ESMAP

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).

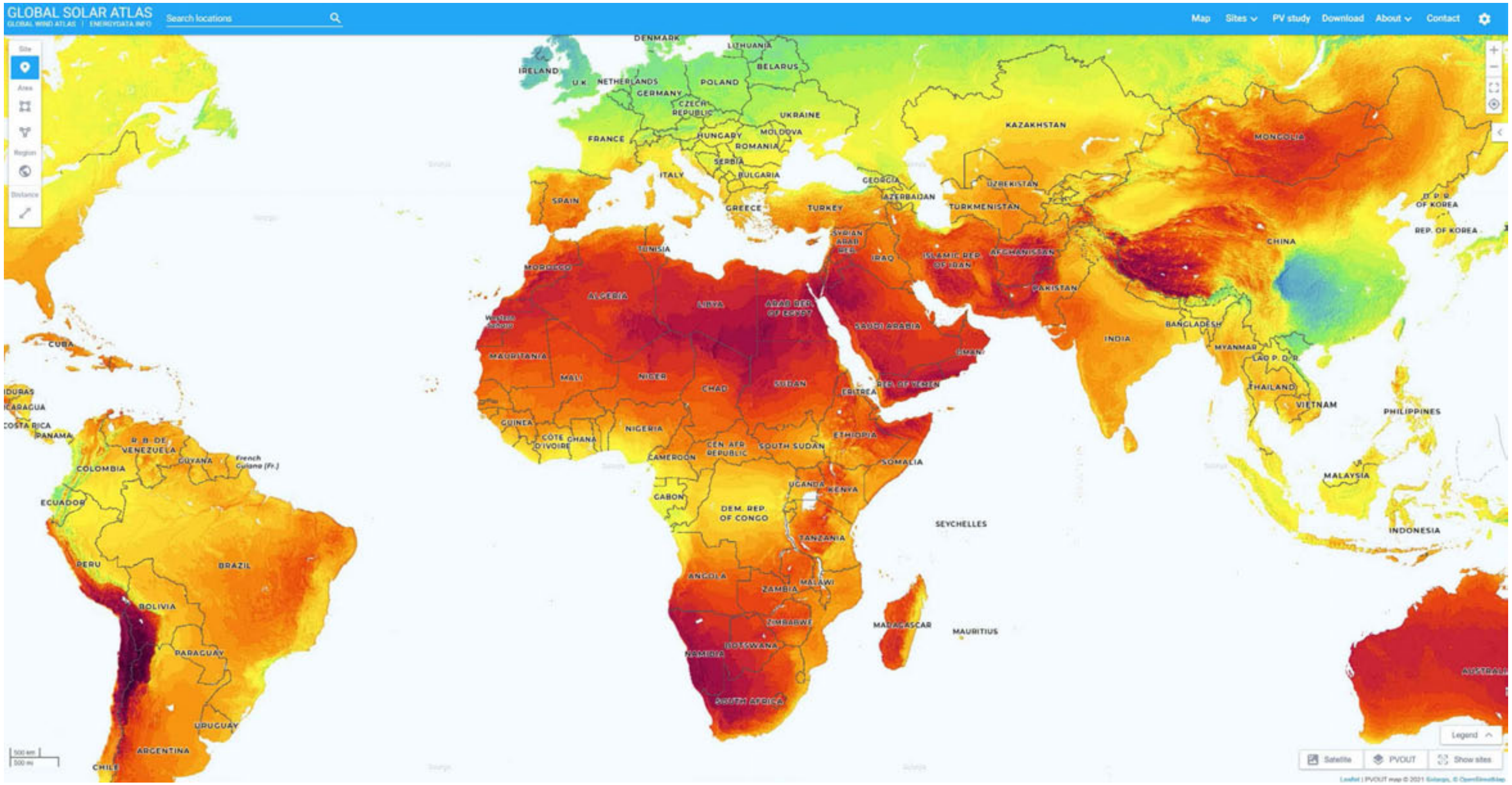
Global Solar Atlas

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