Global Atlas
FOR RENEWABLE ENERGY

IRENA
International Renewable Energy Agency

GEORGIA
ZONING ASSESSMENT

INVESTMENT OPPORTUNITIES FOR UTILITY-SCALE SOLAR AND WIND AREAS

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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.

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ABBREVIATIONS

AC	alternative current
Ah	ampere hours
AHP	analytic hierarchy process
CF	capacity factor
C-FDDA	climate four-dimensional data assimilation
CFSR	climate forecasting system reanalysis
CSP	concentrated solar power
DC	direct current
DHI	diffuse horizontal irradiation
DNI	direct normal irradiation
DTU	Technical University of Denmark
ECMWF	European Centre for Medium-Range Weather Forecasts
EFC	equivalent firm capacity
ELCC	effective load carrying capability
ERA-5	European Centre for Medium-Range Weather Forecasts (ECMWF) 5th Reanalysis
ESA	European Space Agency
ESMAP	Energy Sector Management Assistance Program
ETA	energy transition assessment
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FS	Finkelstein-Schafer
GADM	Global Administrative Areas
GCC	Gulf Co-operation Council
GEOS	Goddard Earth Observing System
GHI	global horizontal irradiation
GIS	geographic information system
GMAO	Global Modelling and Assimilation Office
GSE	Georgian State Electrosystem
GW	gigawatt
GWA	Global Wind Atlas
IEC	International Electrotechnical Commission
IRENA	International Renewable Energy Agency
IUCN	International Union for Conservation of Nature
km	kilometre
km²	square kilometre
kWh	kilowatt hour
kWh/m²	kilowatt hours per square metre
LBNL	Lawrence Berkeley National Laboratory
LCOE	levelised cost of energy
m	metre
m²	square metre
m/s	metres per second
MERRA-2	Modern-Era Retrospective Analysis for Research and Applications, Version 2
MCC	maximum concentration capacity
MCDM	multi-criteria decision making
MEPA	Ministry of Environmental Protection and Agriculture of Georgia
MoESD	Ministry of Economy and Sustainable Development of Georgia
MW	megawatt
MWh	megawatt hour
MW/km²	megawatt per square kilometre
NASA	National Aeronautics and Space Administration
ORNL	Oak Ridge National Laboratory
OSM	OpenStreetMap
PV	photovoltaic
SAR	synthetic aperture radar
SAW	simple additive weighting
SODA	solar radiation data
SRTM	Shuttle Radar Topography Mission
TMY	typical meteorological year
UAE	United Arab Emirates
UNEP	United Nations Environment Programme
USD	United States dollar
WAsP	Wind Atlas Analysis and Application Program
WCMC	World Conservation Monitoring Centre

EXECUTIVE SUMMARY

This report summarises results from an analysis conducted by IRENA to map those zones across Georgia that are highly attractive when it comes to investment in the deployment of utility-scale solar photovoltaic (PV) and onshore wind projects, while also mapping those zones' corresponding techno-economic parameters.

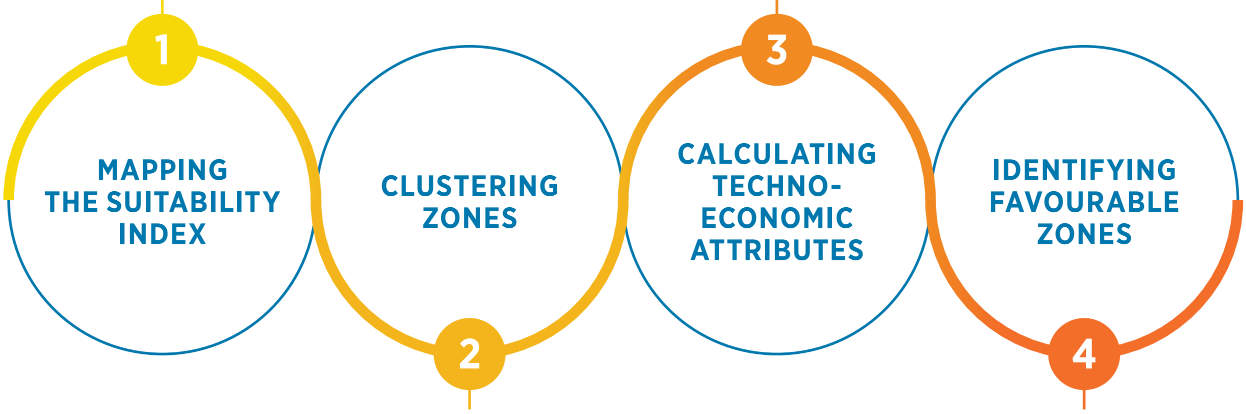
The study aims to: i) provide spatial information on renewable energy potential, along with insights into the country's total development potential when it comes to adopting solar PV and onshore wind power; ii) inform national infrastructure planning across the electricity supply value chain, spanning 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.

This analysis has been conducted via a rigorous and interactive process, involving official representatives from the Ministry of Economy and Sustainable Development of Georgia (MoESD) and Georgian State Electrosystem (GSE), in order to give due consideration to the local context. The analysis relies on high-quality resource and meteorological data (both annual average and hourly), while also taking into account ancillary data on local population density, protected areas, topography, land use, power transmission line networks, road networks, costs (capital and operational) and technological parameters. These criteria have been adapted to the country-specific renewable energy strategy, thus allowing the identification of the zones most promising for prioritisation in the renewable deployment plan.

The zoning approach for a utility-scale renewable energy project development consists of four main steps:

An assessment is made of the technical renewable energy potential of every square kilometre (km^2) of a country or region, based on selected criteria. These criteria are: resource quality; transmission line network; road network; topography; protected areas; population density; and land cover.

The capacity factor, energy output, levelised cost of energy (LCOE) and other factors are calculated. These express the capability of each zone, from the technical and economic perspectives, to host solar PV or onshore wind projects.



Highly suitable contiguous cells are grouped into definitive zones (or clusters) based on a defined cut-off suitability score and on the maximum capacity of each zone.

The most promising zones to be prioritised in order to enable the best investment environment are selected by evaluating and analysing the calculated zone attributes.

This study finds that a significant portion of Georgia's land area is highly suitable for solar PV and onshore wind development. However, the most promising zones to prioritise in the renewable deployment plan are concentrated along existing and planned transmission lines and road networks.

SOLAR PV

Maximum development potential:

87 GW

Installation density of:	Maximum concentration capacities of:	Land utilisation factor of:
50 MW/km²	**5 000** MW per zone	**20-30%**

ONSHORE WIND

Maximum development potential:

5.4 GW

Installation density of:	Maximum concentration capacities of:	Land utilisation factor of:
5 MW/km²	**5 000** MW per zone	**15-20%**

The study suggests a maximum development potential of approximately **87 gigawatts** (GW) for solar PV and **5.4 GW** for onshore wind projects. This takes into consideration land-use footprints of **50 megawatts per square kilometre** (MW/km²) and **5 MW/km²** for solar PV and onshore wind, respectively, along with maximum concentration capacities of **5 000 MW** per zone for both solar PV and onshore wind, given a land utilisation factor of **20-30%** for solar PV and **15-20%** for onshore wind. The utilisation factor was determined based on the premise that not all of the suitable area is eligible for power production due to competing land uses, such as agriculture and heritage protection; this is explored further in section 2.

These findings are intended to prompt further action in identifying specific sites for an in-depth assessment using high resolution spatial and temporal data. The limitations of this study must also be taken into account, however, specifically in terms of the sensitivity of the results both to the assumptions made in setting the thresholds for each criterion and to the underlying quality of the 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 could benefit from the site assessment service of the International Renewable Energy Agency (IRENA). This service offers a pre-feasibility assessment that determines the technical and financial viability of sites for solar PV and wind project development. In this, it uses downscaled time series resource data, site specific characteristics, technology-specific parameters and representative project cost data.

1. INTRODUCTION

This study was carried out at the request of the government of Georgia. It is an extension of the support the International Renewable Energy Agency (IRENA) provided through its energy transition assessment of Georgia, which has been ongoing since 2023 (IRENA, 2025).

The study – a zoning assessment – allows zones (or clusters) that are highly attractive to investment in renewable project development to be spatially mapped, along with their corresponding techno-economic parameters.

Such an assessment can assist the Ministry of Economy and Sustainable Development (MoESD) of Georgia in identifying the best zones for new utility-scale solar photovoltaic (PV) and onshore wind development and for planning transmission and generation expansion. It also helps create least-cost energy master plans, which can reduce the risk of investing in renewable projects and secure sustainable sources of electricity generation.

The second section of the report describes in detail the methodology, the underlying assumptions and the requirements for conducting a zoning assessment for utility-scale power plant deployment.

The methodology for identifying the best zones for renewable projects is based on:

i. A mapping of the technical renewable energy potential of every square kilometre of land, based on resource quality, transmission line network, road network, topography, protected areas, population density and land use.

ii. The clustering of zones with high technical potential based on specific assumptions related to the cut-off suitability score, maximum concentration capacity and land utilisation factor.

iii. The calculation of techno-economic parameters characterising the zones based on the technical equipment specifications and project cost estimates.

The third section of this report explains the data sources for each criterion and the assumptions used to provide a tailor-made analysis for the country. It includes specific details on: the spatial and temporal resolutions; the extent of validation; and the recommended use for each dataset, given its strength.

The results of this study are included in the fourth section and consist of: i) land technical renewable energy potential (suitability maps) for solar PV and onshore wind; ii) zones of high investment attractiveness, with their techno-economic parameters, such as installed capacity, hourly and annual energy generation, capacity factor, levelised cost of electricity (LCOE), and distances to infrastructure such as road and transmission lines; and iii) the country's maximum development potential.

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

Box 1 The Global Atlas for Renewable Energy Initiative

The Global Atlas for Renewable Energy is an initiative developed by IRENA in partnership with the Clean Energy Ministerial Multilateral Solar and Wind Working Group to advance the deployment of renewables.

The initiative assists policy makers, project developers, investors, and the global community by providing a single online repository, namely the **Global Atlas platform**, that assembles and collates over 1000 high-quality renewable resources (solar, wind, bioenergy, geothermal, hydropower, and marine) and supplementary datasets (transmission and road network, land cover, topography, and protected areas) to understand the renewable potential in any region or country. These datasets serve as inputs to the development of the online tools and country-level analyses, including:

- The **Bioenergy simulator**, which is web-based application developed to estimate potential bioenergy and plan bioenergy development considering numerous combinations of area, biomass resource, technology, and end-use. The simulator aims to raise awareness on modern bioenergy production options to help meet global climate goals, decarbonise the world's energy system, and ensure access to affordable, reliable, sustainable energy for all.
- The **SolarCity simulator**, which is web-based application developed to accelerate the deployment of rooftop solar photovoltaic (PV) systems in selected cities, such as Chongli in China, Ulaanbaatar in Mongolia, Port Louis in Mauritius, Burgunj in Nepal, Castries in Saint Lucia, Victoria in Seychelles, and Kasese in Uganda. The simulator assesses rooftop solar PV potential (electricity production, cash flow, and socio-environmental benefits) by testing different policy instruments, incentive schemes, and installation scenarios that could lead to potential economic savings and social-environmental benefits.
- The **zoning Assessment**, which is a GIS-based multicriteria analysis that identifies the favourable zones within a country for developing utility-scale solar PV or wind project. The methodology combines high quality resource data with infrastructure and land features related data, including road and transmission line networks, topography, protected areas, and population density, to identify the zones of high degree of feasibility to develop solar and onshore wind projects. These zones are further characterised with attributes, which include potential installed capacity, hourly energy generation profiles, distances to transmission and road infrastructure, and levelised cost of electricity (LCOE). This service aims to support countries in developing and implementing their national energy masterplan.
- The **site assessment**, which is a cost-effective pre-feasibility analysis developed to support countries in finding financially viable sites for solar (photovoltaic, parabolic trough collector, central receiver system, and linear Fresnel) and wind project development. The service relies on site-specific resource profiles, industry standard energy yield, and financial assessment methodologies to establish a range of tariffs and levelised costs of a site for potential investment on ground measurements and subsequent development. Through this service, the Agency has assisted local authorities – ministries and public utilities – in several countries in Africa, Latin America and Small Island Developing States (SIDs), in the selection and screening of more than 150 promising sites for solar and wind power projects.

