are below 11% (Noorollahi et al., 2016) and 30% (Tegou et al., 2010; Höfer et al., 2016), respectively.

The acceptable proximity to road and transmission line networks have been set by three experts from Mauritania; they must not exceed 77 km and 70 km, respectively. As for the minimum distances, they are generally set to: (i) 0.05 km from the road network and 0 km from the transmission line network (Mott MacDonald, 2017) for solar PV power plants; and (ii) 0.2 km from both road and transmission line networks when accounting for the average tip height (hub height plus rotor radius) of large wind turbine generators (ENA, 2012), (see Table 1).

[1] For further information, see: IRENA (2016b).

[2] For further information, see: IRENA (2016a).

2.2 Scoring system

Each grid cell of the considered criteria is scored in accordance with the thresholds and assumptions set in Table 1. Subsequently, areas not reaching the lower threshold (lower resources, proximity to load centres, road and transmission line networks) or exceeding the upper threshold (steeper slope, higher elevation, and farther from road and transmission line networks) are excluded from the analysis.

In contrast, areas that had values between the lower and upper thresholds were scored following a linear interpolation.

For example, a location with an annual GHI of 1900 kWh/m^2 will score 75%, considering the lower and upper threshold in Table 1.

$$1 - \frac{\text{Threshold}_{\text{upper}} - \text{value}}{\text{Threshold}_{\text{upper}} - \text{Threshold}_{\text{lower}}}$$

2.3 Assigning weights by pairwise comparison

The criteria considered in this analysis to identify suitable areas for solar PV and wind project development are not of equal importance. Areas with high resource potential that are farther away from road networks will most likely be given more consideration than those areas with low resource potential but within close proximity to roads.

The analytic hierarchy process (AHP) developed by Saaty (2008) is a widely used multi-criteria decision-making (MCDM) method. The main advantage of the AHP method is its ability to handle multiple criteria easily by performing pairwise comparisons between them.

However, this method relies on the judgement of experts to determine the level of importance of each criterion when selecting a site for solar PV or wind project planning and subsequent development.

Three experts from the Ministry of Petroleum, Energy and Mines in Mauritania have independently completed a pairwise comparison matrix for both solar PV and wind project areas. These matrices were solved to obtain the assigned weights by the experts for each criterion. These weights were averaged to obtain the final weights for each criterion, as shown in Table 1.

The responses received from the experts also show that most criteria for solar PV and wind were of equal importance

Photograph: Shutterstock

2.4 Aggregating all criteria

The suitability index for each grid cell is calculated by aggregating all considered criteria using the weighted linear combination approach and assigning a weight for each criterion (Table 1).

$$SI_i = \sum_{j=1}^{n} W_j S_{ij}$$

Where,

SI_i is the suitability index for cell I,

W_j is the assigned weight of the criterion j,

S_{ij} is the score of the cell I under criterion j, and

n is the number of criteria.

2.5 Excluding restricted areas

In contrast to the previous criteria, restricted areas – such as protected areas, forests, built up areas and wetlands – are excluded from the suitability index map using a binary constraint map produced using a simple classification procedure. This implies that 0 is applied to all areas within the restricted area, while 1 is applied to all areas located 15 metres beyond the restricted areas.

This binary constraint map is then multiplied by the calculated suitability index (step 4) to obtain the final suitability rating for each grid cell. That is, a grid cell in a restricted area scored at 90% in earlier calculations ultimately will score at 0% (i.e. 90% x 0), while another grid cells with a similar scoring in non-restricted areas will score at 90% (i.e. 90% x 1).

2.6 Quantifying development potential

To quantify the opportunities highlighted by the maps into maximum development potential, land-use footprints (hosting capacity per square kilometre of land area) and land utilisation factors (percentage of total suitable area that may be utilised for project development) for solar PV and wind projects must be defined.

Few studies have estimated the land-use footprint for utility-scale solar PV to 33 MW/km^2 (Ong et al., 2013). However, depending on site conditions and local laws, a larger system up to 50 MW – such as Masdar's Sheikh Zayed power plant in Nouakchott, Mauritania – can occupy a square kilometre of land area (Masdar, 2013).

As for wind, studies conducted by the National Renewable Energy Laboratory (NREL) considering data from 172 wind projects have suggested an overall average capacity density of 3.0 ± 1.7 MW/km^2 (Denholm et al., 2009).

However, a more recent study conducted by the same institution has shown that the land-use footprint has decreased to an average of 5 MW/km^2 (Eurek et al., 2017).

As for the land utilisation factor, it is generally set to 1% to cover areas close to the domiciled section of the country and avoid any over estimation of development potential.

Table 1. Suitability assessment approach for solar PV and wind projects: Scoring system, lower and upper thresholds, and assigned weights for each criterion

Criteria	Scoring system (%)		Units	Weights
Annual global horizontal irradiation	0 [0,100] 100	for GHI < 1000; for 1000 ≤ GHI ≤ 2 200; for GHI ≥ 2 200	kWh/m²	0.38
Annual wind speed at 100 m height	0 [20,100] 100	for WS < 6; for 6 ≤ WS ≤ 8; for WS ≥ 8	m/s	0.39
Distance to the grid for solar PV	0 [0,100]	for distance > 70 for 70 ≥ distance ≥ 0	km	0.33
Distance to the grid for onshore wind	0 [0,100]	for distance > 70 for 70 ≥ distance ≥ 0.2	km	0.33
Distance to the road for solar PV	0 [0,100]	for distance > 77 for 77 ≥ distance ≥ 0.05	km	0.13
Distance to the road for onshore wind	0 [0,100]	for distance > 77 for 77 ≥ distance ≥ 0.2	km	0.13
Slope score for solar PV	0 [0,100]	for slope > 11 for 11 ≥ slope ≥ 0	%	0.05
Slope score for onshore wind	0 [0,100]	for slope > 30 for 30 ≥ slope ≥ 0	%	0.05
Population density	0 [0,100]	for habitants > 500 for 500 ≥ habitants ≥ 0	-	0.11 for PV 0.10 for wind
Protected areas	0 1	within the areas 15 km outside the areas	-	-
Land cover	0 1	within the areas outside the areas	-	-

3

DATA SCOPE AND QUALITY

The data considered to perform the suitability assessment for solar PV and wind projects were sourced for the defined criteria (section 2). These criteria include solar and wind resource maps, topography features (elevation and slope), proximity to transmission line and road networks, and proximity to population centres and environmentally sensitive areas.

