ASSESSING AND MAPPING RENEWABLE ENERGY RESOURCES

2nd edition

LIDAR measurements in Ethiopia/3E

ABOUT ESMAP

The Energy Sector Management Assistance Program (ESMAP) is a partnership between the World Bank and https://esmap.org/donors 22 partners to help low- and middle-income countries reduce poverty and boost growth through sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated within the World Bank's country financing and policy dialogue in the energy sector. Through the World Bank Group (WBG), ESMAP works to accelerate the energy transition required to achieve https://sdgs.un.org/goals/goal7 Sustainable Development Goal 7 (SDG7) to ensure access to affordable, reliable, sustainable, and modern energy for all. It helps to shape WBG strategies and programs to achieve the WBG Climate Change Action Plan targets. Learn more at: https://esmap.org

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ABBREVIATIONS

ADB	Asian Development Bank
AFD	Agence Française de Développement (French Development Agency)
BEFS	Bioenergy and Food Security
ESMAP	Energy Sector Management Assistance Program
FAO	Food and Agricultural Organization (United Nations)
GIS	geographic information system
GSM	Global System for Mobile Communications
GW	gigawatt
IFC	International Finance Corporation
IRENA	International Renewable Energy Agency
ISA	International Solar Alliance
MapRE	Multi-criteria Analysis for Planning Renewable Energy
NREL	National Renewable Energy Laboratory
PV	photovoltaic
SEA/SESA	Strategic Environmental (and Social) Assessment
SRMI	Sustainable Renewables Risk Mitigation Initiative (ESMAP)
TOR	terms of reference
VRE	variable renewable energy
WB/WBG	World Bank/World Bank Group

All currency is in United States dollars (US$, USD), unless otherwise indicated.

INTRODUCTION

Understanding the location and potential of renewable energy resources is a crucial prerequisite to their utilization and to scaling up clean sources of electricity generation, such as biomass, geothermal, hydropower, solar, and wind. Such information is critical for policy development, including zoning guidance, shared infrastructure investments, generation, and transmission network planning, and estimating the cost of power. It is also heavily utilized by commercial project developers, where reliable data can help reduce the resource risk requested by lenders, and therefore the unit price for generated power.

This report draws on many years of experience within the World Bank Group (WBG) and among other development partners in carrying out renewable energy resource assessment and mapping, both globally and at the country level, and particularly from 12 projects funded by the Energy Sector Management Assistance Program (ESMAP) under a major global initiative that ran from 2012 to 2020.[1] This paper's purpose is to explain, for a wide range of audiences, the importance of resource assessment and mapping, and how to obtain and/or commission reliable resource data and potential sources for further advice and support.

The first edition of this report was published in April 2016, providing an overview of good practice at that time. Since then, the World Bank (WB), funded and led by ESMAP, has released the Global Solar Atlas and supported major improvements to the Global Wind Atlas. These web-based tools, and the underlying data sets, have fundamentally changed the landscape by making high quality solar and wind resource data available at no cost and at a global level. In response, this report has been revised and republished to update the advice provided to World Bank client countries, development partners, and other stakeholders.

STRATEGIC IMPORTANCE

Unlike with fossil fuels, generating electricity from renewable energy resources has to happen at, or near (in the case of biomass), locations with sufficient resource availability. This fact, combined with the direct correlation between the magnitude of the resource and the financial viability of the project, means that understanding which renewable energy resources exist where, to what extent, and how they complement each other is critical to scaling up commercial development in a planned and affordable manner. As part of the Sustainable Renewables Risk Mitigation Initiative (SRMI), the World Bank, in partnership with the International Solar Alliance (ISA), the French Development Agency (AFD), and the International Renewable Energy Agency (IRENA), developed the key steps that governments should follow to develop and implement renewable energy programs to mobilize private investments (World Bank; Agence Française de Développement; International Renewable Energy Agency; International Solar Alliance 2019). Resource assessment is a critical input to any sound and comprehensive generation and transmission planning exercise to identify future private investments that will be affordable and needed for the system. In addition to informing government policy, resource assessment is also utilized at a more granular level to inform individual project development decisions.

From the strategic perspective of governments, and the citizens and consumers they represent, the following objectives are likely to be important factors in obtaining and utilizing high quality resource data:

- Ensuring that commercial development is planned, coordinated, and focused on the best locations from a power system perspective, taking into account the magnitude and quality of the resource (capacity factor and temporal profile), proximity to demand centers, potential to reduce costs through the sharing of core infrastructure/transmission lines (e.g., developing hydropower with solar, or solar with wind, if their generation profiles are complementary), and streamlined permitting
- Obtaining good value for money when carrying out competitive bidding (sometimes called "auctions") through a better-informed regulator and off-taker, and by reducing the resource and regulatory risk for developers
- Avoiding or minimizing adverse environmental and social impacts by screening out sensitive locations, analyzing cumulative impacts, and facilitating transparent stakeholder engagement in the planning and investment process
- Identifying alternative and potentially competing uses of available natural resources and land to avoid conflicts and promote sustainable resource management
- Supporting grid stability by providing the data necessary to perform grid integration studies at the system level and grid interconnection studies for specific projects

Commercial developers benefit through well-informed government policies that support and guide private investment for new power plants, and by obtaining access to valuable (and in the case of solar, bankable) data that can be used for initial site identification purposes or to carry out prefeasibility analyses.[2] Publishing high quality resource maps, geospatial planning studies, and any underlying data sets in the public domain can help to level the playing field for participants in new or immature markets, crowd in more investors, and promote transparency in the project development process. For example, ESMAP supported the publication by the World Bank Group of a study on offshore wind potential in eight key markets (ESMAP 2019c), followed by a comprehensive mapping exercise covering 48 client countries (ESMAP 2020a). The resulting maps have been used by both governments and private developers in assessing opportunities for offshore wind development and have generated interest in countries not previously on the radar.

Finally, there are likely to be a range of potential users of the data produced from the wider academic and research community, including those working on meteorology, agriculture, or the study of long-term climate change. In many countries, the academic community can play an important role in supporting the long-term development of renewable energy, for example, by providing inputs to government policy and by addressing skills gaps for project development, construction, and operations.

In summary, assessing and mapping renewable energy resources are classic examples of public good, where a relatively small up-front investment can leverage very significant and diverse economic, environmental, and social benefits. It can be particularly valuable when combined with support on developing the right policies for private investment mobilization and utility-led generation planning exercises.

OBTAINING RESOURCE DATA

Until the launch of the Global Solar Atlas in January 2017 and an improved version of the Global Wind Atlas in November 2017, resource data for solar and wind were only freely available at a relatively low resolution from a combination of public and commercial providers, including the Global Atlas for Renewable Energy provided by IRENA (IRENA 2017). Such data were from a range of sources based on differing methodologies and were often outdated, patchy in coverage, and difficult to utilize.