2. THE ZONING ASSESSMENT

Zoning for utility-scale renewable projects aims to deliver a refined mapping of development potential at a scale that delimits the zones of high investment attractiveness (or cost-effectiveness). It does this by considering: high renewable resource potential; proximity to the necessary infrastructure; the current financial context; and areas where there would be a low environmental and social impact.

Such an assessment helps authorities make good strategic decisions when planning generation and transmission expansion. This can reduce the risks of investing in renewable projects and secure sustainable sources of electricity generation.

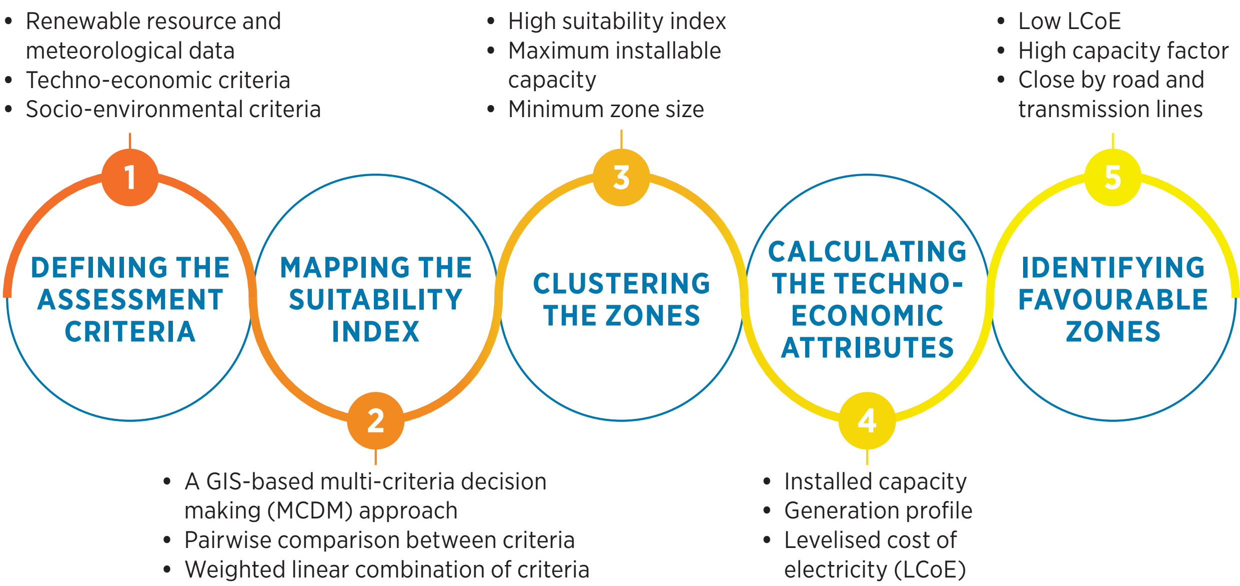
The zoning approach (Figure 1) consists of:

i. defining the assessment criteria;
ii. mapping the suitability index for project development at the country level;
iii. clustering suitable adjacent areas;
iv. calculating the techno-economic attributes for each zone identified; and
v. identifying cost-effective favourable zones.

2.1. DEFINING THE ASSESSMENT CRITERIA

A zoning analysis relies on renewable resource and meteorological datasets, combined with techno-economic and socio-environmental criteria.

Figure 1 Zoning assessment method



Renewable resource and meteorological data

Renewable resource data, such as solar irradiance, or wind speed at a specific height, along with meteorological data, provide the most important information needed in evaluating the feasibility of hosting a renewable project in a particular zone. Such data make it possible to determine the development capacity and hourly generation profiles of such projects.

The solar irradiance component affecting the output of PV cells is global horizontal irradiance. This is commonly calculated using either physically-based or statistically-based approaches that require high temporal and spatial resolution satellite or ground measurements.

The long-term average annual global horizontal irradiation (GHI) at 1 km to 3 km grid cell resolution – as given in the World Bank's Global Solar Atlas and Transvalor's SODA solar datasets, which cover more than 20 years of hourly historical data – are used to produce the feasibility index for hosting a renewable project. In addition, the hourly historical global horizontal irradiance data at around 25 km grid cell resolution – as given in the Modern-Era Retrospective Analysis for Research and Applications Version 2 (MERRA-2) dataset developed by the National Aeronautics and Space Administration (NASA) – are used to calculate the generation profile of a potential solar PV power plant (see section 3.1).

Wind speed data are commonly derived using weather research and forecasting models and data assimilation techniques. These are used in order to achieve the most realistic description of weather occurrences in what is known as 'reanalysis' data. The long-term annual average wind speed at a 1 km to 3 km grid cell resolution, such as that given in the global wind atlas of the Technical University of Denmark (DTU) and in Vortex's wind maps, covers long-term hourly historical datasets at different heights. These data are used to produce the feasibility index for hosting renewable projects. Conversely, the hourly historical wind data at around 25 km grid cell resolution, such as that given by the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis 5th Modern-Era (ERA5), are used to calculate the generation profile from wind power plants (see section 3.2).

Other meteorological data are also commonly derived using weather research and forecasting models and data assimilation techniques to produce reanalysis data. These data, such as the historical long-term air temperature and pressure recorded in the MERRA-2 and ERA5 reanalysis datasets, are important to calculate the hourly and annual potential energy generation of a renewable project site (see section 2.4). Such evaluation is commonly conducted considering typical meteorological year (TMY) data, which represent the most frequent weather conditions at a given location (Capacity4dev, EU, 2011) (see section 3.3).

Techno-economic criteria

Techno-economic criteria are of great importance in estimating the feasibility of hosting a renewable project in a given area and for calculating the hourly generation profiles of the zones identified. These criteria include: land features; slope and elevation; infrastructure, such as transmission lines and road networks; land-use constraints, such as the suitability cut-off value, the maximum concentration capacity, installation density and the land utilisation factor; renewable equipment specifications; and project costs.

- The land elevation and slope have an influence on the equipment installation. Areas with steep slopes and high elevations pose challenges in terms of site access for construction and maintenance, which increases the costs. The characteristics of these areas also affect the mounting of the equipment, often leading to poor resource extraction. The elevation is derived from stereo image pairs using soft photogrammetry, or from radar data using synthetic aperture radar (SAR) interferometry methodology. Slope, meanwhile, is derived directly from elevation.

- Proximity to existing or planned infrastructure, such as transmission lines and road networks, is an important economic advantage in siting a renewable energy project, given the high costs associated with infrastructure construction or expansion. Transmission line and road network data are generated using satellite and aerial images, which chiefly use geographic information system (GIS) technology.
- The suitability cut-off, or threshold, value is a subjective point that is used to decide whether or not a grid cell is worth choosing for project development. This value is generally chosen by analysing the results of the suitability map for renewables and by considering the country potential.
- The maximum concentration capacity (MCC) expresses the highest generation capacity that can be handled in a single zone to limit the associated risks – security, reliability, or equitable regional planning. A range between 2 000 megawatts (MW) and 5 000 MW, depending on country size and system configuration, is suggested. But the MCC is generally defined by the country in question, based on its generation planning approach, power management strategies and other constraints.
- The installation density expresses the average capacity that can occupy a square kilometre of land area, depending on site conditions, local laws and technology. For solar PV, the density value may reach 50 MW/km^2 of land area – such as at Masdar's Sheikh Zayed power plant in Mauritania, or Siwa power plant in Egypt (a 10 MW facility built on 0.175 km^2). A similar density was also reached at the Cestas power plant in France (a 300 MW facility built on 2.65 km^2) (Masdar, 2013). For wind, the installation density value ranges between 3.0 ± 1.7 MW/km^2 (Denholm *et al.*, 2009) and 5 MW/km^2 (Eurek *et al.*, 2017).
- The land utilisation factor is defined in order to limit the full utilisation of a zone due to competing land uses, including agriculture and heritage protection. Along with the installation density, this factor helps in estimating the maximum installable capacity within the zones identified. The value is generally set by the country in question in order to comply with local regulations.
- Equipment specifications include information provided by the manufacturer related to the typical rated performance parameters of the renewable energy equipment that is to be installed in the zones. The model, type, rated power and efficiency specifications selected for PV modules are based on those of prominent, high-performing modules from reputable module manufacturers, while the model, rated power and size of a wind turbine is selected according to the International Electrotechnical Commission (IEC) classification of wind speed. The specifications for PV modules and wind turbines are obtained from the open access libraries *pvlib*[1] and *windpowerlib*.[2]
- Financial data include: the cost of installing, operating, and maintaining the power plant; the cost of developing and maintaining new infrastructure, such as transmission lines and access roads; and the discount rate over the project lifetime. These are the parameters used to calculate the LCOE of the renewable project zone. These data are obtained from country and IRENA databases.

Socio-environmental criteria

Socio-environmental criteria include protected areas, land cover and population growth. These criteria help determine which areas are to be avoided when selecting a location for solar or wind projects. The land cover feature is less significant, as it is concerned with national legislation. Taking protected areas and population growth into account, however, is crucial in reducing the possible negative impact on the environment and on human communities. The related datasets for these criteria are generated using different techniques and technologies, such as satellite imagery (see sections 3.5, 3.8, and 3.9).

[1] *https://pvlib-python.readthedocs.io/en/latest/*

[2] *https://windpowerlib.readthedocs.io/en/latest/*

Box 2 The typical meteorological year (TMY)

The use of the TMY is common in renewables and is a collection of representative renewable resource and meteorological parameters for every hour in a one-year period (8 760 hours) at a given location. These mainly include the three components of solar radiation (global horizontal irradiance, direct normal irradiance [DNI] and diffuse horizontal irradiance [DHI]) wind speed, ambient temperature, and relative humidity.

Multiyear, hourly historical data (usually spanning 10 years or more) is used to determine the 12 'typical' meteorological months for a given location that best represent median conditions, rather than extreme conditions. For instance, a TMY developed using a dataset spanning from 2010 to 2022 might incorporate data from January 2010, February 2014, March 2017, and so on. The computation is conducted using the Finkelstein-Schafer (*FS*) statistical methodology (Capacity4dev, EU, 2011).

2.2. MAPPING THE SUITABILITY INDEX

The suitability assessment is the first step of the zoning assessment and is an opportunity-based approach. It enables the objective mapping of the technical renewable energy potential of a given utility-scale power plant deployment in a particular country or region.

The outcome of the analysis is a suitability index map, scored between 0% (the most unfavourable sites) and 100% (the best sites). The map shows the degree of feasibility (or opportunity) for each grid cell of the country when it comes to hosting a solar PV or wind project.

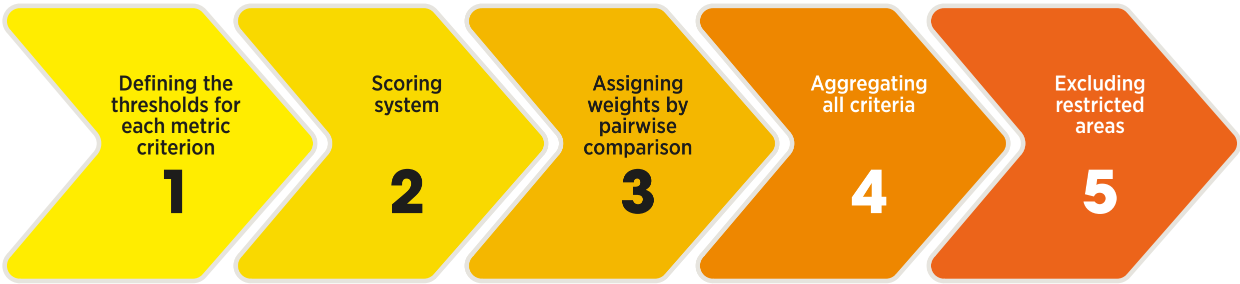
The mapping is conducted by combining the potentially available renewable resources (the theoretical solar PV or wind potential) with techno-economic constraints, such as slope and elevation, distances to transmission lines and road networks, and socio-environmental factors, such as protected areas, land use, and population growth (see section 2.1). This is done through a GIS-based multi-criteria decision analysis.