Criteria include resources, topography, local infrastructure and environmental protection

15 MW Sheikh Zayed Solar Power Plant in Nouakchott

Photograph: Masdar and SOMELEC (Societe Mauritanienne de l'electricite / Mauritanian Electricity Company)

3.1 Solar resource data

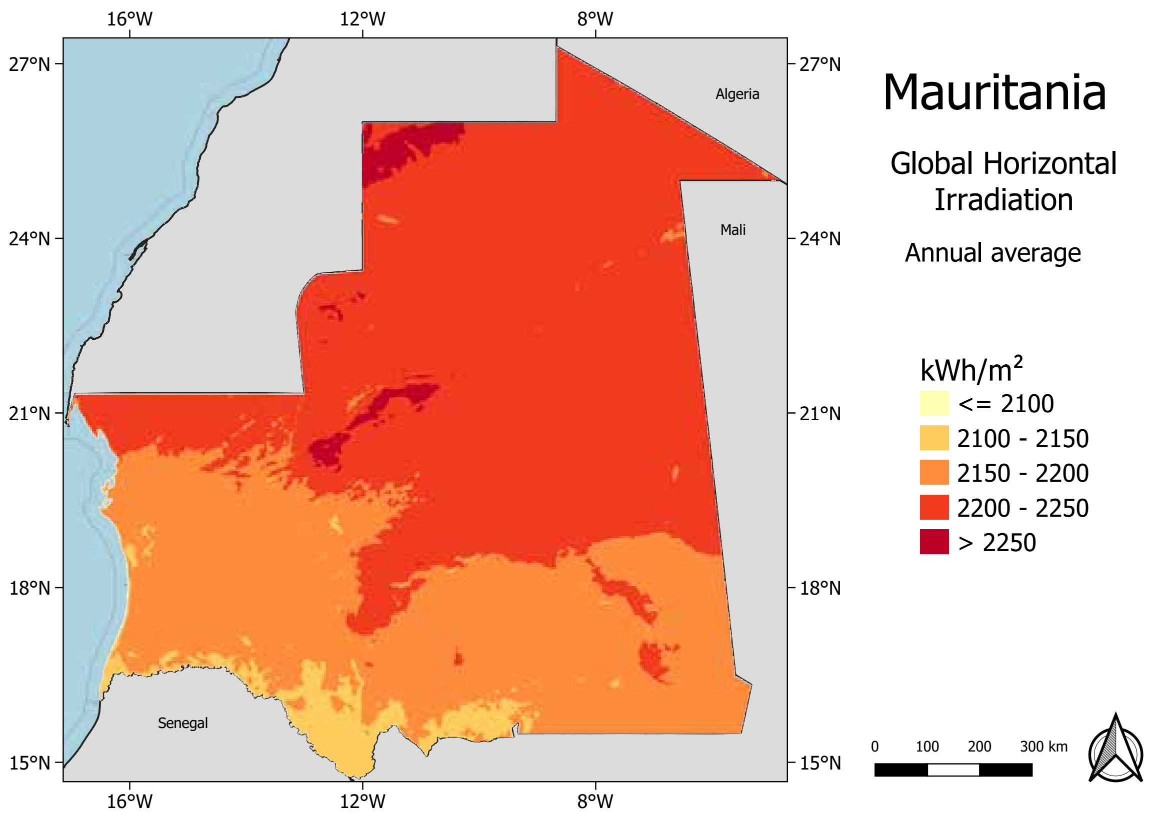
The average annual global horizontal irradiation (GHI) data employed in this study were sourced from the World Bank's Global Solar Atlas, developed by Solargis (ESMAP, 2019b), (Figure 2).

The data are calculated at a grid cell resolution of 1 km using long-term satellite-based solar irradiance covering a time period from 1994 to 2015.

Satellites used include those of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), Japan's Geostationary Meteorological series (known as "Himawari"), and the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce (ibid.).

The Global Solar Atlas has been validated using ground measurements from 228 sites worldwide. The corresponding accuracy of annual GHI values ranges between ±4% to ±8% (ESMAP, 2019a).

Figure 2. Average annual global horizontal solar Irradiation in Mauritania



Source: Global Solar Atlas (ESMAP, 2019b).
Note: also available on the IRENA Global Atlas for Renewable Energy web platform.
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

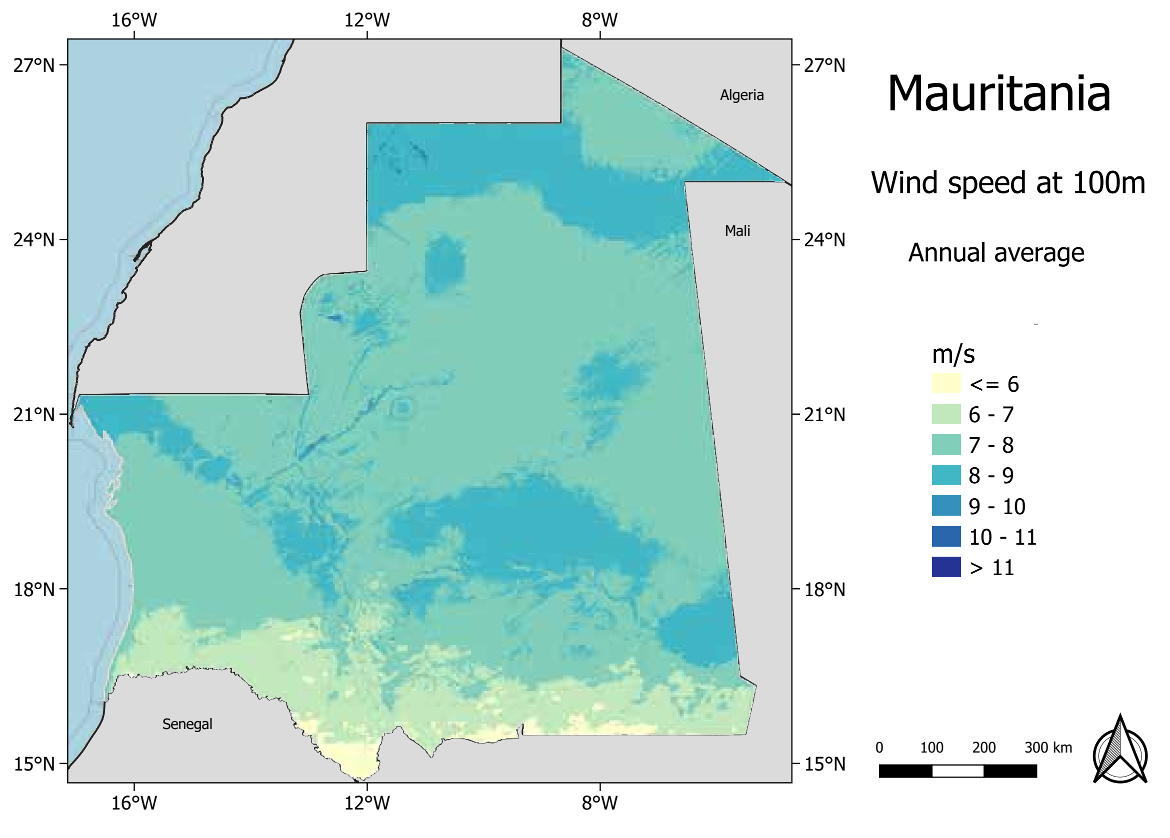
3.2 Wind resource data

The annual average wind resource data considered in this study were sourced from the Global Wind Atlas (GWA 1.0) developed by the Technical University of Denmark (DTU) in collaboration with IRENA and other international institutes (Figure 3).

The Global Wind Atlas dataset provides wind climatology layers at 1 km grid cell resolution and hub heights of 50, 100, and 200 metres above ground level.