To obtain higher resolution and more accurate resource data, countries needed to commission a resource assessment modeling study, but this was a costly exercise and such studies were limited. Due to high degrees of uncertainty in the resulting data sets, especially in parts of the world where good, quality, ground-based measurements were lacking, standard practice was to “validate” the modeled data by commissioning a ground-based measurement campaign over at least one year, with highly accurate monitoring equipment installed at multiple locations across the country.[3] The measurement data would then be used to assess the accuracy of the modeled data for the same period, potentially leading to adjustments or refinements in the modeling methodology that could be globally or regionally applied.

From 2013 to 2017, ESMAP provided funding for a series of World Bank–executed projects in support of client country governments to carry out extensive solar and/or wind measurement campaigns. This included the following country or regional projects:

- Bangladesh
- East Africa (encompassing Kenya, Tanzania, and Uganda)
- Ethiopia
- Malawi
- Maldives
- Nepal
- Pakistan
- Papua New Guinea
- Vietnam
- Zambia

The data from these projects have been made publicly available via the World Bank’s ENERGYDATA platform,[4] and the measurement sites are also displayed in the Global Solar Atlas[5] and Global Wind Atlas.[6] Some country government and development partners also carried out measurement campaigns,[7] and in a number of countries validation exercises have been carried out against previously generated resource data sets, or more recently, the Global Solar Atlas (ESMAP 2019b) and Global Wind Atlas (Technical University of Denmark 2020) data.

Since the launch of both the Global Solar Atlas and Global Wind Atlas, there are now globally available, harmonized data sets at no cost to end users, and a number of commercial and noncommercial providers have made available similar free-to-use tools. Furthermore, due to improvements in the input data and methodological advances, the resolution and accuracy of the data are now far superior to what was available previously. As a result, there is no need for any government, agency, development partner, or developer to commission or purchase solar or wind resource data for the purposes of planning, initial site investigation, or other purposes outlined earlier in this report. In fact, doing so represents a misuse of resources that may be better spent on improving the underlying modeling or validation data, or more downstream analyses.

Currently, there is no global atlas product for biomass, geothermal, or hydropower resources, although it may be possible to generate these in the future. Consequently, obtaining resource data for biomass, geothermal, and hydropower still requires a country or regional study, and, in the case of biomass, the results may need to be regularly updated due to changes in land use and agricultural production over time.

The following subsections provide further details on assessing and mapping each of the five renewable energy resources covered in this report.

BIOMASS

Biomass resource assessment and mapping can be complicated due to the diverse types of biomass that can be used for power generation. Biomass can be collected from agricultural and forestry (harvesting) residues, agriculture, wood processing industries, and municipal waste.

Each biomass type requires a specific methodological approach. As documented by the Food and Agriculture Organization of the United Nations (FAO), assessment of biomass resources must take into account competing uses and environmental sustainability issues to provide an accurate picture of the potential availability of biomass resources, so as to avoid creating conflicts with other biomass uses (FAO 2010).

ESMAP-funded World Bank projects on biomass assessment and mapping were carried out in Pakistan (completed in July 2016) and Vietnam (completed in August 2018). No further projects were carried out due to the complexity of implementing such activities and the limited uptake of the results by commercial developers.

A typical scope of work involves the following steps:

Phase 1

- Identification and specification of biomass resources to be assessed, considering the specific context being analyzed
- Stakeholder and data identification to pre-identify as much existing data as possible
- Use of earth observation data to highlight key areas of interest and to develop a plan for data gathering (existing and foreseen land use plans can be consulted too)

Phase 2

- A combination of field surveys, site visits, questionnaires, and consultative events to verify any data gaps in existing national or local data sets, and to validate the earth observation data

Phase 3

- Matching of the field and other data to the earth observation data to produce spatial and point source resource availability data sets, and ultimately create a Biomass Atlas

To understand real biomass availability, it is important to gain a clear understanding of local uses, including seasonal patterns. Obtaining regular feedback on emerging results is likely to be very important in mapping biomass resources, which are highly contingent on data collection, availability, quality, and data interpretation. One approach that the World Bank adopted in both Pakistan and Vietnam is commissioning universities for field data collection, thereby bringing important domestically anchored institutions into the projects and also building capacity throughout the process. This is crucial for biomass mapping, which requires national ownership and regular updating to remain relevant.

GEOTHERMAL

An initial assessment and mapping of geothermal resource potential does not require extensive or costly work, but understanding the resource is the first step to minimize the resource risk associated with exploration drilling, which is capital intensive and generally undertaken only at the most promising sites. Geothermal resource estimation requires a methodological approach to data gathering and interpretation, as well as presentation (IGA Service GmbH 2014), and can be split into two distinct phases:

Phase 1: Preliminary Survey

The first phase involves a study assessing the already available evidence for geothermal potential, including a literature review of:

- Geological, hydrological, and/or hot spring/thermal data
- Drilling data (including gas, oil wells, if available)
- Accessibility, distance to grid connection, and land use issues
- Key environmental and social issues/factors
- Anecdotal information from local populations
- Remote sensing data from satellites, if available

The objective of this phase is to demonstrate the existence and extent of the geothermal resource and identify priority sites for further studies.

There is currently no global atlas showcasing geothermal potential. So far, assessment and mapping of geothermal resources has been conducted on a country level or case-by-case basis. ESMAP has funded projects on resource mapping for Indonesia (World Bank 2014) and Central America (World Bank 2012), as well as other efforts to make international data available on preliminary surveys, including the IRENA Global Atlas for Renewable Energy and the United Nations Framework Classification for Resources (UNFC),[8] which ESMAP also supported.

Phase 2: Exploration

The objective of the second phase is to cost effectively reduce risks related to the resource characteristics, such as temperature, depth, productivity, and sustainability, through further exploration studies prior to exploration drilling (often called “test drilling”). The site or sites of exploration should be selected from the preliminary prioritization established in Phase 1; and the work begins with gathering data from existing nearby wells and other surface manifestations and goes on to surface and subsurface surveying

TABLE 1: GEOTHERMAL STUDIES REQUIRED TO IDENTIFY CANDIDATE SITES FOR EXPLORATION DRILLING

SURFACE STUDIES	GEOCHEMICAL SURVEYING	GEOPHYSICAL SURVEYING
Gathering local knowledge	Geothermometry	Gravity
Locating active geothermal surface features	Electrical conductivity	Electrical resistivity
Assessing surface geology	pH	Magneto telluric
	Flow rate of fluids from active features	Temperature gradient drilling (if applied)
	Soil sampling	2D and 3D seismic

Source: Original figure for this publication.

using geological, geochemical, and geophysical methods. Table 1 lists the main geothermal studies to be conducted. While these are ongoing, there is a simultaneous effort to collect key background (or baseline) information for environmental studies.