This approach was developed by IRENA in 2013 and updated in 2021, based on accumulated global experience and heightened data collection capacity. In the context of intensified renewable energy development, the approach has enabled the identification of areas in multiple regions worthy of further investigation (IRENA, 2016a). The analysis has been carried out across Latin America,[3] the Gulf Co-operation Council (GCC) states,[4] Southeast Asia, Southeast Europe and Africa.[5] The analysis has also been carried out specifically for Mauritania[6] and Burkina Faso,[7] in order to support those governments in planning their renewable projects and setting their targets.

The approach involves the following steps (Figure 2).

3 *For further information, see: (IRENA, 2016b).*
4 *For further information, see: (IRENA, 2016c).*
5 *For further information, see: (IRENA and AfDB, 2022).*
6 *For further information, see: (IRENA, 2021a).*
7 *For further information, see: (IRENA, 2021b).*

Figure 2 Suitability assessment method



Defining the thresholds for each criterion

Lower and upper thresholds have to be set for each of the above criteria (resource, techno-economic, and socio-environmental) in order 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 1 275 kilowatt hours per square metre (kWh/m^2) are deemed to be unsuitable and are assigned a 0% score, while areas with an annual GHI of 1 600 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 6.5 metres per second (m/s) may not be worth considering for project development and are assigned a 0% score (Höfer *et al.*, 2016). In contrast, areas with wind speeds above 12 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, which was conducted on 36 wind project sites characterised by different wind regimes, layouts, and terrain types. These assessments demonstrated that sites experiencing 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 also have slope values that are below 11% (Noorollahi *et al.*, 2016) and 30% (Höfer *et al.*, 2016; Tegou *et al.*, 2010), respectively.

For road and transmission line networks, the acceptable distance from a project to these lines has been set by three experts from Georgia and must not exceed 30 kilometres (km) from a road and 100 km from the transmission line for solar PV and onshore wind. As for the minimum distances, for solar PV power plants they are generally set at 0.1 km from the road network and 0.1 km from the transmission line network. For large wind turbine generators, the minimum is 0.3 km from both road and transmission line networks, to account for the average tip height (hub height plus rotor radius) (ENA, 2012), (see Table 1).

Scoring system

Each grid cell of the criteria being considered is scored in accordance with the thresholds and assumptions set in Table 1. Consequently, areas not reaching the lower threshold (lower resources and proximity to load centres and to 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.

As an example, a location with an annual GHI of 1 500 kWh/m^2 will score 70%, considering the lower (1 275 kWh/m^2) and upper (1 600 kWh/m^2) threshold in Table 1.

$$1 - \frac{Threshold_{upper} - value}{Threshold_{upper} - Threshold_{lower}}$$

Assigning weights by pairwise comparison

The criteria for identifying suitable areas for solar PV and wind project development considered in this analysis are not of equal importance. Areas with high resource potential that are farther from road networks will most likely be given more consideration than areas with low resource potential but closer proximity to roads. Therefore, weights are assigned to each criterion based on their degree of importance in the local country context.

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

This method, however, relies on the judgement of experts in determining the level of importance of each criterion used when selecting a site for solar PV or wind project planning and development.

Experts from Georgia have independently completed a pairwise comparison matrix for both solar PV and wind project areas to determine the level of importance of each of the above criteria. These matrices were solved using the AHP 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 not of equal importance.

Aggregating all criteria

The suitability index for each grid cell is calculated by aggregating all the criteria considered 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.

Excluding restricted areas

In contrast to the previous criteria, restricted zones – 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. A value of 0 is applied to all areas within the restricted area, while 1 is applied to all areas located at least 15 metres (m) beyond the restricted areas.

This binary constraint map is then multiplied by the calculated suitability index (step 4 in Figure 2) 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 cell with a similar scoring in non-restricted areas will score at 90% (*i.e.* 90% x 1).

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 GHI	0: GHI < 1275; [0-100]: 1275 ≤ GHI ≤ 1600; 1: GHI ≥ 1600	kWh/m^2	0.25
Annual wind speed (WS) at 100 m height	0: WS < 6.5; [0-100]: 6.5 ≤ WS ≤ 12; 1: WS ≥ 12	m/s	0.43
Distance to the grid for solar PV	0: distance > 100 [0-100]: 100 ≥ distance ≥ 0.1	km	0.39
Distance to the grid for onshore wind	0: distance > 100 [0-100]: 100 ≥ distance ≥ 0.3	km	0.29
Distance to the road for solar PV	0: distance > 30 [0-100]: 30 ≥ distance ≥ 0.1	km	0.20
Distance to the road for onshore wind	0: distance > 30 [0-100]: 30 ≥ distance ≥ 0.3	km	0.17
Slope score for solar PV	0: slope > 11 (0-100]: 11 > slope ≥ 0	%	0.12
Slope score for onshore wind	0: slope ≥ 30 (0-100]: 30 > slope ≥ 0	%	0.03
Population density:	0: inhabitants > 500 [0-100]: 500 ≥ inhabitants ≥ 0	-	0.05 for PV 0.07 for wind
Protected areas	0: within the areas 1: 15 m outside the areas	-	-
Land cover	0: within the areas 1: Outside the areas	-	-

Notes: GHI = global horizontal irradiation; km = kilometre; kWh/m^2 = kilowatt hours per square metre; m = metre; m/s = meter(s) per second; PV = (solar) photovoltaic; WS = wind speed.

2.3. CLUSTERING OF SUITABLE AREAS

Spatial clustering is the third step of the zoning assessment (see Figure 1) and is a common technique for statistical data analysis (or classification). It enables the detection of clusters of contiguous grid cells, referred to as zones, which have a high technical renewable potential greater than the suitability cut-off value. The zone also has a possible ceiling value, which is defined as the maximum concentration capacity.

Assumptions about the suitability cut-off (or threshold) value, the maximum concentration capacity, the installation density, and the land utilisation factor (see section 2.1.2) are required in order to define the best zones for project development.

These assumptions are determined by the experts from the MoESD based on their generation planning approach, power management strategies and constraints, as shown in Table 2.

For most countries, the smallest zone for a project is defined as a 6 km² area, offering an opportunity to install a maximum capacity of 300 MW of solar PV or 30 MW of onshore wind power. For smaller countries with limited land area, the smallest zone is redefined as a 1 km² area, in order to limit the exclusion of zones of interest.

The output of the analysis is a map identifying zones with a high degree of feasibility (or opportunity) for hosting utility-scale solar PV or onshore wind power plants, where each zone has an identifier, the geographical coordinates of its centre point and defined boundaries.

Table 2 Assumptions on technical parameters for zoning assessment

PARAMETERS	UNITS	SOLAR PV	ONSHORE WIND
Suitability cut-off value	%	57	50
Maximum concentration capacity	MW	5 000	5 000
Installation density	MW/km²	50	5
Land utilisation factor	%	20-30	15-20

Notes: MW = megawatt; MW/km² = megawatt(s) per square kilometre; PV = (solar) photovoltaic.

2.4. CALCULATING TECHNO-ECONOMIC ATTRIBUTES

The calculation of the techno-economic attributes that characterise each zone for solar PV and wind is the fourth step of the zoning assessment (see Figure 1) and aims to evaluate the projected power plants' economic performance.

An appropriate calculation of these attributes relies on simplified financial model and advanced power model. These consider up-to-date and representative input data related to technological equipment specifications, and investment rates (Table 3).

The targeted attributes consist of:

- Theoretical power capacity (MW), which is calculated based on the available area, installation density and land utilisation factor, as defined by Georgia.
- Hourly and annual electricity generation in megawatt hours (MWh), which are simulated based on the hourly TMY data and technical equipment specifications for solar PV and wind turbines systems (see section 2.1).
- The capacity factor, which is calculated as a percentage based on the simulated generation output and maximum possible output.
- The LCOE, which is calculated based on the project cost estimates (capital, operations, and maintenance). These reflect the local or regional fiscal context, the cost of developing and connecting the power plant to the infrastructure (transmission lines and access roads), and the discount rate over the project's lifetime.

Table 3 Technology specifications and infrastructure costs

SOLAR PV	Module peak	-	400
	Fixed operational expenditure	USD/kWh/year	6.6
	Capital expenditure	USD/kW	700
ONSHORE WIND	Turbine class	-	Turbine Class 1-3
	Fixed operational expenditure	USD/kWh/year	31.3
	Capital expenditure	USD/kW	1 050
ROADS	Capital expenditure	USD/km	225 000
	Maintenance	USD/km/year	4 680
TRANSMISSION LINES	Capital expenditure	USD/km	732 919
	Maintenance (as % of its capital cost)	%	3.5

Notes: PV = (solar) photovoltaic; USD/km = United States dollars per kilometre; USD/kWh = United States dollars per kilowatt hour.

2.5. IDENTIFYING FAVOURABLE ZONES

The identification of favourable zones is the last step in the zoning assessment.

Such identification focuses on evaluating and analysing the attributes calculated for the zones identified in order to select the most promising candidates for further investment and subsequent development.

This step's outputs therefore correspond to the zones specifically listed as the most suitable, from a technical or economic perspective. This calculation is based on the most recent and accurate information available from the authorities and stakeholders of a specific country or region.

The points to consider in evaluating assessment results include:

- Ranking zones in consideration of the different parameters, such as capacity factor, LCOE and distance to the transmission line, where the best zones are highlighted and the worst zones (those with low capacity factors and extremely high LCOE values) are discarded.
- Benchmarking results with current renewable targets, where the feasibility or ambitiousness of those targets is evaluated according to the potential determined.
- Cross-checking results by taking into account current developments. In this, the existing utility-scale generators and prospective sites identified by countries and developers are geo-positioned on the resulting zones map. This information is gathered through local stakeholders and any available public information.
- Comparing LCOE results with current grid and technology LCOE values, where zones are identified based on their financial competitiveness under current domestic market conditions. Such a comparison allows the identification of cost-competitive locations for the development of projects while also providing insight into the prices to be targeted by new developments. The comparison also gives an opportunity to look for possible optimisations in terms of electricity generation through power plant layout or size, while revealing any gaps to be overcome in order to achieve a level of market maturity that can welcome renewable generation.

3. DATA SCOPE AND QUALITY

In performing the zoning assessment for solar PV and wind projects, the data considered were sourced according to defined criteria and metrics. This was done in order to better reflect the local characteristics of the country (see section 2).

The criteria used included: solar and wind resource maps; topographical features (elevation and slope); the proximity to transmission line and road networks; proximity to population centres and environmentally sensitive areas; technological requirements; and investment costs (capital and operational).

The collection of these data is challenging, as availability on the ground can be limited or almost non-existent in some cases. To cope with this lack of information, open databases that are available for a range of parameters were used in this assessment, when necessary.