The layers have been produced using the Wind Atlas Analysis and Application Program (WAsP) micro-scale model with reanalysis data, such as the Climate Forecasting System Reanalysis (CFSR), the Climate Four-Dimensional Data Assimilation (C-FDDA), the Modern-Era Retrospective Analysis for Research and Applications (MERRA), and the European Centre for Medium-Range Weather Forecasts Reanalysis (ECMWFRA or ERA). The data produced captures the small-scale spatial variability of wind speeds due to high-resolution terrain elevation, surface roughness and the effects of change (Badger et al., n.d).

Figure 3. Annual average wind speed in Mauritania



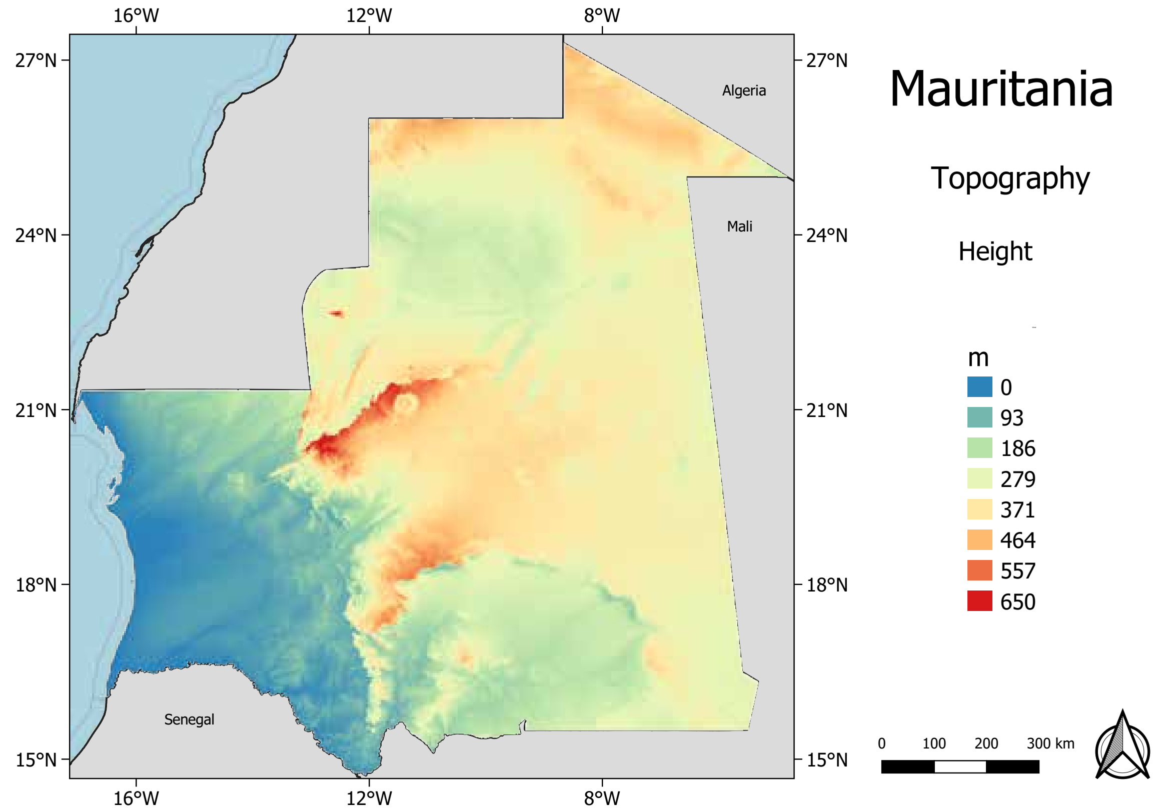
Source: Global Wind Atlas 1.0 (DTU, 2015).
Note: also available on the IRENA Global Atlas for Renewable Energy web platform.
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries..

3.3 Topography

The digital elevation of land above the sea level was drawn from the high-resolution digital topographic dataset (90 metres) developed in 2004 using data from the Shuttle Radar Topography Mission (SRTM).

This dataset established the slope of the land areas, enabling the delineation of the complex environments from which developments will likely be excluded. The considered topography for Mauritania is shown in Figure 4.

Figure 4. Topography of Mauritania



Source: Shuttle Radar Topography Mission digital elevation model.
Note: also available in the IRENA Global Atlas for Renewable Energy web platform.
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

3.4 Population distribution

The population density layer considered in this study was sourced from the Oak Ridge National Laboratory's (ORNL) LandScan™ 2018 Global Population Distribution dataset. These data are generated at approximately 1 km grid cell resolution and distributed by East View Geospatial. The data represents ambient population distribution in day/night time, modelled using dasymetric algorithms. These algorithms are based on intra-country census information and are combined with spatial information (e.g. terrain, road infrastructure, urban and rural settlements) to delineate those areas that are uninhabitable as well as to refine their distribution. This is carried out until an approximate population count is achieved.

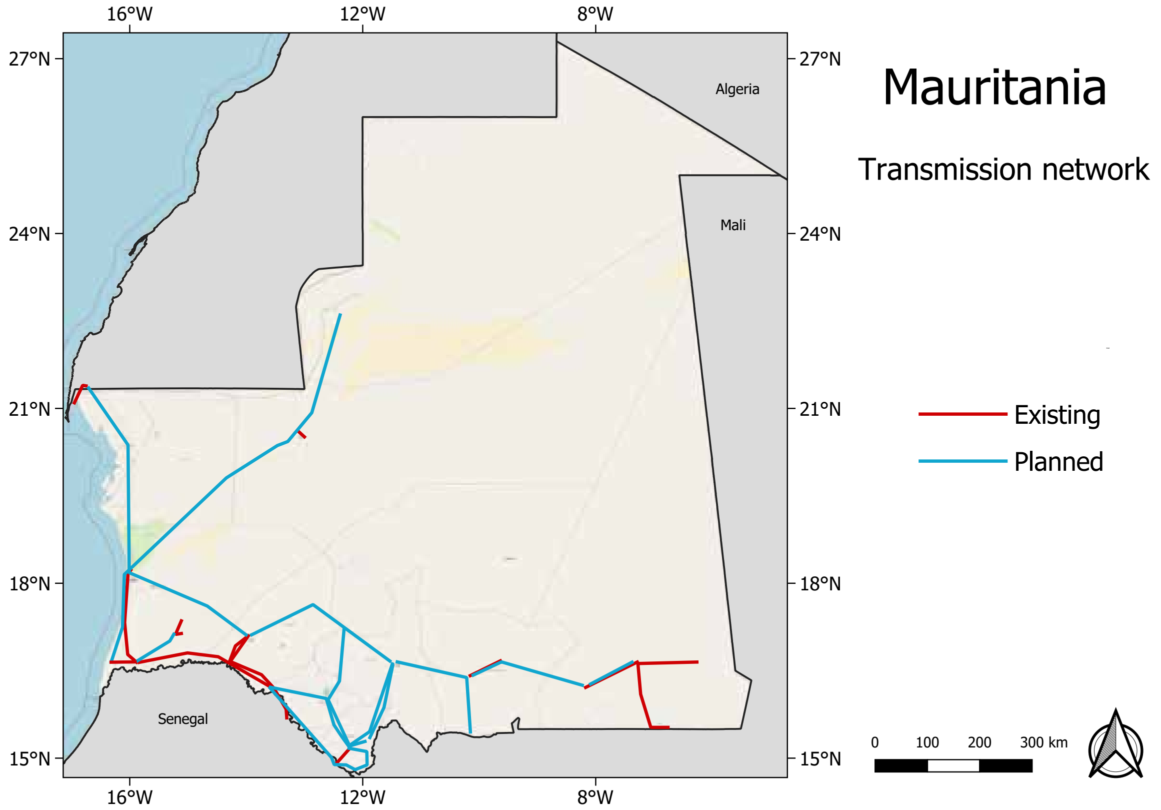
Nouakchott

Photograph: Shutterstock

3.5 Transmission line network

The transmission line network used in this analysis was provided by the Ministry of Petroleum, Energy and Mines of Mauritania, as shown in Figure 5.