By the end of Phase 2, sufficient data should have been collected and analyzed to select sites and targets for the first exploration wells. The developer should have a good understanding of the risks remaining around resource temperature and size, depth, permeability, productivity, and sustainability, and these risks will have been reduced to a level to justify drilling. Results after this stage should include site selection, target of the first exploration wells, a preliminary estimate of the resource with initial conceptual and numerical models, and a decision on whether to continue.

Various data from Phases 1 and 2 are brought together to prioritize and map out the geothermal potential to create a geothermal strategy. Since geothermal resource uncertainty is not eliminated in Phases 1 and 2, explorational drilling is needed to attract financing for full power plant development. This phase of the assessment is capital intensive and, because of the remaining perceived risk, is difficult to finance (Gehringer and Loksha 2012). Thus, the World Bank and other international financial institutions have supported countries, such as Indonesia and Turkey, with a risk-sharing mechanism to attract both private and public developers to initiate exploration drilling. It is not until after the drilling of a few wells that the resource is fully understood and potentially "bankable" in terms of development of a geothermal power plant.

HYDROPOWER

Assessing and mapping small hydropower resources are often comparatively neglected in countries with large hydropower resources, as most attention is focused on the large watersheds and rivers. This can lead to underutilization of resources that may make a small contribution to the national electricity supply in capacity terms, but, due to their distributed nature, could make a much larger contribution to improving rates of electricity access, by allowing for mini grids to be set up in locations off the main electricity network. This is what is being seen in Liberia, Madagascar, Nepal, Rwanda, and Tanzania, where there are hundreds of potential small hydropower sites near off-grid communities. This distributed potential adds up to a globally significant resource, which has been estimated at 173 gigawatts (GW) (Liu, Masera, and Esser 2013).

ESMAP-funded World Bank projects in the Democratic Republic of Congo, Indonesia, Madagascar, Tanzania, and Vietnam focused on small hydropower assessment and mapping, whereas in the Lao People's Democratic Republic an assessment of large and small hydropower resources was carried out. This latter approach may be helpful in highlighting tradeoffs between development of a smaller number of large hydropower sites versus more extensive development of medium or small hydropower sites, particularly environmental and social impacts.

As with biomass, the hydropower resource assessment under the above projects followed three phases:

Phase 1

Hydropower mapping is limited in what can be achieved using earth observation data and modeling, and will often require, relative to other resources, more extensive site visits to properly identify the potential. The basis for hydropower resource assessment is to map slopes and flow data for the river systems, which is usually conducted through geographic information system (GIS) modeling during Phase 1. Inputs to the analysis are a Digital Elevation Model and historical point stream flow data, which is extrapolated to river stretches with high slopes using catchment area characteristics. If observed stream flow data are scarce, a hydrological model using rainfall records may be required.

Phase 2

The suitability of a location for hydropower is very dependent on site-specific factors, such as geological features, environmental and social considerations, access, and distance to transmission connection points or local load centers. Although some of these factors can be included in the GIS modeling exercise, Phase 2 for hydropower mapping is likely to involve site visits by geological and hydrological experts. These site visits would include a visual assessment of site-specific key factors and a limited measurement of stream flow, soil, and riverine sediment transport. The combination of measured and modeled data for the potential hydropower sites provides a better estimation of the resource minimum and maximum levels in the mid to long term.

Installing stream gauges as part of a hydropower assessment and mapping project may only be partially useful due to the high variability in rainfall between years and the likely time constraints on the exercise. However, for the most promising sites such installations may provide inputs for subsequent feasibility assessment and detailed design to be carried out by potential developers.

Phase 3

In Phase 3, as for biomass mapping, the various data sources would be brought together to produce an integrated Hydropower Atlas that includes earth observation data on high potential areas, plus more specific data that may indicate sites of potential interest. The final study may also include a more in-depth analysis to provide public authorities and commercial developers with the data needed to further investigate, and potentially develop, the highest priority sites.

SOLAR

Solar power development is and increasingly high priority for countries that want to take advantage of what is now a least-cost source of power generation in many countries (IEA 2020; IRENA 2020). However, with the existence of the Global Solar Atlas and other free tools, further public investments in the assessment of solar resource potential can be focused on zones or sites of high potential, and on systemwide planning to ensure that development occurs in the optimal locations.

For commercial developers and lenders, the need for accurate resource data increases in relation to the size of the development being considered, as small differences in resource potential will have a big and absolute impact on revenues for the largest projects. Conversely, accuracy is less of an issue for solar home systems, mini grids, rooftop solar, or smaller utility-scale projects, where the economics are frequently dictated by balance-of-system costs and other factors, than by the amount of sunlight available (and for which project financing is usually not available). According to an ESMAP working paper, installation of a solar meteorological station at a prospective site for 1 GW of solar photovoltaic (PV) capacity could lower the tariff by up to 6 percent, leading to an economic savings of up to US$89 million (Knight and Tabassum 2019).