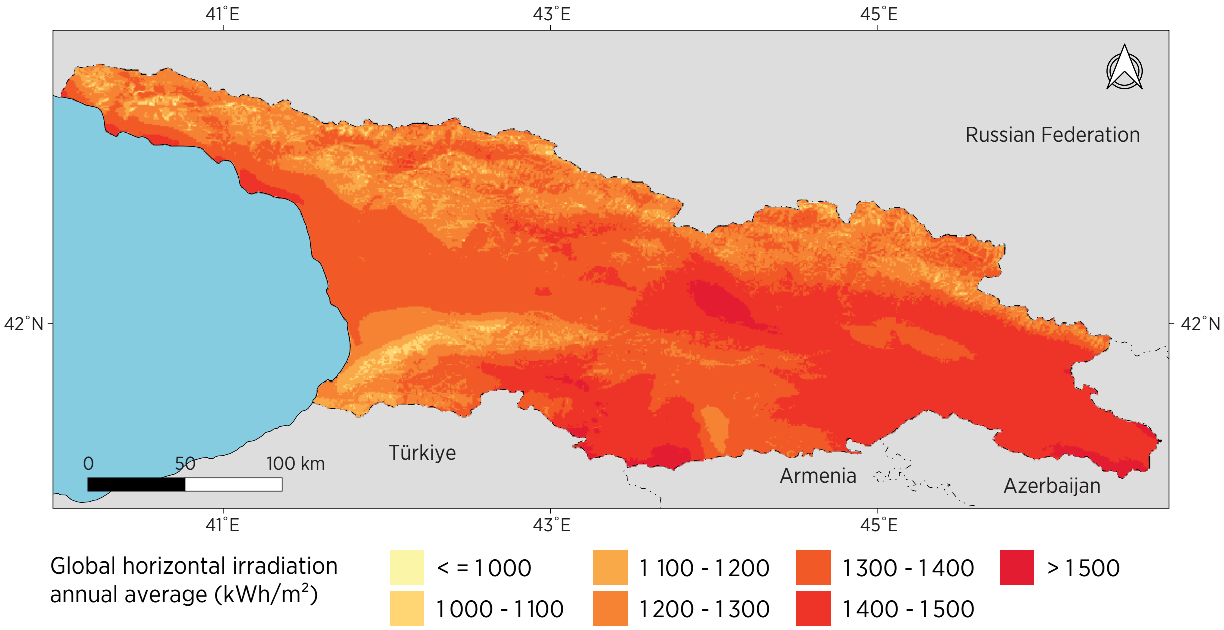
3.1. SOLAR RESOURCE DATA

The solar resource data used for this analysis were the average annual global horizontal irradiation (GHI) and the hourly long-term global horizontal irradiance.

The average annual GHI data employed in this study were sourced from the World Bank's Global Solar Atlas, developed by Solargis (ESMAP, 2019a), (Figure 3). This uses data calculated at a grid cell resolution of 1 km using long-term satellite-based solar irradiance and covering a time period from 1994 to 2015. The atlas uses satellites that include those of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the Japanese Geostationary Meteorological series (known as 'Himawari'), and the National Oceanic and Atmospheric Administration of the US Department of Commerce (NOAA) (ESMAP, 2019b). The Global Solar Atlas was validated using ground measurements from 228 sites worldwide where the corresponding accuracy of annual GHI values ranged between ±4% to ±8% (ESMAP, 2019a).

As for the hourly long-term global solar irradiance, these data were extracted for each identified zone from the MERRA-2 dataset developed by NASA's Global Modelling and Assimilation Office (GMAO). The original dataset provides long-term hourly data from 1980 to the present day at approximately 25 km resolution. For this assessment, data from 2010 to 2021 were extracted from the Goddard Earth Observing System (GEOS) atmospheric model (NASA, 2022). At the planning stage, coarse resolution should be sufficient to perform the zoning assessment.

Figure 3 Average annual global horizontal Irradiation in Georgia



Source: Global Solar Atlas (ESMAP, 2019b); base map: UN boundaries. Maps are also available from the IRENA Global Atlas for Renewable Energy.

Notes: km = kilometre; kWh/m² = kilowatt hours per square metre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

3.2. WIND RESOURCE DATA

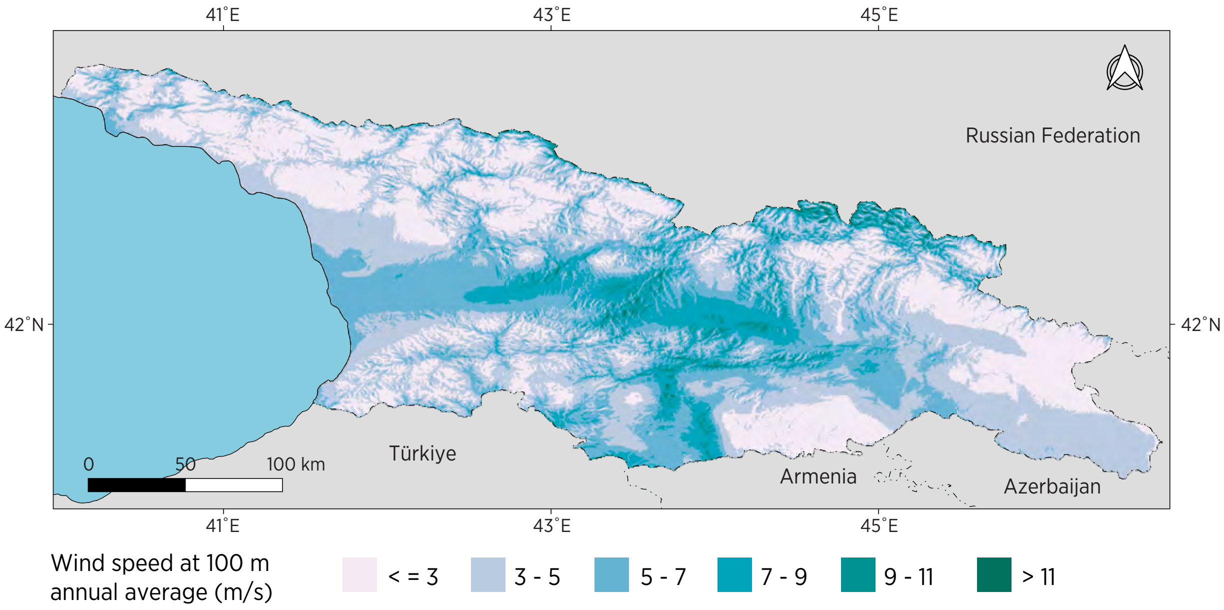
Both the average annual and average hourly long-term wind speeds, determined at different heights, constitute the wind resource data used in this analysis.

The annual average wind speed data were sourced from the Global Wind Atlas 3.0 (GWA 3.0) developed by DTU in collaboration with other international institutes (Figure 4). The dataset provides wind climatology layers at a 250 m grid cell resolution and hub heights of 50 m, 100 m and 200 m above ground level.

The layers were produced using DTU's Wind Atlas Analysis and Application Program (WAsP) micro-scale model with reanalysis data. Sources for the reanalysis data included Climate Forecasting System Reanalysis (CFSR), Climate Four-Dimensional Data Assimilation (C-FDDA), Modern-Era Retrospective Analysis for Research and Applications (MERRA), and the European Centre for Medium-Range Weather Forecasts Reanalysis (ECMWF). The data produced capture the small-scale spatial variability of wind speeds due to high-resolution terrain elevation, surface roughness, and the roughness change effects (Davis *et al.*, 2023).

Hourly long-term wind speeds and directions at hub heights of 10 m, 50 m and 100 m were extracted for each identified zone from the ECMWF's ERA-5 historical observations reanalysis database, at a resolution of approximately 30 km. These data cover the period from 1979 to within five days of the present time (ECMWF, 2019). For this assessment, data from 2010 to 2021 were obtained through Vortex. These data were used to calculate the TMY data, as explained in section 2.2. Since the reanalyses usually fail to represent local climatic conditions, due their coarse spatial resolution, they were corrected for spatial biases using the global wind atlas approach proposed by (Gruber *et al.*, 2020).

Figure 4 Annual average wind speed in Georgia



Source: Global Wind Atlas; (DTU, 2023); base map: UN boundaries.

Notes: km = kilometre; m = metres; m/s = metres per second.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

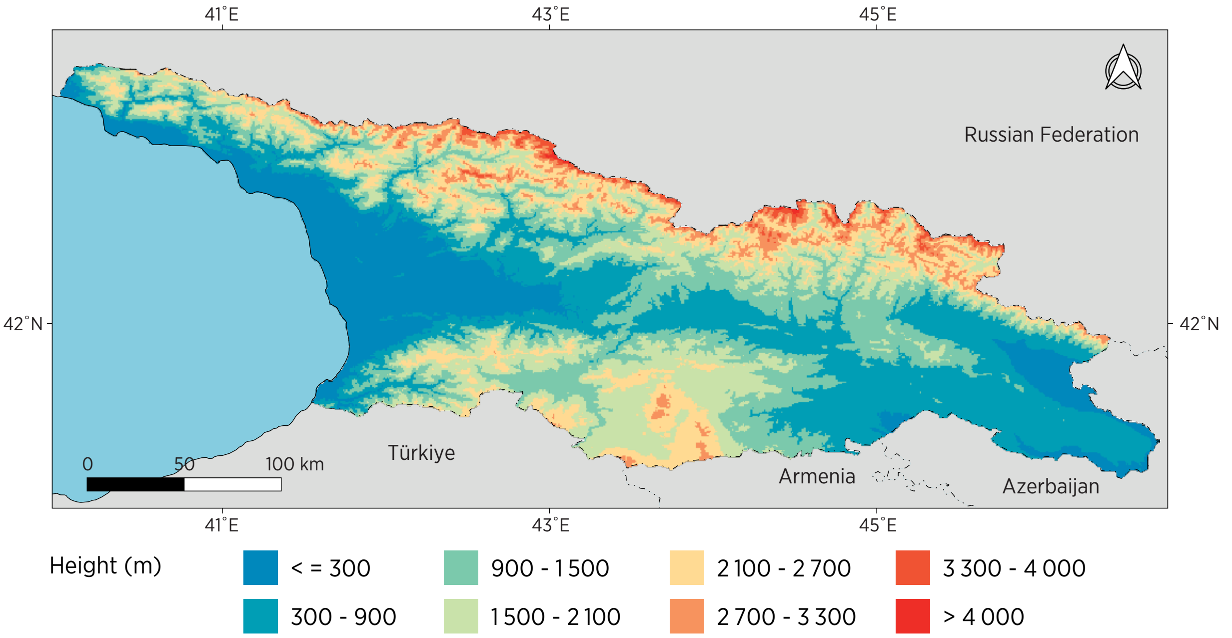
3.3. METEOROLOGICAL DATA

Additional, hourly long-term meteorological data, such as air temperature and pressure, were extracted for the zones identified for solar PV and wind projects from the ECMWF's ERA-5 and NASA's MERRA-2 datasets for dates between 2010 and 2021 (ECMWF, 2019).

3.4. TOPOGRAPHY

The digital elevation of land above sea level was drawn from the 90 m high-resolution digital topographic dataset developed in 2004 using data from the Shuttle Radar Topography Mission (SRTM). The dataset established the slope of the land areas, enabling the delineation of complex environments from which developments will likely be excluded. The topography considered for Georgia is shown in Figure 5.

Figure 5 Topography of Georgia



Source: SRTM digital elevation model (2008); base map: UN boundaries. Maps are also available from the IRENA Global Atlas for Renewable Energy.

Notes: km = kilometre; m = metre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

3.5. POPULATION DISTRIBUTION

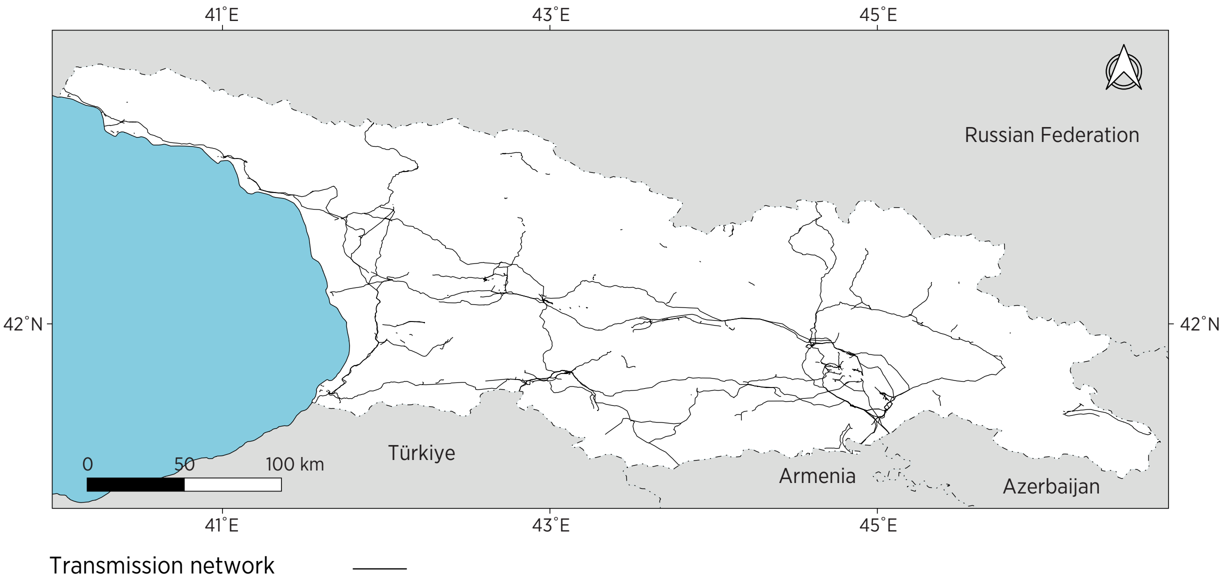
The population density layer considered in this study was sourced from the LandScan™ 2018 Global Population Distribution dataset produced by Oak Ridge National Laboratory (ORNL). These data are generated at approximately 1 km grid cell resolution and distributed by East View Geospatial. The data represent 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.