Figure 5. Mauritania's transmission line network



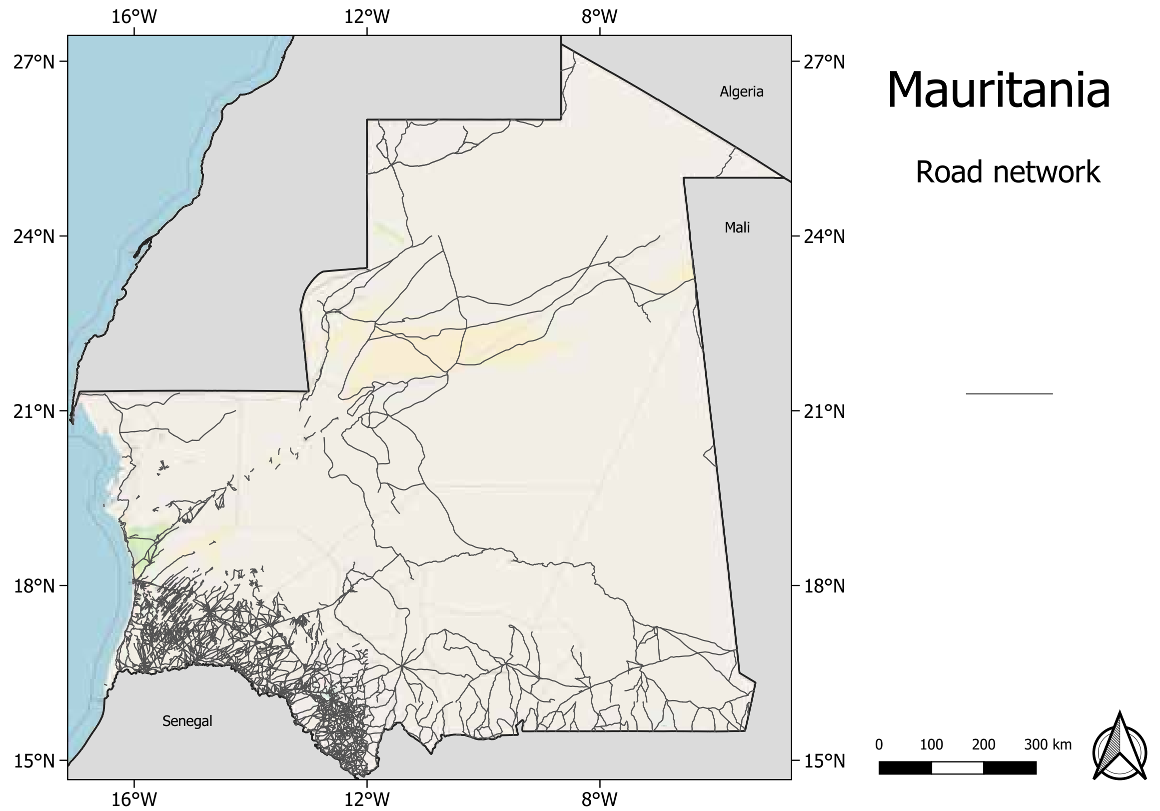
Source: Ministry of Petroleum, Energy and Mines, Mauritania (2019).
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

3.6 Road network

The road network considered in this analysis was extracted from the Global Roads Open Access Data Set (gROADs). This dataset was developed under the auspices of the CODATA Global Roads Data Development Task Group by Columbia University's Center for International Earth Science Information Network (CIESIN) in collaboration with NASA's Socioeconomic Data and Applications Center (SEDAC) and the University of Georgia's Information Technology Outreach Services (ITOS) Center.

The dataset combines the best available country road data to present global coverage using the UN Spatial Data Infrastructure Transport (UNSDI-T v.2) data model (SEDAC, 2020). The corresponding road network layer for Mauritania is shown in Figure 6.

Figure 6. Mauritania's road network



Source: NASA Socioeconomic Data and Applications Center, SEDAC (2013).
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

3.7 Protected areas

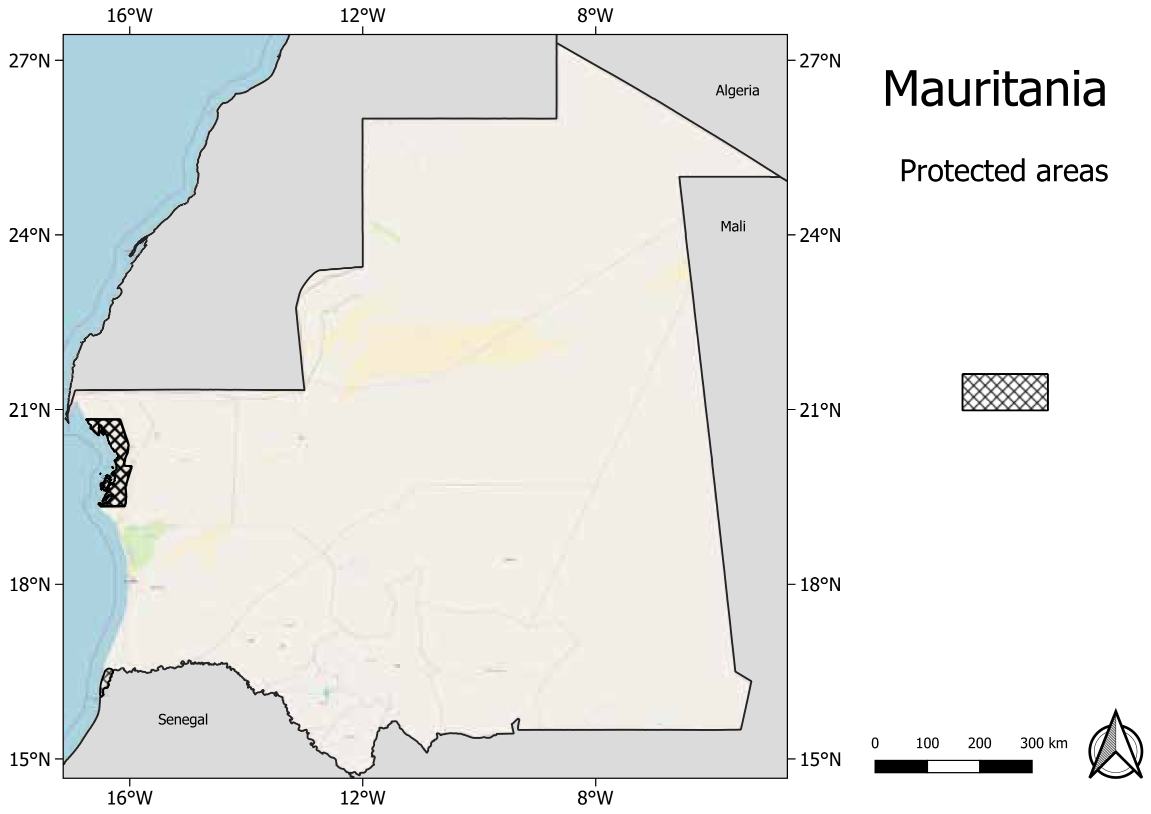
The World Database for Protected Areas (WDPA) is the most comprehensive global database on terrestrial and marine protected areas and is updated monthly. It is used by scientists, the public and private sectors, and international development organisations, among others, to inform planning, policymaking and management (UNEP et al., 2019).