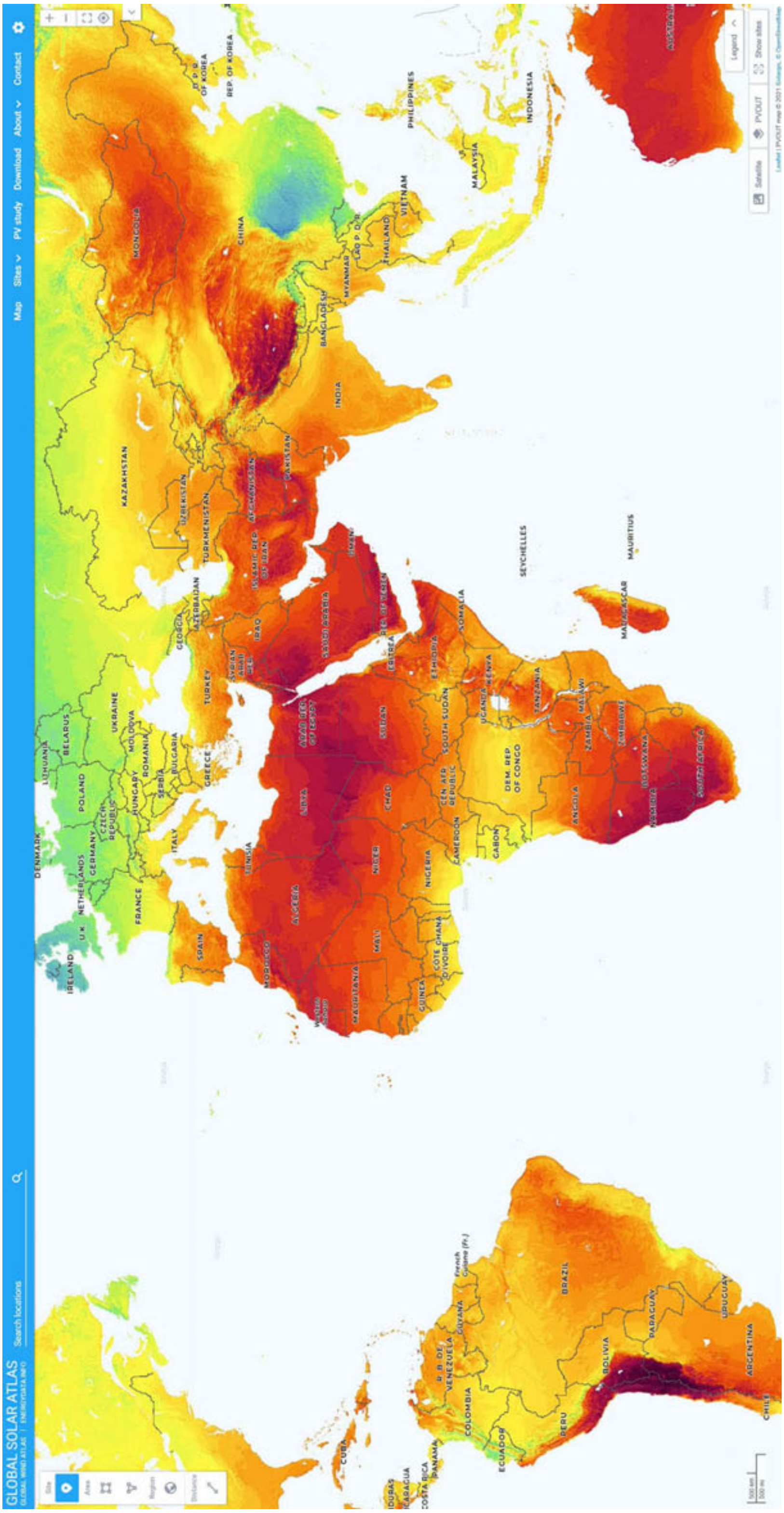
Global Solar Atlas

The Global Solar Atlas was launched by the World Bank Group, thanks to funding from ESMAP, in January 2017, and benefited from a major upgrade in October 2019, with additional updates thereafter (see Figure 1). A full description of the methodology and data available from the Global Solar Atlas is available on the website and is further described in the accompanying Technical Report (ESMAP 2019b). A Validation Report is also available that describes the validation carried out using measurement data from ESMAP-funded World Bank solar measurement campaigns (ESMAP 2019a).

In summary, the Global Solar Atlas provides the following:

- Global solar radiation data at 1 kilometer (km) resolution
- Web-based tools for site queries and analyses
- Monthly average hourly data and site profile data for download
- Downloadable maps for countries and regions, and user-generated maps
- Details on global measurement sites
- A mapping of hydro-connected PV potential, recognizing the potential for hybridization of these two renewable energy resources where existing hydropower capacity exists

FIGURE 1: GLOBAL PHOTOVOLTAIC POWER POTENTIAL



Source: Global Solar Atlas.

Time Series Data

For some applications, such as hourly or subhourly resolution power system optimization models, or for solar plant optimization and design tools, time series data may be required. Free tools such as the Global Solar Atlas will generally only provide average hourly values by month, or annual average data. This will not be suitable for applications that require greater granularity. For example, in building a least-cost capacity expansion model, it is important to understand the historical variation in the solar resource for theoretical or real sites to understand how the power system will handle the variability of solar generation output. While there are several free sources for time series data, many users will procure such data from a commercial provider, where the underlying data sets are enhanced with every year of additional satellite data collection.

Ground-Based Measurement Data

To improve the accuracy of the modeled solar data available in tools, such as the Global Solar Atlas and from commercial providers (as time series data), it is necessary to utilize high accuracy measurement data from as many sites as possible within a country or region over a period of at least one year, with two or more years preferred. Ground-based measurement data are also necessary for a project feasibility assessment of larger solar generation projects and may be required by financiers as part of their due diligence.

Carrying out a solar measurement campaign will usually require installation of dedicated solar measuring stations, some of which look very much like standard meteorological stations except with extra equipment added (see Figure 2). The number of stations required depends on several factors, but in general the objective is to take measurements from at least one location within each identified climatic zone, which can be identified in consultation with solar data providers. In many medium-sized countries, this might mean around 10 measurement stations, if the country has poor existing data.

However, with the increasing accuracy of solar resource modeling, countries may decide to skip the step of commissioning a broad, nonsite-specific solar measurement campaign, and instead opt to install solar measurement stations at sites already identified as having a strong potential for solar power generation. If the data from such installations are made publicly available, then many of the same benefits can be achieved, with the data utilized by academic and commercial entities to improve and validate their solar resource models.

Many options exist in terms of equipment specification and configuration: from high accuracy thermopile radiometers (preferred in locations where daily cleaning is possible), to rotating shadowband radiometers (preferred in more remote locations where daily cleaning is unlikely), to simpler sensors that only measure global horizontal irradiance (GHI).[9] Further technical details and guidance can be found in a report published by the United States (US) National Renewable Energy Laboratory (Sengupta et al. 2017), and in the terms of reference (TOR) published by the World Bank (ESMAP 2020c).

Data will usually be transmitted using mobile phone networks Global System for Mobile Communications (GSM) or a satellite link to the equipment operator, who can periodically check the data for anomalies and errors, which can then be flagged. Best practice is for the data to be published or made easily accessible on an ongoing basis—for example, monthly during the measurement campaign. The World Bank Group's ENERGYDATA platform can provide free hosting for high quality solar measurement data and already provides access to such data from a number of measurement campaigns (World Bank Group 2020).