3.6. TRANSMISSION LINE NETWORK

The transmission network map used in this analysis was obtained from OpenStreetMap, as shown in Figure 6.

Figure 6 Georgia's transmission line network



Source: OpenStreetMap contributors (2022); base map: UN boundaries. Maps are also available from the IRENA Global Atlas for Renewable Energy.

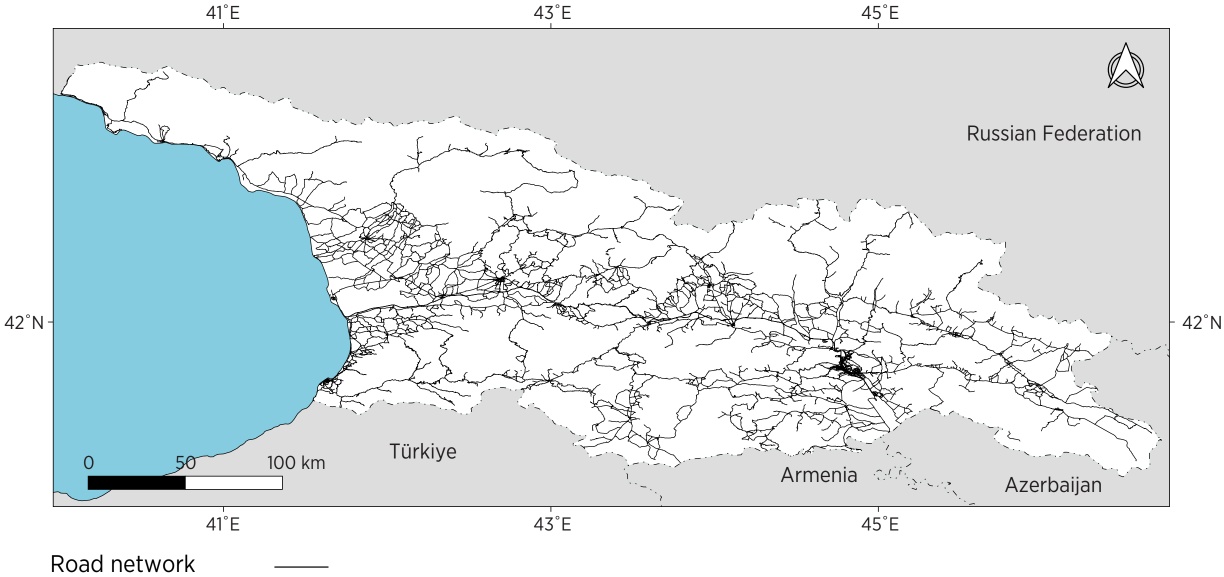
Note: km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

3.7. ROAD NETWORK

The road network considered in this analysis was extracted from the OpenStreetMap, which is collected by volunteers using GPS devices, aerial imagery and other free sources. The corresponding road network layer for Georgia is shown in Figure 7.

Figure 7 Georgia's road network



Source: OpenStreetMap contributors (2022); base map: UN boundaries. Maps are also available from the IRENA Global Atlas for Renewable Energy.

Note: km = kilometre.

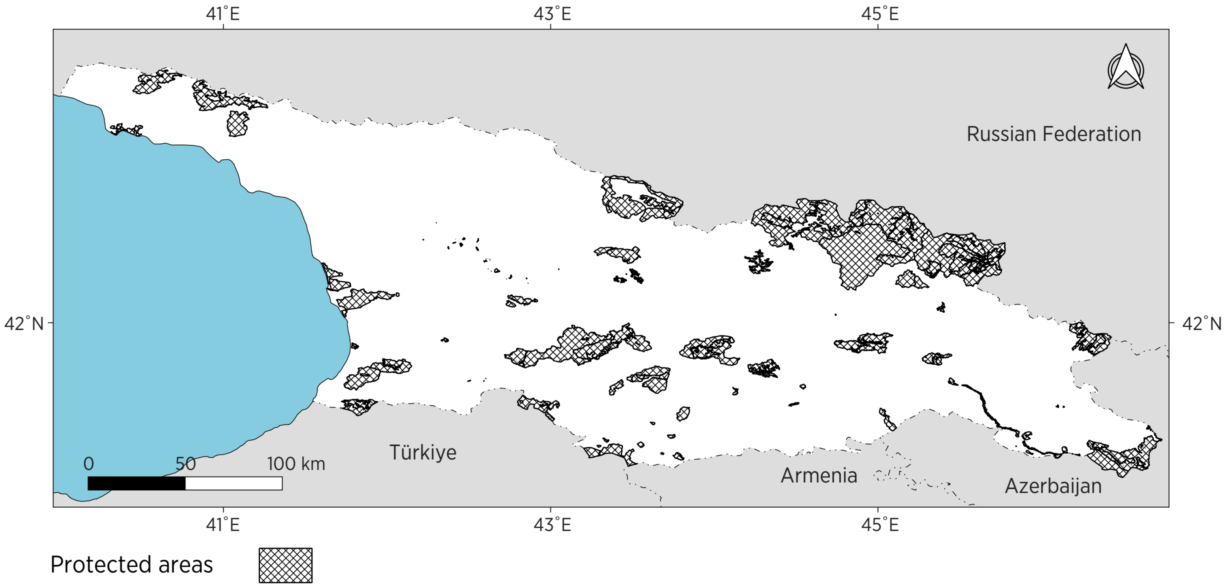
Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

3.8. PROTECTED AREAS

The terrestrial protected area considered in this analysis was provided by the country.

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 8.

Figure 8 Protected areas in Georgia



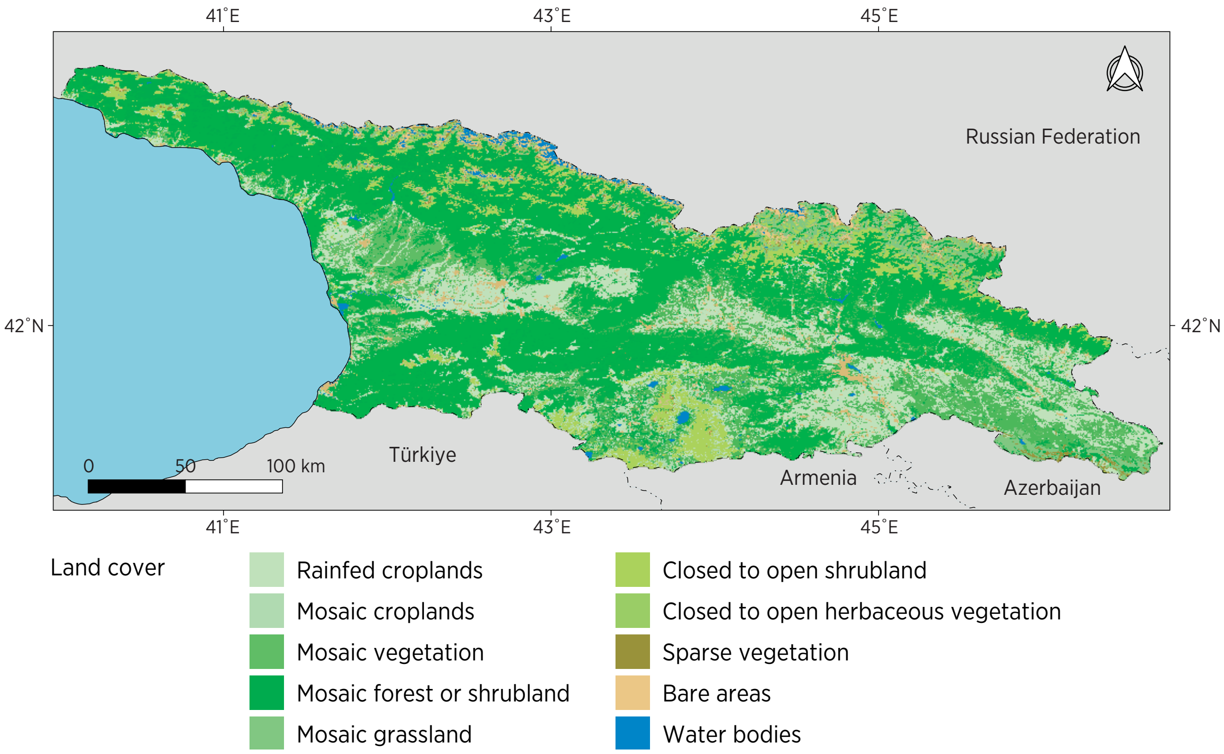
Source: Ministry of Environmental Protection and Agriculture (2024); base map: UN boundaries.
Note: km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

3.9. LAND COVER

The 2009 Global Land Cover Map (GlobCover) dataset represents the worldwide spatial distribution of 22 distinct land cover types, such as built-up areas, bodies of water, croplands and vegetation, at a 300 m 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% (Bontemps *et al.*, 2011). Figure 9 shows the land cover for Georgia.

Figure 9 Land cover in Georgia



Source: ESA Climate Change Initiative – Land Cover project (2017); base map: UN boundaries. Maps are also available from the IRENA Global Atlas for Renewable Energy.

Note: km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

3.10. ANCILLARY DATASETS

Several other inputs are required for this study, including:

- Technical equipment specifications for solar PV and wind turbines, obtained from the open access libraries pvlib[8] and windpowerlib.[9]
- Applicable project costs reflecting either local trends, which are obtained from countries, if available, or regional trends, which are reported values from project average costs referenced by IRENA's Costing Alliance.

8 *https://pvlib-python.readthedocs.io/en/latest/*

9 *https://windpowerlib.readthedocs.io/en/latest/*

4. ASSESSMENT RESULTS

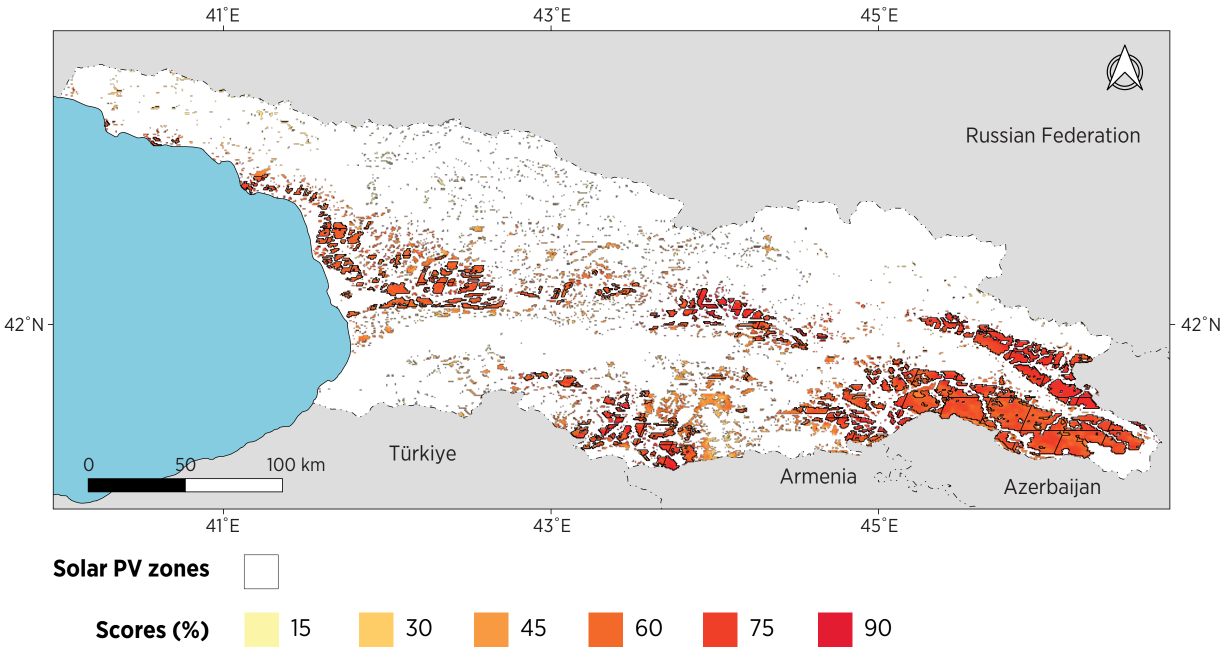
Georgia has a solar resource potential characterised by an average annual GHI of 1 350 kWh/m² (Figure 3) and low wind potential characterised by average onshore wind speed at 100 m height of 4.4 m/s (Figure 4). These renewable resource potentials, along with the technical, economic and socio-environmental criteria, have been used to identify and map the most promising zones for the deployment of utility-scale projects, including their corresponding techno-economic attributes, based on the zoning assessment approach described in section 2.