The WDPA is a joint project undertaken by UN Environment and the International Union for Conservation of Nature.

The compilation and management of the WDPA, currently in its 2018 edition, is carried out by UN Environment's World Conservation Monitoring Centre in collaboration with governments, non-governmental organisations, academia and industry (UNEP et al., 2019).

Areas that are considered environmentally or culturally sensitive will most likely be excluded from project development and, as such, also from the assessment, as shown in Figure 7.

Figure 7. Protected areas in Mauritania



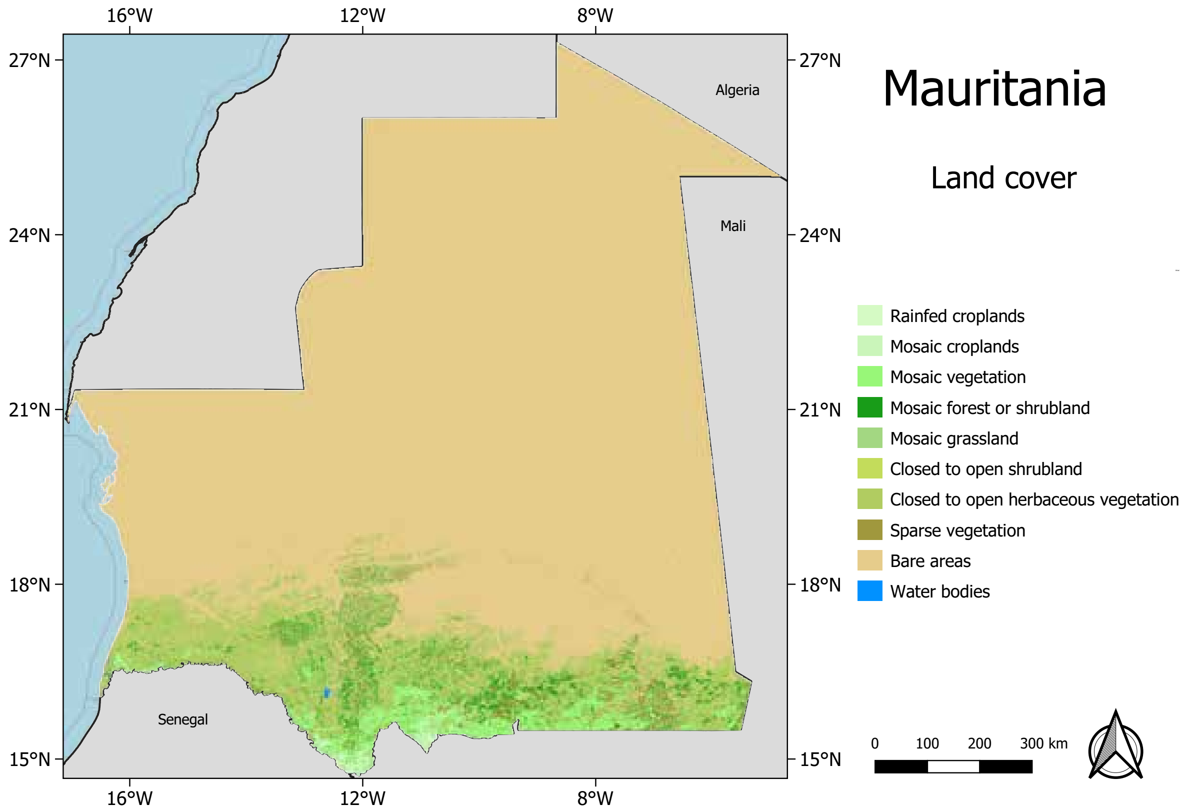
Source: UN Environnent, WCMC, IUCN (2019).
Note: Copy in "Global Atlas for Renewable Energy" of the International Renewable Energy Agency.
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

3.8 Land cover

The 2009 GlobCover (Global Land Cover Map) dataset represents the spatial distribution of 22 distinct land-cover types – such as built-up areas, bodies of water, croplands and vegetation – across the world at a 300-metre resolution.

This dataset has been extensively validated using in situ information from 3 134 stations around the world. As such, the accuracy of the land cover classification is approximately 62.6% (Bontempts et. al, 2011). Figure 8 shows the land cover for Mauritania.

Figure 8. Land cover in Mauritania



Source: GlobCover 2009 (ESA and UCLouvain).
Note: Copy in the "Global Atlas for Renewable Energy" of the International Renewable Energy Agency.
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

4

RESULTS

Figures 9 and 10 display the land suitability map for solar PV and wind project development in Mauritania generated using the suitability assessment approach discussed in section 2.