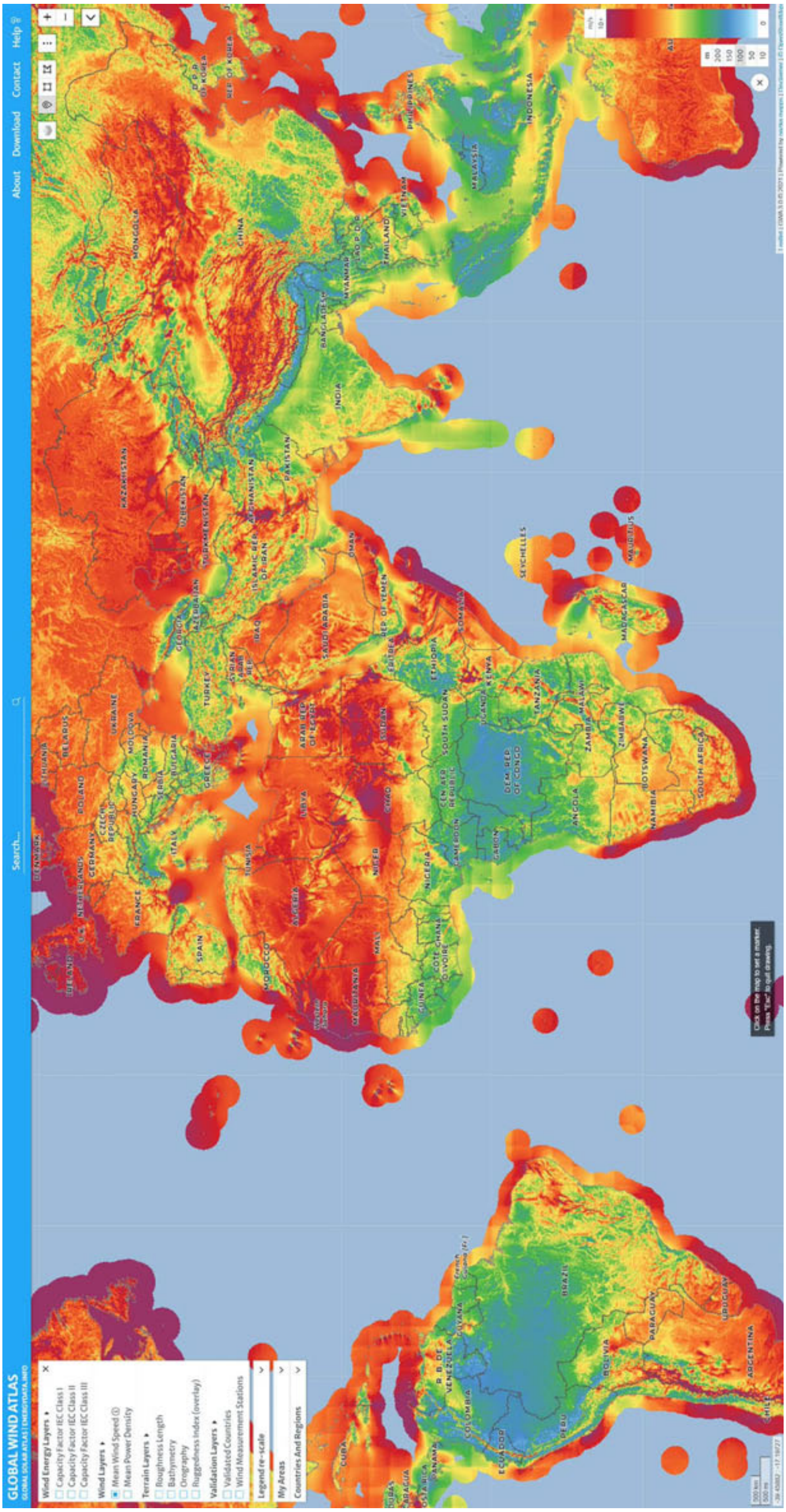
FIGURE 2: SOLAR MEASUREMENT STATION, VIETNAM

Source: Suntrace GmbH.

WIND

Wind resource assessment has benefited from many years of study and methodological improvements, but it is also one of the more complex due to the highly localized nature of wind resources both between and within countries. Because of the effect of topography, land cover, and obstacles within any area of interest, the viable wind resource can vary significantly within a single grid cell, even if the cell itself is in a high wind climatic zone.

Until the publication of the Global Wind Atlas, it was generally considered necessary for countries to carry out a mesoscale wind mapping exercise to obtain a good picture of their wind resource potential (ESMAP 2018). This approach, which was carried out globally for the Global Wind Atlas development, is intended to take into account regional weather systems and larger land features to produce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Mean Wind Speed
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Terrain Layers
Roughness Length
Bathymetry
Orography
Ruggedness Index (overlay)
Validation Layers
Validated Countries
Wind Measurement Stations
Legend re-scale
My Areas
Countries And Regions

a “generalized wind climate” for each cell in a country, from which more detailed estimations can be performed (see Figure 3). The input data are derived from global reanalysis data sets such as ERA5 (European Centre for Medium-Range Weather Forecasts 2020) and Modern-Era Retrospective-Analysis for Research and Applications, Version 2 (MERRA-2) (National Aeronautics and Space Administration 2019), which provide hourly estimates of a large number of atmospheric, land, and oceanic climate variables. As a result, the computing requirements to carry out mesoscale modeling are very intensive, with the mesoscale modeling for the Global Wind Atlas requiring around four months of processing on a dedicated computer cluster (Vortex FdC 2018).

Following the mesoscale modeling stage is microscale modeling, which adds in more localized effects such as topography, surface roughness, and turbulence. This requires further computing resources to produce the final data set of wind resource potential with a better horizontal resolution.

Global Wind Atlas

The Global Wind Atlas was first released by the Technical University of Denmark (DTU) in 2015 as part of a research project. With funding from ESMAP, and in partnership with the World Bank, a completely revised version (2.0) of the Global Wind Atlas was published in November 2017, including a new user interface. A further major upgrade (3.0), also funded by ESMAP, including fresh mesoscale and microscale modeling, was published in October 2019 with a microscale resolution of 250 meters (m) and coverage out to 200 km offshore, followed by another update (3.1) in March 2021. The Global Wind Atlas has been validated with data from six countries (Bangladesh, Maldives, Pakistan, Papua New Guinea, Vietnam, and Zambia), and efforts continue to improve the underlying data, the user interface, and add new tools (Technical University of Denmark 2020).