4.1. FAVOURABLE ZONES

The land suitability index and those zones with a high degree of feasibility for the deployment of solar PV (*i.e.* those with a suitability cut-off value exceeding 57%) and wind (*i.e.* those with a suitability cut-off value exceeding 50%) projects have been mapped in Figures 10 and 11, respectively. These figures show that the zones favourable for project development have the following characteristics:

- They are located along road and transmission line networks, while they are concentrated in the eastern, southern, central and western parts of the country for solar PV and central and southern and central parts for onshore wind.
- They cover a total area of 6 877 km² (*i.e.* ~9.9% of the country's total land) for solar PV and 795 km² (*i.e.* 1.14% of the country's total land) for onshore wind.

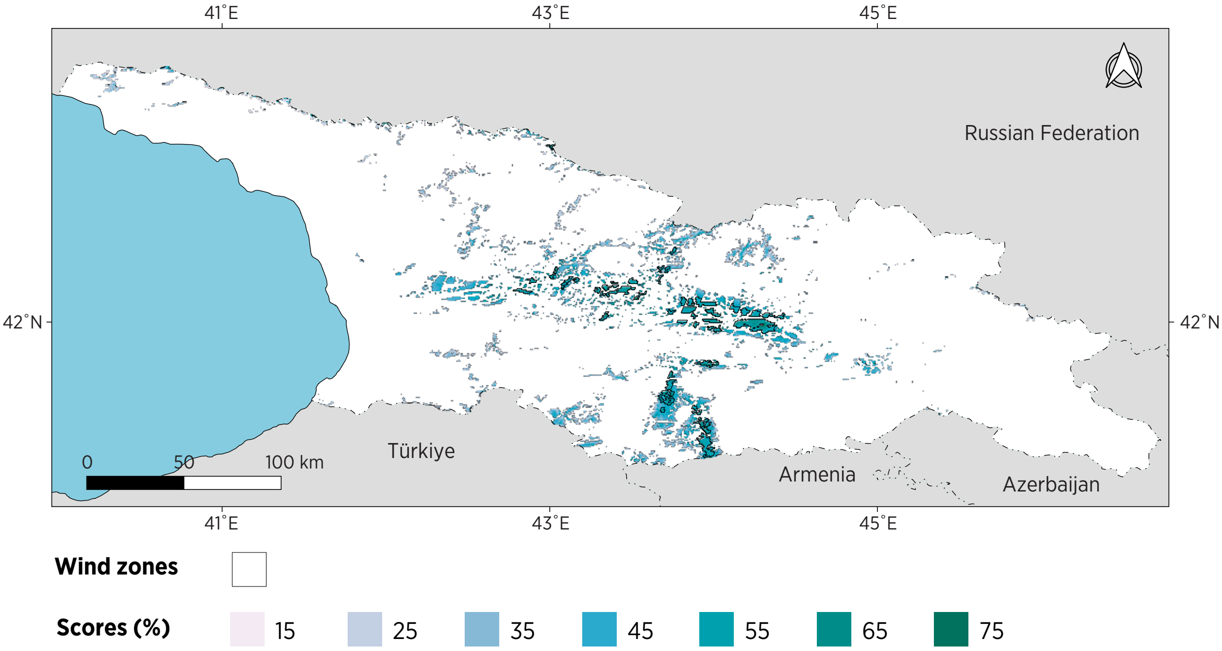
Figure 10 Land suitability index with the most promising zones for utility-scale solar PV projects



Source: base map: UN boundaries. Maps are also available from the IRENA Global Atlas for Renewable Energy.
Notes: PV= (solar) photovoltaic; km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

Figure 11 Land suitability index with the most promising zones for utility-scale onshore wind projects



Source: base map: UN boundaries. Maps are also available from the IRENA Global Atlas for Renewable Energy.
Note: km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

4.2. TECHNO-ECONOMIC ATTRIBUTES

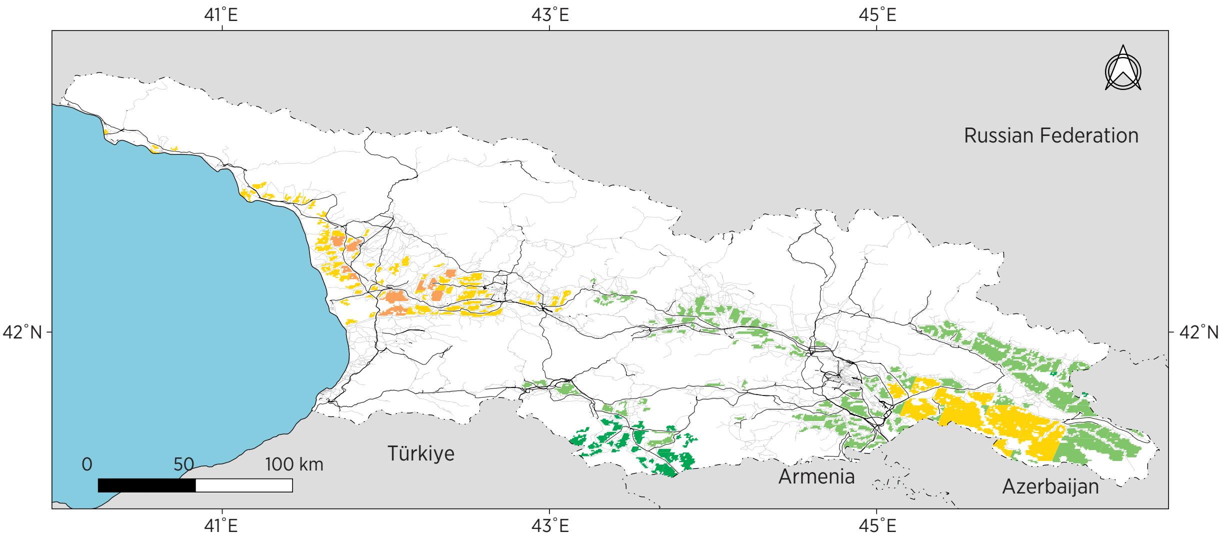
Table 4 summarises the techno-economic attributes of zones favourable for hosting utility-scale solar PV and onshore wind projects with the considered requirements for their calculations, while Figures 12, 13, 14, 15, 16, and 17 map the associated capacity factors, LCOE and distance to transmission lines. The road and transmission line networks and power plants (operating and under construction) are also shown in these figures.

These zones all have the following characteristics:

- A maximum development potential of approximately ~87 GW (267 zones) for solar PV and ~5.4 GW (46 zones) for wind projects, given maximum concentration capacities of 5 000 MW for both solar PV and onshore wind technologies, along with a land utilisation factor of 20-30% for solar PV and 15-20% for onshore wind (Table 4) (Eurek *et al.*, 2017). The highest development potentials are observed in the eastern region of the country for solar PV and central region for onshore wind (Figure 18). Of the total developable potential, 43.7 GW (distributed across 227 zones) of solar PV could have a project size of up to 500 MW per zone, and 2.15 GW (distributed across 21 zones) of onshore wind could have a project size of up to 200 MW (Figure 19).
- An annual electricity generation of ~137 902 GWh/year for solar PV and ~17 874 GWh/year for onshore wind (Table 4).

- A capacity factor that ranges between 16.8% and 19.9% for solar PV (Figure 12) and between 31.9% and 60.5% for onshore wind (Figure 13). Zones with capacity factors below 16% for solar PV and 20% for onshore wind have been discarded from the analysis. The zones for solar PV with capacity factors greater than 19% are located in Samtskhe-Javakheti and Kakheti regions and cover 573 km^2, while zones for onshore wind with capacity factors greater than 40% are limited to five zones sporadically spread in the central and north regions and cover 32 km^2.
- An LCOE that ranges between USD 49.5/MWh and USD 75.2/MWh for solar PV (Figure 14) and USD 35.6/MWh and USD 57.3/MWh for onshore wind (Figure 15). The zones for solar PV with LCOE below USD 55/MWh are located in Imereti, Kakheti, Kvemo Kartli, Mtskheta-Mtianeti, Samtskhe-Javakheti, Shida Kartli and Tbilisi regions and cover 5 249 km^2, while the zones for onshore wind with LCOE below 45/MWh are located in Imereti, Kvemo Kartli, Samegrelo-Zemo Svaneti, Samtskhe-Javakheti and Shida Kartli regions and cover 180 km^2.
- A distance to transmission lines for solar PV (Figures 16) and wind (Figures 17) project ranging between ~0.6 km and ~32.3 km.

Figure 12 Capacity factors of the most promising zones for utility-scale solar PV projects



Capacity factor (%) 16 - 17 | 17 - 18 | 18 - 19 | 19 - 20

Transmission network

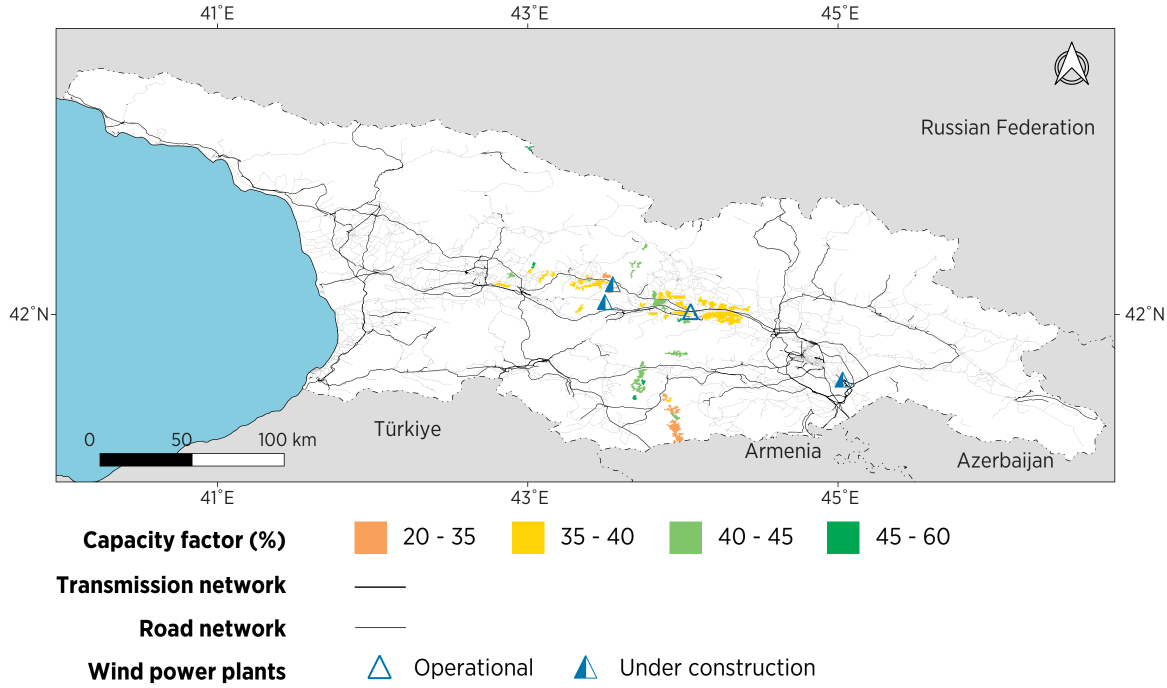
Road network

Source: transmission line network and road network: OpenStreetMap contributors (2022); base map: UN boundaries. Maps are also available from the IRENA Global Atlas for Renewable Energy.