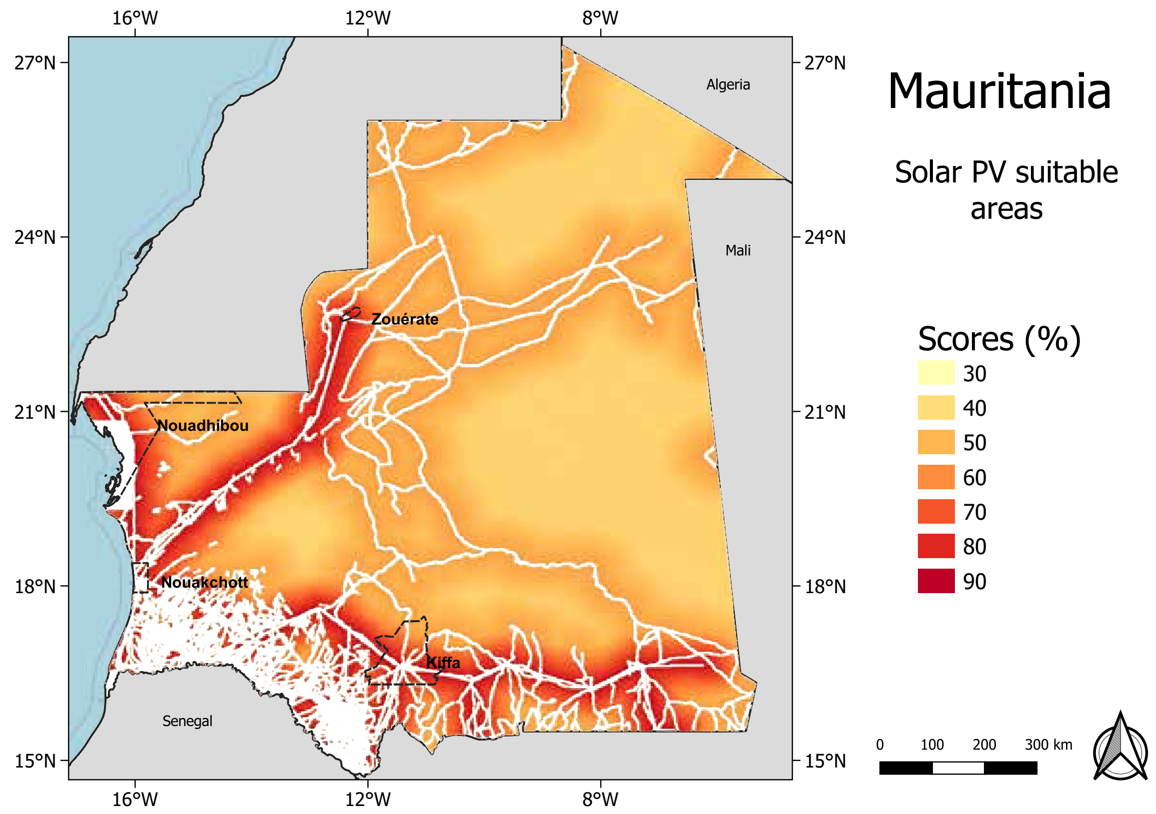
The results obtained indicate that 23% and 18.5% of the total country land area is suitable for solar PV and wind project development, respectively (i.e. suitability index exceeding 60%). These areas are largely located in the northern and eastern parts of the country, far from the population centres in the west and south of the country.

To secure the development potential of the opportunities highlighted by the maps, two consecutive assumptions are made:

a. Land-use footprints for solar PV and wind projects have been set to 50 MW/km^2 (Masdar, 2013) and 5 MW/km^2, respectively (Eurek et al., 2017), which equate to maximum development potentials of approximately 45 787 GW for solar PV and 4 700 GW for wind projects.

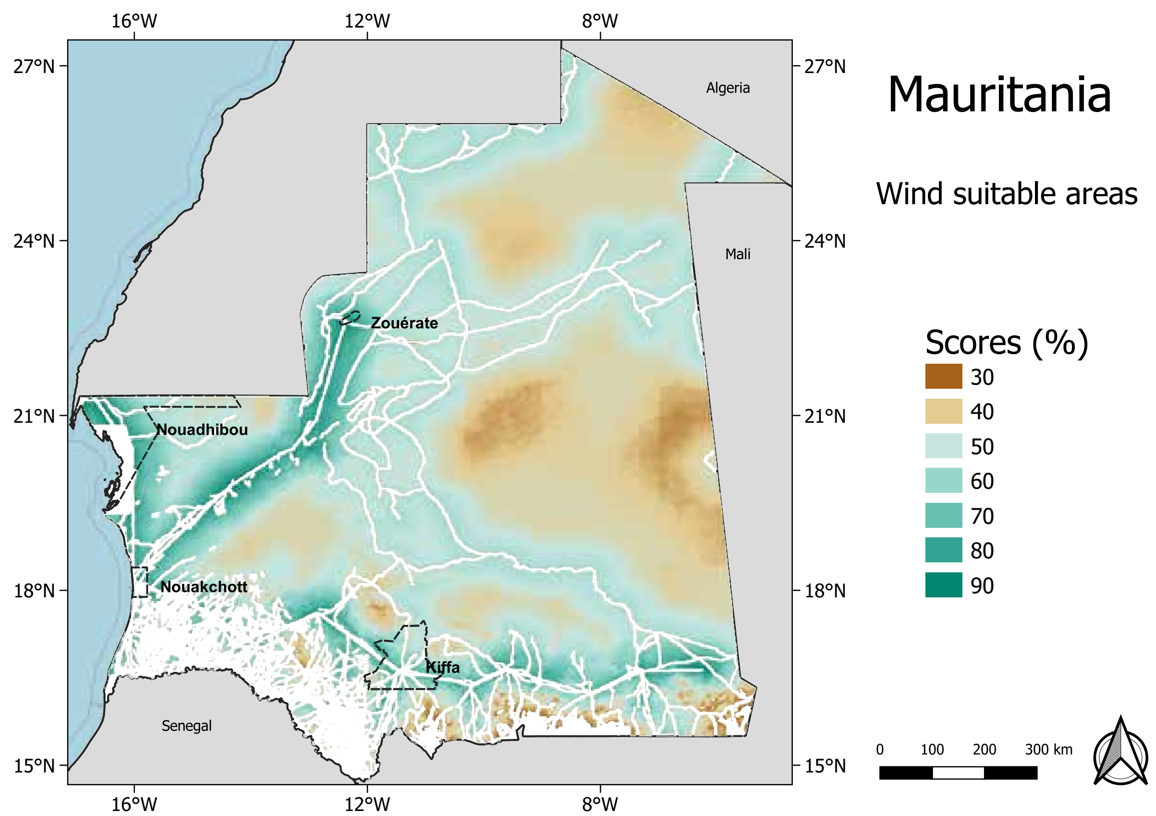
b. The land utilisation factor for project development has been set to 1%, which translates into a drop in development potential to approximately 457.9 GW and 47 GW for solar PV and wind projects.

Figure 9. Utility-scale solar PV: Most suitable prospecting areas in Mauritania



Source: Base map (OpenStreetMap); suitability scoring and areas (IRENA).

Figure 10. Utility-Scale Wind: Most suitable prospecting areas in Mauritania

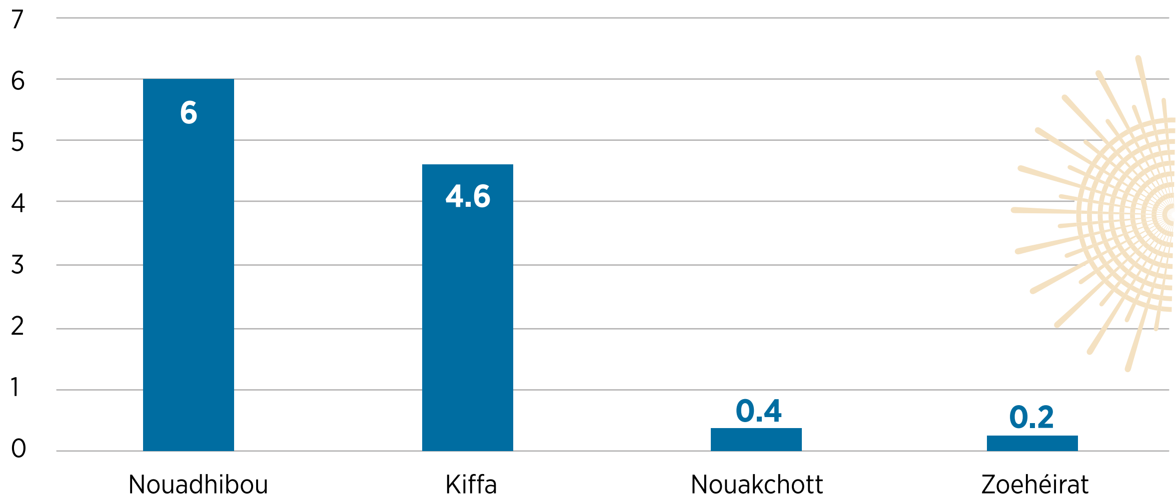


Source: Base map (OpenStreetMap); suitability scoring and areas (IRENA).
Disclaimer: These maps are provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

Specifically, Figures 11 and 12 display the development potential for solar PV and wind projects in four cities – namely, Nouakchott (population, 661 400), Nouadhibou (population, 72 337), Kiffa (population, 40 281) and Zouérate (population, 38 000).