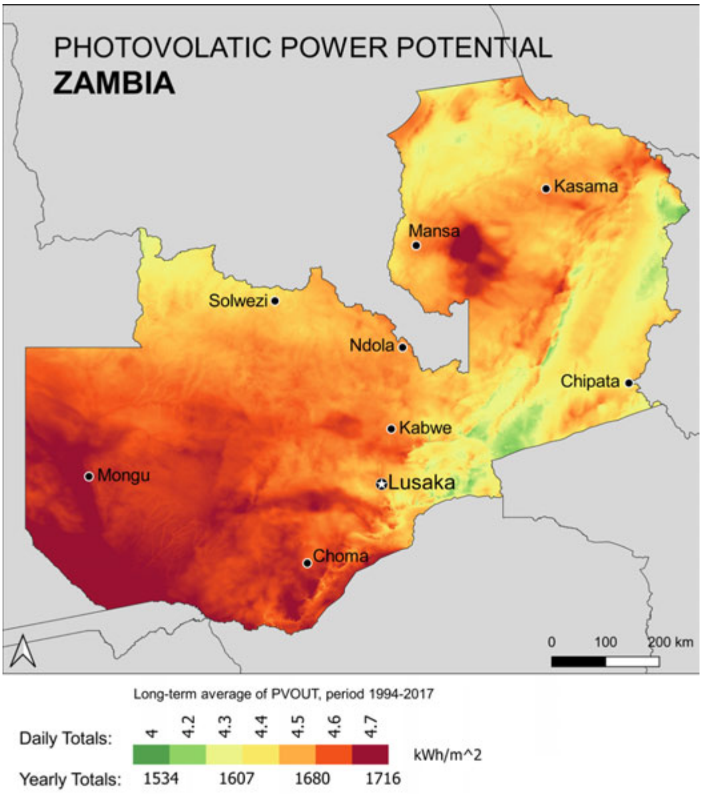
Time Series Data

As for solar, it is sometimes necessary to obtain time series data for the wind resource in multiple locations across a country or region to carry out more sophisticated modeling or for power system planning purposes. However, unlike solar, wind data are much more locationally specific, and it may be necessary to do some preliminary analyses to determine likely sites for wind power development before ordering or downloading time series data. Furthermore, the data will likely be far more useful if delivered as an estimated energy yield for each time period, rather than as wind speeds. A number of factors go into determining the energy yield, including the height, type of turbine, and layout of the prospective wind farm. It may not be possible or strictly necessary to accurately model the latter variable for the types of modeling that would be carried out, but it is important to be aware of these factors.

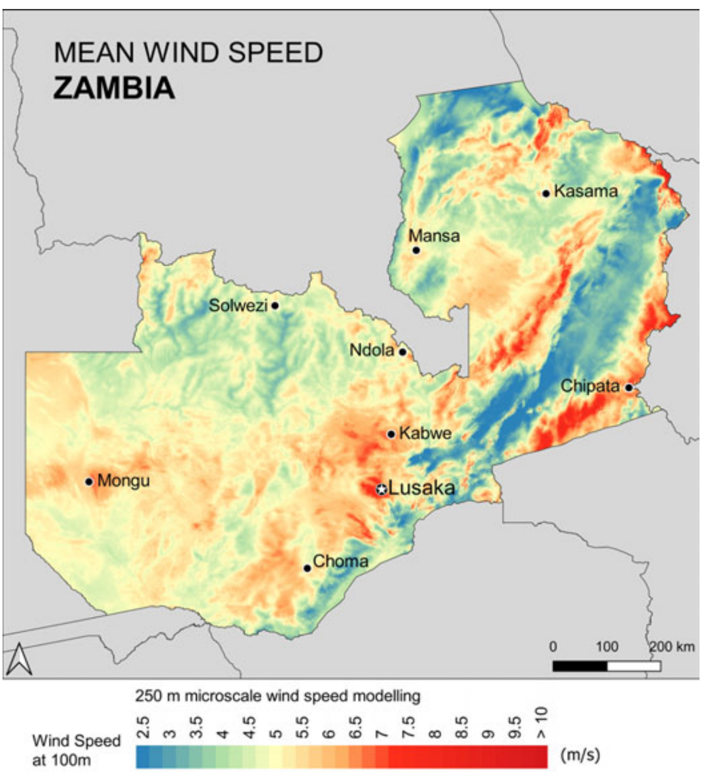
Ground-Based Measurement Data

Unlike solar, it is virtually unheard of to develop a wind farm project without having at least a year of ground-based measurement data from a high quality measurement campaign. Until recently, this has meant installation of wind measurement masts, and for larger projects, or a higher degree of reliability, more than one such mast would be installed on a site. However, there is increasing acceptance among wind project financiers of laser imaging, detection, and ranging (LIDAR) devices, either used in isolation (i.e., for offshore wind measurement campaigns, which are much more expensive), or to help provide additional data from heights above ground level that can be reached economically using tall meteorology masts (see Figure 4).

FIGURE 3: SOLAR AND WIND POSTER MAPS: ZAMBIA



Source: Global Solar Atlas.



Source: Global Wind Atlas.

FIGURE 4: WIND MEASUREMENT STATION (LIDAR)

Source: 3E.

A standard wind measurement mast will consist of a lattice or tubular tower, upon which wind speed measurements (using anemometers) will typically be taken at vertical intervals of 20 m above ground level. The industry standard height at the time of writing is 80 m (with anemometers at 20 m, 40 m, 60 m and 80 m), although taller masts up to 120 m are now being used by some developers. Shorter masts may be more appropriate in certain circumstances (e.g., islands with limited land area or areas of high hurricane risk, where a tilt-up mast is required). The wind mast will also be equipped with wind vanes (for determining the wind direction), sensors for temperature, barometric pressure, humidity, lightning protection, a power source (usually a small solar panel and battery), and a data logger connected to a GSM or satellite connection for data transfer. The mast will usually be protected against vandalism and theft by fencing and anticlimbing measures and will include aircraft warning features. As masts are best installed in rural locations without major wind obstacles, they tend to be situated in more remote regions where security can be an issue. A common approach is to find land that is already protected (e.g., on a research campus), or a location where the land can be leased from a nearby private owner, who then has an interest in protecting the site and the equipment installed.

ENSURING HIGH STANDARDS IN MEASUREMENT CAMPAIGNS

The value of measurement data is highly dependent on the quality of the measurement campaign itself, both in terms of the equipment and implementation standards, but also documentation and data archiving. It is, therefore, important that projects are well designed and commissioned to the highest standards so that funds are efficiently used and the outputs have a long shelf life. In effect, this means the following:

- Adopting **international standards** where they exist and ensuring that all specifications meet or exceed those applied by commercial lenders when assessing project proposals (this is often referred to as ensuring the data are "bankable")
- Using high quality, calibrated **measurement equipment** and ensuring a high data recovery rate
- Ensuring **methodological transparency,** so that the outputs can be properly analyzed or reconfigured by others
- Ensuring that all generated outputs (including documentation and metadata) are **freely and widely accessible,** and adopting open data principles (Open Knowledge Foundation 2015) where relevant
- Commissioning **experienced firms** to carry out the core technical work while also building in-country capacity

In our experience, substandard campaigns stem from one or more of the above conditions not being applied. There are numerous examples of solar and wind measurement campaigns carried out using high quality equipment, but where the accompanying documentation is not provided or is of poor quality, rendering the data virtually worthless because users are unable to determine the coordinates, methodology, equipment used, or other key variables.