Note: km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

Figure 13 Capacity factors of the most promising zones for utility-scale onshore wind projects

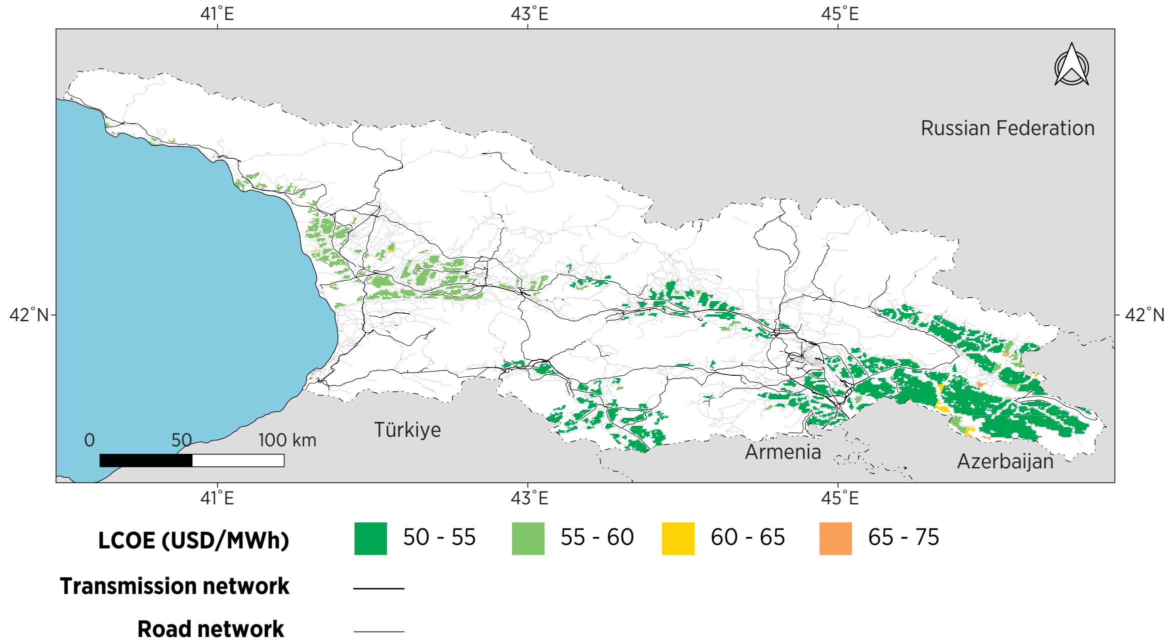


Source: wind power plants: The Wind Power (2023) and the Ministry of Economy and Sustainable Development of Georgia (2025); transmission line network and road network: OpenStreetMap contributors (2022); base map: UN boundaries.

Note: km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

Figure 14 LCOE of the most promising zones for utility-scale solar PV projects

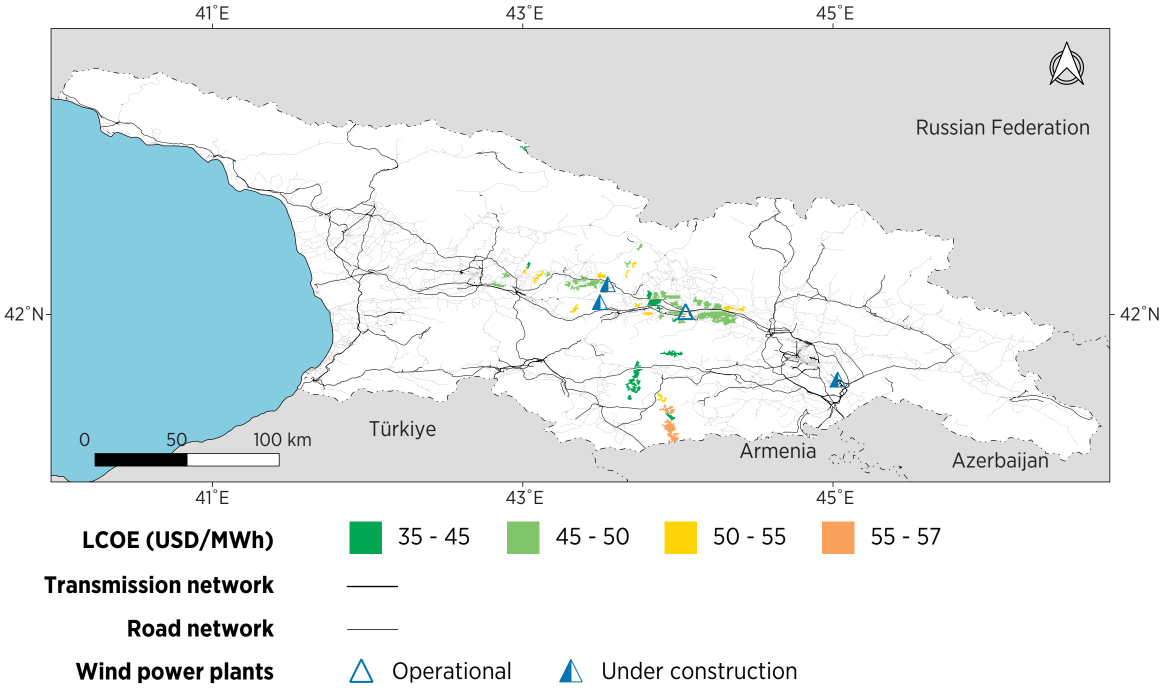


Source: transmission line network and road network: OpenStreetMap contributors (2022); base map: UN boundaries. Maps are also available from the IRENA Global Atlas for Renewable Energy.

Notes: LCOE = levelised cost of electricity; USD/MWh = United States dollars per megawatt hour; km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

Figure 15 LCOE of the most promising zones for utility-scale onshore wind projects

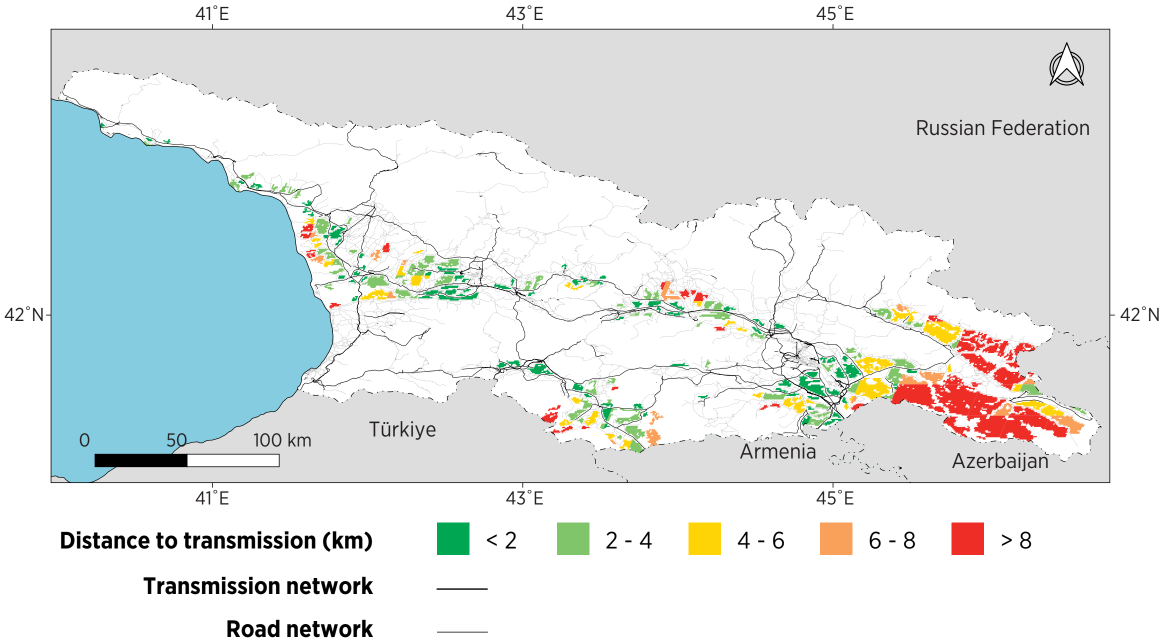


Source: wind power plants: The Wind Power (2023) and the Ministry of Economy and Sustainable Development of Georgia (2025); transmission line network and road network: OpenStreetMap contributors (2022); base map: UN boundaries.

Notes: LCOE = levelised cost of electricity; USD/MWh = United States dollars per megawatt hour; km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

Figure 16 Distance of the most promising zones for utility-scale solar PV projects to the nearest transmission lines

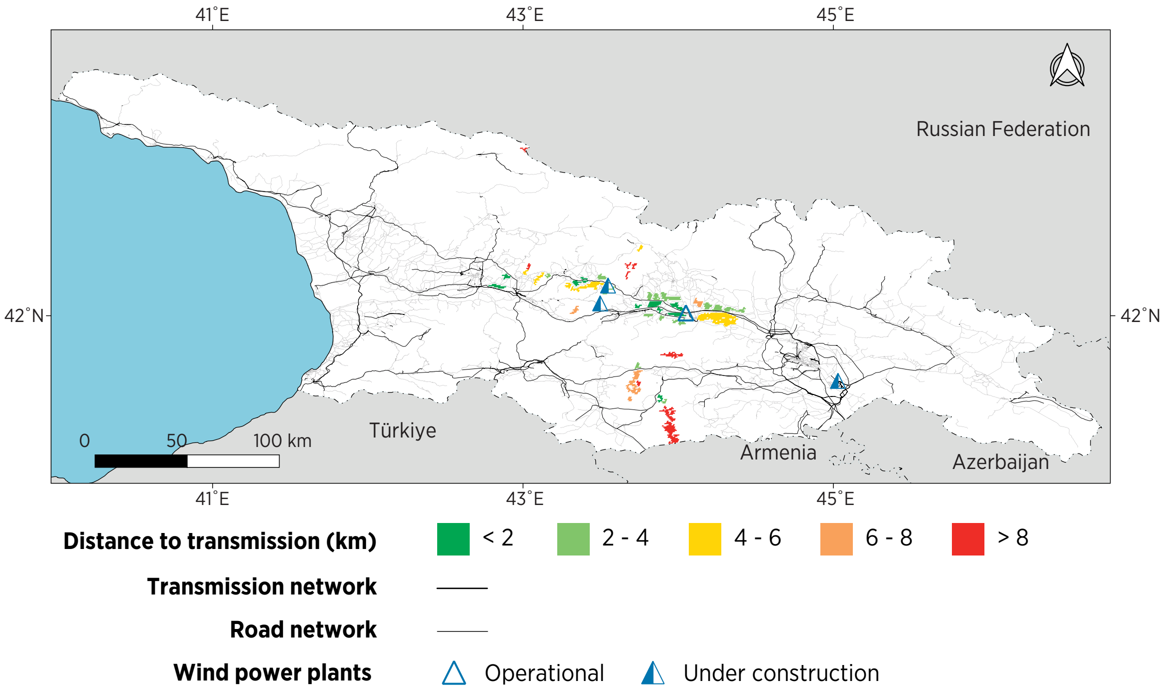


Source: transmission line network and road network: OpenStreetMap contributors (2022); base map: UN boundaries. Maps are also available from the IRENA Global Atlas for Renewable Energy.