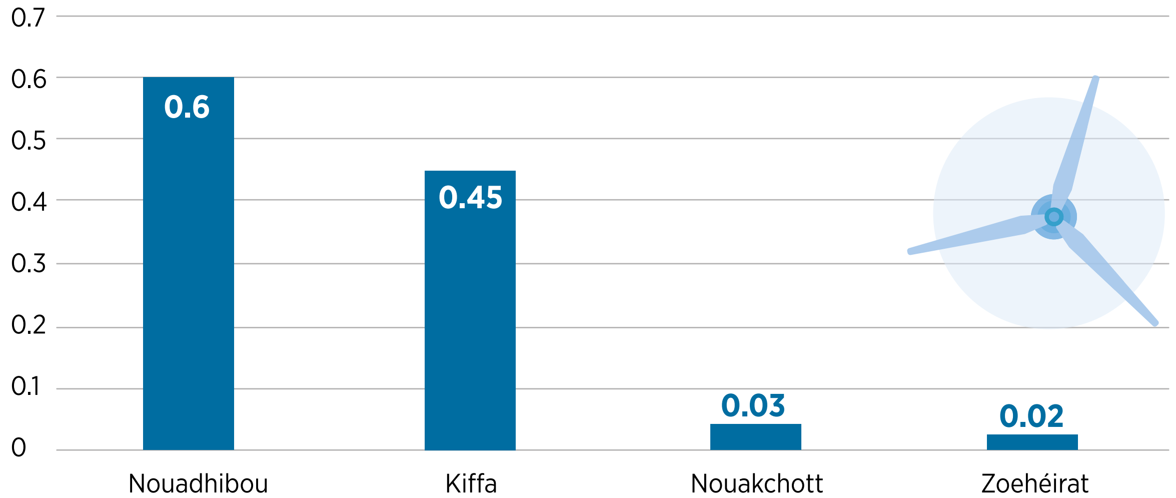
As shown in this figure, higher development potential is seen in Nouadhibou and Kiffa due to their size, proximity to transmission and road infrastructure, and low population density. Furthermore, the total development potential for these four cities translates into a capacity of approximately 11.2 GW for solar PV and 1.12 GW for wind.

Figure 11. Solar PV power: Technical potential across four cities in Mauritania (GW)



Source: IRENA.

Figure 12. Wind power: Technical potential across four cities in Mauritania (GW)



Source: IRENA.

However, the maximum development potential obtained from this analysis across the country and the four cities should be interpreted with caution in light of the following limitations:

1. Proximity to a transmission line does not mean that a connection is assured, as it may already be operating at its maximum carrying capacity.
2. Protected areas do not necessarily have the same level of protection and sometimes local authorities reverse areas' protected status.
3. Project development will most likely not occur in vast unoccupied areas of land in the foreseeable future owing to their distance from infrastructure and population centres.
4. Other factors, such as air density, surface roughness, terrain complexity and wind direction, could significantly influence the electricity output of a wind farm. More in-depth studies must be carried out to further screen areas, using criteria beyond annual average wind speeds and the other parameters highlighted in this study.

30 MW Nouakchott Wind Farm in Nouakchott

Photograph: Government of Mauritania

5

CONCLUSION

The findings of this study indicate that there is significant potential for utility-scale solar PV and wind power development in Mauritania. The maximum development potential across the country is estimated at approximately 457.9 GW and 47 GW for solar PV and wind projects, respectively, considering land-use footprints of 50 MW/km^2 for solar PV and 5 MW/km^2 for wind, with a land utilisation factor of 1%.

However, the combined development potential in areas surrounding the main cities of Nouadhibou, Kiffa, Nouakchott and Zoihérat, considering the same assumptions, is estimated at approximately 11.2 GW for solar PV and 1.12 GW for wind.

These findings are intended to prompt more in-depth investigation to establish specific sites for detailed evaluation using high temporal and spatial resolution resource data.

Yet the limitations of this study must be noted – including the sensitivity of the land suitability maps to the assumption made to set the thresholds and the underlying quality of criteria datasets. Notably, non-technical issues, such as land ownership, can also influence the selection of land for further prospecting.

Mauritania can select promising sites within the areas identified by this study to submit to IRENA's site assessment service (www.irena.org/globalatlas/Services) – a pre-feasibility assessment that determines the financial and technical viability of a site for solar PV and wind project development using a downscaled time series of solar irradiance and wind speed data, respectively. The time series data are fed into a robust power generation model and a simplified financial model developed to simulate a range of tariffs at which specific sites are viable for development.

BIBLIOGRAPHY

Anon. (2012), *"Separation between wind turbines and overhead lines", Energy Networks Association (ENA) Engineering Recommendations L44, (1);* available at: www.spenergynetworks.co.uk/userfiles/file/Energy_Networks_Association_Separation_Wind_Turbines_Overhead.pdf, accessed 4 June 2020.

Anon. (2017), *Transmission lines solar farm clearances,* Dublin: Mott MacDonald.

Baban, S., and T. Parry (2001), *"Developing and applying a GIS-assisted approach to locating wind farms in the UK"*, Renewable energy 24, pp. 59–71.

Badger, J.G., et al., *"Methodology",* Global wind atlas; available at: http://science.globalwindatlas.info/methods.html, accessed 3 October 2019.

Bontemps, S., et al. (2011), *GLOBCOVER 2009 Products description and validation report;* available at: https://epic.awi.de/31014/16/GLOBCOVER2009_Validation_Report_2-2.pdf, accessed 1 June 2020.

Denholm, P., M. Hand, M. Jackson and S. Ong (2009), *Land-use requirements of modern wind power plants in the United States, Technical Report* NREL/TP-6A2-45834, National Renewable Energy Laboratory, Golden, Colorado; available at: www.nrel.gov/docs/fy09osti/45834.pdf

Eurek, K., et al. (2017), *An improved global wind resource estimate for integrated assessment models, preprint.*

DTU (Technical University of Denmark) (2015), *Global wind atlas, Database,* DTU, Lyngby (Denmark), http://science.globalwindatlas.info/map.html, accessed 20 June 2019.