Making an early commitment to open data principles at the start of the project can be a good way to build confidence and stimulate interest in the data. In some cases, a cost recovery model may be necessary—for example, by requiring commercial developers to pay a reasonable fee for access to the most valuable data sets—but this should be done fairly and consistently while potentially exempting certain public interest users (academia, policy makers, etc.). A further benefit of open data (particularly data that goes back many years) is that data may be utilized for multiple other purposes that were not envisaged by the commissioning entity, such as for academic or meteorological studies. However, there are risks that need to be considered, particularly the possibility of land speculation where high potential resources are discovered that are perhaps not known to, or understood by, the respective landowner(s) or local communities. This should be less of a risk over time, as awareness of areas with high wind resource potential increases.

In preparing for the close of a resource mapping project, implementing agencies may want to explore ways of transferring ownership of meteorological equipment (relating to solar and wind mapping projects) to universities, industry associations, private data providers, or specialized agencies, so that the sites are maintained and long-term reference data continues to be generated by a wind reference mast.

If a developer measures wind for a limited period of time, typically a year, in reasonable proximity to a concurrently operating reference mast, the two data sets can be correlated. This procedure allows the developer to "hindcast" the new data series to the entire period where the reference mast has been operating, thus creating a long-term data set for the wind farm site, with a very low degree of uncertainty, and consequently, a very high degree of bankability. In the World Bank's experience, equipment handover has proven difficult to implement due to the recurring cost of maintaining the equipment and the risks of it falling into disrepair. Under such circumstances, it may be better to design the contract for implementing the measurement campaign to require the contracted firm to remove all equipment at the end of the project, thus, enabling them to factor in any secondhand or resale value, and removing any residual liabilities on the project sponsor.

GEOSPATIAL AND LOCATIONAL PLANNING

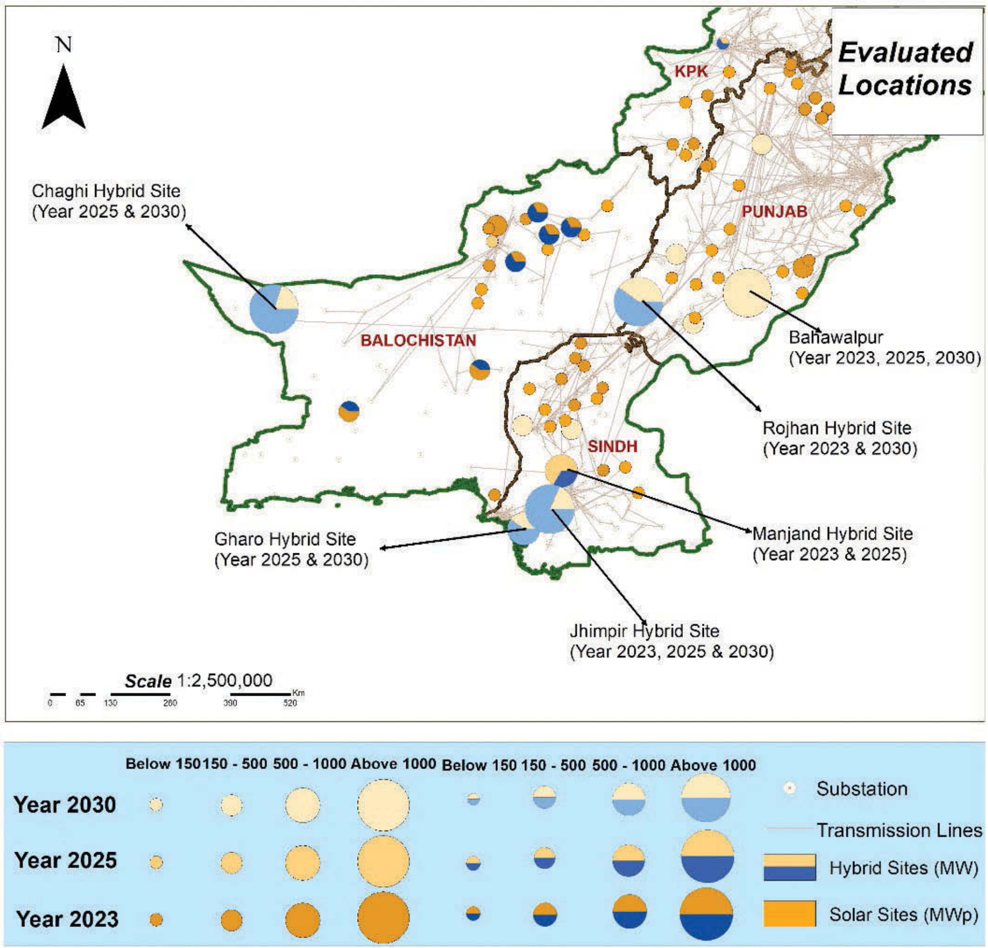
As presented further in the SRMI guidelines for solar deployment, carrying out renewable energy resource assessment and mapping should not be seen as an end in itself, but as an input into a broader and ongoing process of policy development and power system planning (generation and transmission). While renewable energy resource data are useful for awareness raising and initial prospecting, the real value comes from utilizing such data to carry out "locational studies" that then integrate other factors and constraints (including grid load flow analysis by substation) to identify zones or priority areas for development.[10] In some countries this is a formalized process—such as, the Strategic Environmental (and Social) Assessment (SEA or SESA) required under European Union law (Loayza 2012)—but in other cases, it may require a dedicated study to be commissioned. A locational study or SESA allows for consideration of the existing or planned transmission grid, exclusion zones (e.g., military or national parks), major load centers, and cumulative environmental or social impacts—such as those affecting migratory avian species, or uneven burdens affecting one or more communities, tribes, or indigenous peoples. For example, a country may have three zones with high wind energy potential, but one of these is in a national park with fragile fauna, and another is far from existing transmission lines and load centers, meaning that only one of these zones is viable for development.

Locational studies with variable renewable energy (VRE) integration analyses are a critical input to the planning of transmission expansion, upgrades, and generation, and in helping to ensure long-term system stability especially as the penetration of VRE increases (ESMAP 2019d; World Bank; Agence Française de Développement; International Renewable Energy Agency; International Solar Alliance 2019). A good practical example is a study that was carried out by the World Bank in Pakistan that modeled the electricity system using hourly data for several "spot" years to determine the optimal level of solar and wind capacity that should be installed over the coming decade (World Bank 2020).

The inherent spatial variability of renewable energy resources makes them particularly well suited to geospatial analysis and other systematic planning processes. These will often benefit from concerted stakeholder and community engagement to raise awareness, generate buy-in to what is being proposed, and ensure the early identification of adverse impacts or other issues. An excellent example is provided by South Africa, which undertook an SEA on solar and wind development following a comprehensive resource mapping exercise (Council for Scientific and Industrial Research 2020). Another example is a recent locational study on solar and wind in Pakistan (World Bank 2021), which involved consultations with the grid operator, provincial energy departments, and local distribution supply companies (Figure 5).