Note: km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

Figure 17 Distance of the most promising zones for utility-scale onshore wind projects to the nearest transmission lines

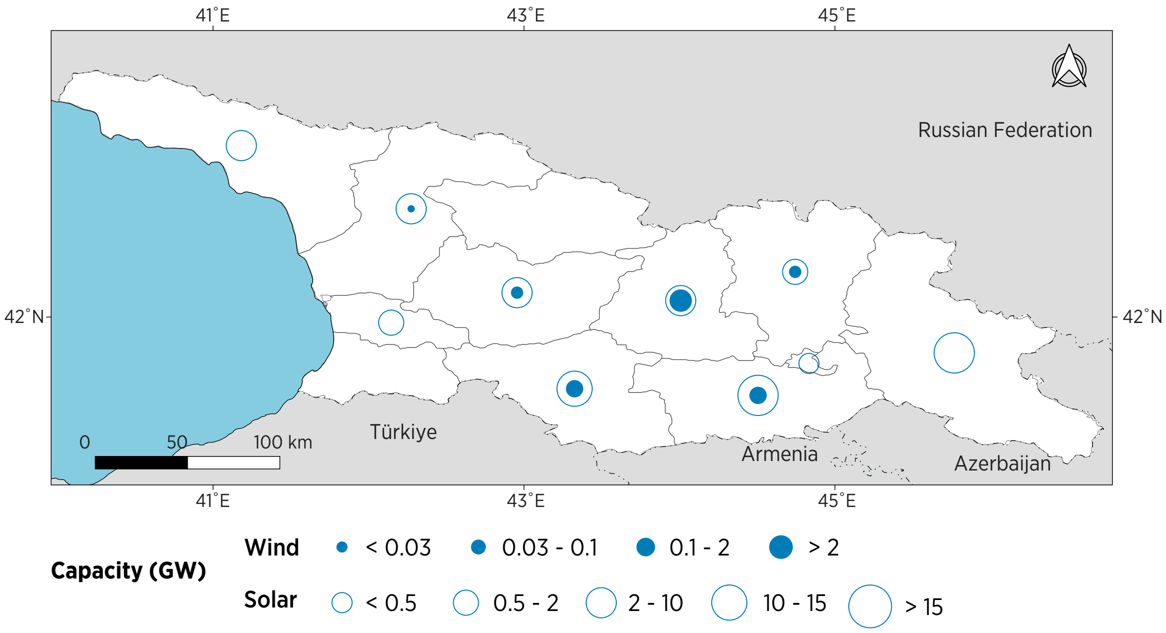


Source: wind power plants: The Wind Power (2023) and the Ministry of Economy and Sustainable Development of Georgia (2025); transmission line network and road network: OpenStreetMap contributors (2022); base map: UN boundaries.

Note: km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

Figure 18 Maximum development potential for utility-scale solar PV and onshore wind projects per region

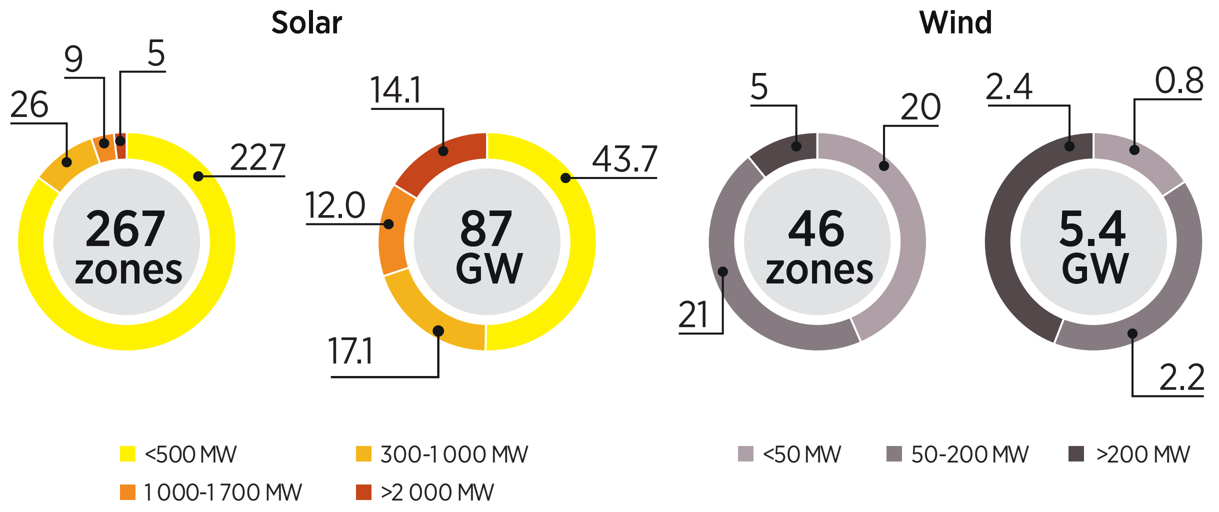


Source: region: GADM; base map: UN boundaries. Maps are also available from the IRENA Global Atlas for Renewable Energy.

Notes: GW = gigawatt; km = kilometre.

Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

Figure 19 Cumulative solar and wind potential vs. zonal capacity range



Notes: GW = gigawatt; MW = megawatt.

Notably, the results obtained demonstrate the following:

- The country has a considerable amount of solar PV (87 GW) and wind (~5.4 GW) development potential, enabling it to achieve its renewable targets through 2030, which are set at 5.289 GW in the National Energy and Climate Plan of Georgia, according to the Global Energy Monitor (2024).
- The country could increase its current renewable energy targets, especially for solar energy, where the development potentials are ~17 times higher than the current targets for solar PV and wind.
- The country has selected appropriate zones for deployed and commissioned utility-scale wind projects, which are geo-positioned on the resulting zones and attributes maps (Figures, 13, 15, and 17).[10] The upcoming wind project in Imereti 1, for instance, will have an installed capacity of 100 MW, while the near identified wind zone has an estimated installed capacity of 40 MW.

The maximum, country-wide development potential obtained from this analysis should be treated with caution, however, in light of the following limitations:

- The selection of the thresholds and cut-off values is subjective, and may vary depending on the opinions and experiences of the country's renewable energy planning experts.
- Proximity to a transmission line does not mean that a connection is assured, as it may already be operating at its maximum carrying capacity.
- All protected areas do not necessarily have the same level of protection, while sometimes local authorities reverse an areas' protected status.
- Other factors, such as air density, surface roughness, terrain complexity and wind direction, can 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.
- Verification of the results can be nuanced in consideration of the period in which the existing generators were commissioned, the maturity of the technology at that time and the motivations driving the development.

[10] *Data provided by the Ministry of Economy and Sustainable Development (MoESD) of Georgia.*

Table 4 Zoning assessment requirements and results

A. DATA SETTING		
Solar resource		
Annual global horizontal irradiation (GHI)	ESMAP	
Hourly global horizontal irradiance	MERRA2	
Wind resources – meteorology		
Yearly 100 m wind speed (WS)	Technical University of Denmark (DTU)	
Hourly 100 m wind speed and weather variables	ERA5	
Technical, financial, and socio-environmental data		
Power transmission line network	OpenStreetMap	
Road network	OpenStreetMap	
Topography	Shuttle Radar Topography Mission (SRTM)	
Population density	Oak Ridge National Laboratory (ORNL)	
Protected areas	Ministry of Environmental Protection and Agriculture – Georgia	
Land cover	Global Land Cover map (GlobCover)	
Equipment specifications	Open libraries	
Capital installation – solar PV/onshore wind	700/1 050	USD/kW
Operation installation – solar PV/onshore wind	6.6/31.3	USD/kW-year
Investment grid/road	732 919/225 000	USD/km
Maintenance grid	3.5	% of grid line cost
Maintenance road	4 680	USD/km-year
Discount rate	10	%
B. SUITABILITY ASSESSMENT		
Lower and upper bounds		
Annual global horizontal irradiation: {0; [0–100]; 100} %	{GHI<1 275; 1 275≤GHI≤1 600; GHI≥1 600}	kWh/m^2
Yearly wind speed at 100 m height: {0; [20–100]; 100} %	{WS<6.5; 6.5≤WS≤12; WS≥12}	m/s
Distance to the grid – solar PV: {0; [0–100]} %	{distance>100; 100≥distance≥0.1}	km
Distance to the grid – onshore wind: {0; [0–100]} %	{distance>100; 100≥distance≥0.3}	km
Distance to the road – solar PV: {0; [0–100]} %	{distance>30; 30≥distance≥0.1}	km
Distance to the road – onshore wind: {0; [0–100]} %	{distance>30; 30≥distance≥0.3}	km
Slope score for solar PV/onshore wind: {0; [0–100]} %	{slope≥11/30; 11/30>slope≥0}	%
Population density: {0; [0–100]} %	{habitants>500; 500≥habitants ≥0}	-
Protected areas: {0; 1}	{within the areas; outside the areas}	-
Land cover: {0; 1}	{within the areas; outside the areas}	-
Scores		
Solar PV {resource; distance grid/road; population; slope}	{0.41, 0.17, 0.06, 0.03, 0.33}	-
Wind {resource; distance grid/road; population; slope}	{0.52, 0.19, 0.05, 0.16, 0.08}	-
C. CLUSTERING		
Threshold for clustering		
Cut-off index – solar PV/onshore wind	57/50	%
Maximum concentration capacity – solar PV/onshore wind	5 000	MW
Installation density – solar PV/onshore wind	50/5	MW/km^2
Land utilisation factor	20-30/15-20	%

Table 4 Continued

Zones – solar PV		
Number of zones	267	-
Total area	6 877	km^2
Zones – onshore wind		
Number of zones	46	-
Total area	795	km^2
D. ZONE ATTRIBUTES CALCULATION		
Solar zone		
Development potential capacity	87	GW
Annual electricity production	137 902	GWh/year
Capacity factor [min, max]	[16.8, 19.9]	%
LCOE [min, max]	[49.5, 75.2]	USD/MWh
Proximity to substation [min, max]	[0.6, 32.3]	km
Wind zone		
Development potential capacity	5.4	GW
Annual electricity production	17 874	GWh/year
Capacity factor [min, max]	[31.9, 60.5]	%
LCOE [min, max]	[35.6, 57.3]	USD/MWh
Proximity to substation [min, max]	[0.6, 13]	km

Notes: Results are marked in red; GHI = global horizontal irradiation; GW = gigawatt; GWh = gigawatt hour; km = kilometre; km^2 = square kilometre; kWh/m^2 = kilowatt hours per square metre; LCOE = levelised cost of electricity; m= metre; m/s = metre per second; MW = megawatt; MW/km^2 = megawatt per square kilometre; PV = (solar) photovoltaic; USD/km = United States dollars per kilometre; USD/km = United States dollars per kilometre; USD/kW = United States dollars per kilowatt; USD/MWh = United States dollars per megawatt hour; WS = wind speed

5. CONCLUSION

In this report, the zoning assessment methodology has been adapted to local conditions in Georgia. This has allowed for the identification and mapping of the most promising zones, including their corresponding techno-economic attributes, for hosting utility-scale solar PV and onshore wind projects. These attributes include the zones' installed capacities, capacity factors, potential hourly and annual energy generation, LCOEs, and distances from transmission line networks. All these factors can help set priorities in the country's renewable deployment plan.

The key findings of this study are:

- There is significant potential for utility-scale solar PV and wind power development in Georgia. The maximum development potential across the country is estimated at approximately 87 GW and 5.4 GW for solar PV and wind projects, respectively, considering maximum concentration capacities of 5 000 MW for both solar PV and wind, with a land utilisation factor of 20-30% for solar PV and 15-20% for onshore wind. This potential can largely cover the current (and potential future revised) renewable targets through 2030, which are now set at 5.289 GW, according to the Global Energy Monitor (2024).
- Most of the solar PV and wind potential identified is located in the central, southern, southwestern and southeastern parts of the country, respectively, along the transmission line and road networks.

These findings are intended to prompt more in-depth investigation that will establish specific sites for detailed evaluation using high temporal and spatial resolution resource data. The limitations of this study must also be noted. These include the sensitivity of the land suitability maps to the assumptions 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.

However, Georgia can select promising sites within the areas identified by this study to submit to IRENA's site assessment service (Technical Assessment Services). This is a pre-feasibility assessment that determines the financial and technical viability of a site for solar PV and wind project development using 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.

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