ESMAP (Energy Sector Management Assistance Program) (2017), *"Data description: Geographical coverage and spatial resolution",* Global solar atlas, World Bank, Washington, DC, https://globalsolaratlas.info/about/data-description, accessed 3 March 2019.

ESMAP (2017), *"Global solar atlas." Database (2017).* World Bank, Washington, DC. https://globalsolaratlas.info, retrieved on 3 March 2019.

IRENA (International Renewable Energy Agency) (2019), Global atlas database, https://irena.masdar.ac.ae/gallery, accessed 24 March 2019.

IRENA (2017), *Cost-competitive renewable power generation: Potential across South East Europe,* IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Cost-competitive_power_potential_SEE_2017.pdf

IRENA (2016a), *Investment opportunities in the GCC: Suitability maps for grid-connected and off-grid solar and wind projects,* Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Atlas_investment_GCC_2016.ashx

IRENA (2016b), *Investment opportunities in Latin America (Global Atlas)*, Abu Dhabi, https://www.irena.org/publications/2016/Jan/Investment-Opportunities-in-Latin-America-Global-Atlas

IRENA (2016c), *Investment opportunities in West Africa: Suitability maps for grid connected and off-grid solar and wind projects,* Abu Dhabi.

Masdar (2013), *The Sheikh Zayed Solar Power Plant,* https://masdar.ae/en/masdar-clean-energy/projects/the-sheikh-zayed-solar-power-plant, accessed 11 May 2020.

Noorollahi, E., et al. (2016), *"Land suitability analysis for solar farms exploitation using GIS and fuzzy analytic hierarchy process (FAHP): A case study of Iran"*, Energies, vol. 9, no. 8, p. 643.

Saaty, T.L. (2008), *"Decision making with the analytic hierarchy process", International journal of services sciences,* vol. 1, no. 1, pp. 83–98.

Sean Ong, S., C. Campbell, P. Denholm, R. Margolis and G. Heath (2013), *Land-use requirements for solar power plants in the United States, prepared under Task Nos. SS12.2230 and SS13.1040,* National Renewable Energy Laboratory, Golden, Colorado, United States, www.nrel.gov/docs/fy13osti/56290.pdf

Tegou, L-I., H. Polatidis and D. A. Haralambopoulos (2010), *"Environmental management framework for wind farm siting: Methodology and case study"*, Journal of environmental management, vol. 91, no.11, pp. 2134–2147, doi:10.1016/j.jenvman.2010.05.010

Center for International Earth Science Information Network (CIESIN)/Columbia University, and Information Technology Outreach Services (ITOS)/University of Georgia (2013), *Global roads open access data set*, version 1 (gROADSv1), Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC), http://sedac.ciesin.columbia.edu/data/set/groads-global-roads-open-access-v1, accessed 5 May 2020.

UNEP (UN Environment Programme), WCMC (World Conservation Monitoring Centre) and IUCN (International Union for the Conservation of Nature) (2019), *"About protected planet"*, UN Environment, WCMC, IUCN, www.protectedplanet.net/c/about, accessed 24 March 2019.

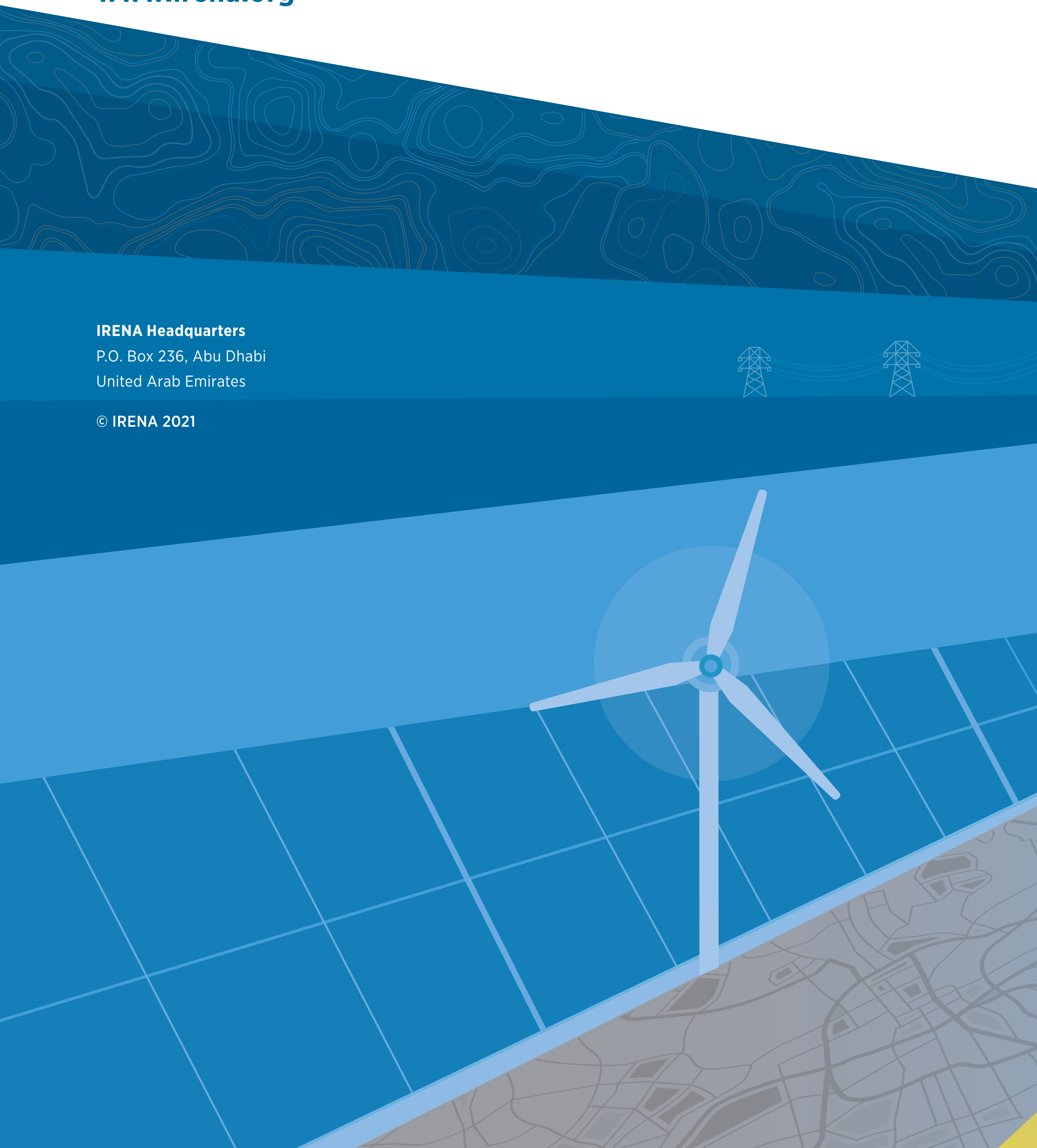
World Population Review (2019). *"Population of cities in Mauritania"*, database, http://worldpopulationreview.com/countries/mauritania-population/cities/, accessed 24 March 2020.

The potential exists on the ground for Mauritania to develop strong solar and wind power industries

IRENA

International Renewable Energy Agency

www.irena.org



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