For the developers themselves, having a well-informed government tender policy with clearly stated zoning guidance with integration availability at substations enhances the bankability of projects, shortens project timelines, and reduces the risk profile of the investment. With this in mind, there is significant

FIGURE 5: GEOSPATIAL PLANNING MAP, PAKISTAN



Source: World Bank 2021.

potential for easily accessible software tools to simplify the process of conducting an initial geospatial analysis. A collaboration between IRENA and the Lawrence Berkeley National Laboratory created the Multi-criteria Analysis for Planning Renewable Energy (MapRE) tool, which used off-the-shelf GIS software to carry out zoning studies, and was initially applied in Africa and India (Lawrence Berkeley National Laboratory 2021). The tool was also deployed by World Bank teams in Afghanistan (World Bank Group 2018), Nicaragua, and Vietnam (Cornieti, et al. 2018). More recently ESMAP, in collaboration with the University of California–Santa Barbara, is supporting the development of an interactive, web-based platform based on MapRE that will help identify, visualize, and rank zones that are most suitable for the development of solar, wind, and offshore wind projects. The Renewable Energy Zoning Tool will be powered by global geospatial data sets and use baseline assumptions as default values for economic calculations, while providing users with the option to customize the spatial and economic filters to best represent the specific country context. It is important to use the MapRE tool in parallel to a full VRE integration analysis to identify space in the grid for integration of new generation, as well as to identify potential investments needed for the grid stability.

ADVICE AND SUPPORT

Although a significant number of developed and developing countries have carried out renewable energy resource assessment and mapping studies, this can still be a highly complex area for governments or specialized national agencies to navigate, and small errors can be costly later on. Thankfully, support is available from a number of institutions, and there is a growing network of international experts that can assist countries that want to commission work in this area.

ASIAN DEVELOPMENT BANK

Under their Quantum Leap in Wind Power Development Initiative, the Asian Development Bank (ADB) has supported wind resource assessment in three countries (Mongolia, the Philippines, and Sri Lanka), along with other project development activities (ADB 2018). As part of this work, ADB produced a guide to undertake a project-specific wind resource assessment, which will be of particular relevance to governments and commercial developers (ADB 2014).

FOOD AND AGRICULTURE ORGANIZATION

To promote a sound and integrated approach to sustainable bioenergy development, including biomass to power, FAO, in collaboration with other partners, has developed a Bioenergy Support Package (FAO 2021), including a Decision Support Tool for Sustainable Bioenergy (FAO 2010). The package includes different elements that can be used independently or in combination, relevant to different aspects of the energy and agriculture nexus and to different stages of the decision-making process. A key part of the package includes the Bioenergy and Food Security (BEFS) Approach (FAO 2014), which supports countries in formulating and implementing sustainable bioenergy development policies and strategies, derived from country-level information and cross-institutional dialogue involving relevant stakeholders. The BEFS Approach includes two sets of methodologies and tools to conduct an assessment of the sustainable bioenergy potential, an initial level called the BEFS Rapid Appraisal and a more in-depth level called the BEFS Detailed Analysis.

INTERNATIONAL RENEWABLE ENERGY AGENCY

IRENA provides a Global Atlas for Renewable Energy, which was upgraded to version 3.0 in 2017 (IRENA 2017). While IRENA does not currently fund or carry out resource assessment studies, their Global Atlas brings together a large number of solar and wind resource assessment studies.

NATIONAL RENEWABLE ENERGY LABORATORY

The National Renewable Energy Laboratory (NREL) of the United States (US) has been supporting and carrying out renewable energy resource assessment and mapping for over three decades, both within the US and internationally. Jointly with the United Nations Environment Program (UNEP), they implemented the Solar and Wind Energy Resource Assessment (SWERA) program (OpenEI 2018), which carried out mainly desk-based modeling of solar and wind resource potential in over 10 countries from

2005 to 2010. More recently, NREL has published the National Solar Radiation Database (NSRDB) to provide solar resource data primarily for the United States, but with international coverage of Central America and South Asia (NREL 2019). NREL has active programs on resource assessment and geospatial planning, supported by the US Department of Energy and the US Agency for International Development (USAID). NREL also produces useful guidance documents and technical publications on resource assessment.

WORLD BANK GROUP

The World Bank and the International Finance Corporation (IFC)—collectively the World Bank Group—have supported many countries with renewable energy resource assessment and mapping studies, as part of lending operations and also via grant-funded technical assistance. In 2013, ESMAP established a global initiative on Renewable Energy Resource Assessment and Mapping, providing a combination of technical support and grant funding for World Bank-executed technical assistance projects in 12 countries (ESMAP 2020b). Under this initiative, ESMAP has invested in standardized TOR for solar and/or wind measurement campaigns (ESMAP 2020c), supported the development of the Global Solar Atlas and Global Wind Atlas, and published a number of related knowledge products.

ENDNOTES

[1] Further details can be found on the ESMAP website. The initiative covered biomass, hydropower, solar, and wind resources. A separate initiative covered geothermal resources.

[2] In some cases, such as smaller solar photovoltaic plants, freely available public data may be sufficient for full project planning and financing purposes.

[3] Further details of the process for wind modeling can be found in the ESMAP Working Paper, "*Guidance on Mesoscale Wind Mapping"* (ESMAP 2018).

[4] https://energydata.info

[5] https://globalsolaratlas.info

[6] https://globalwindatlas.info

[7] For example: The German Agency for International Copperation (GIZ) supported a wind measurement campaign in Vietnam from 2012–2014; the Pacific Power Association is currently implementing a solar and wind measurement campaign in the Pacific Islands with funding from Small Island Developing States Docking station (SIDS-DOCK); and the World Bank is financing a solar measurement campaign being implemented by the West Africa Power Pool in 14 countries.

[8] https://unece.org/sustainable-energy/unfc-and-sustainable-resource-management

[9] This is an option for extending the measurement campaign, or potentially taking solar measurements from already existing meteorological sites.

[10] The concept of locational studies is explained further in the report "A Sure Path to Sustainable Solar: Solar Deployment Guidelines" (World Bank; Agence Française de Développement; International Renewable Energy Agency; International Solar Alliance 2019).

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ESMAP MISSION

The Energy Sector Management Assistance Program (ESMAP) is a global knowledge and technical assistance program administered by the World Bank. It provides analytical and advisory services to low- and middle-income countries to increase their know-how and institutional capacity to achieve environmentally sustainable energy solutions for poverty reduction and economic growth. ESMAP is funded by Australia, Austria, Denmark, Finland, France, Germany, Iceland, Lithuania, the Netherlands, Norway, Sweden, and the United Kingdom, as well as by the World Bank. https://esmap.org

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