ESMAP

Energy Sector Management Assistance Program

Knowledge Series 025/16

Assessing and Mapping Renewable Energy Resources

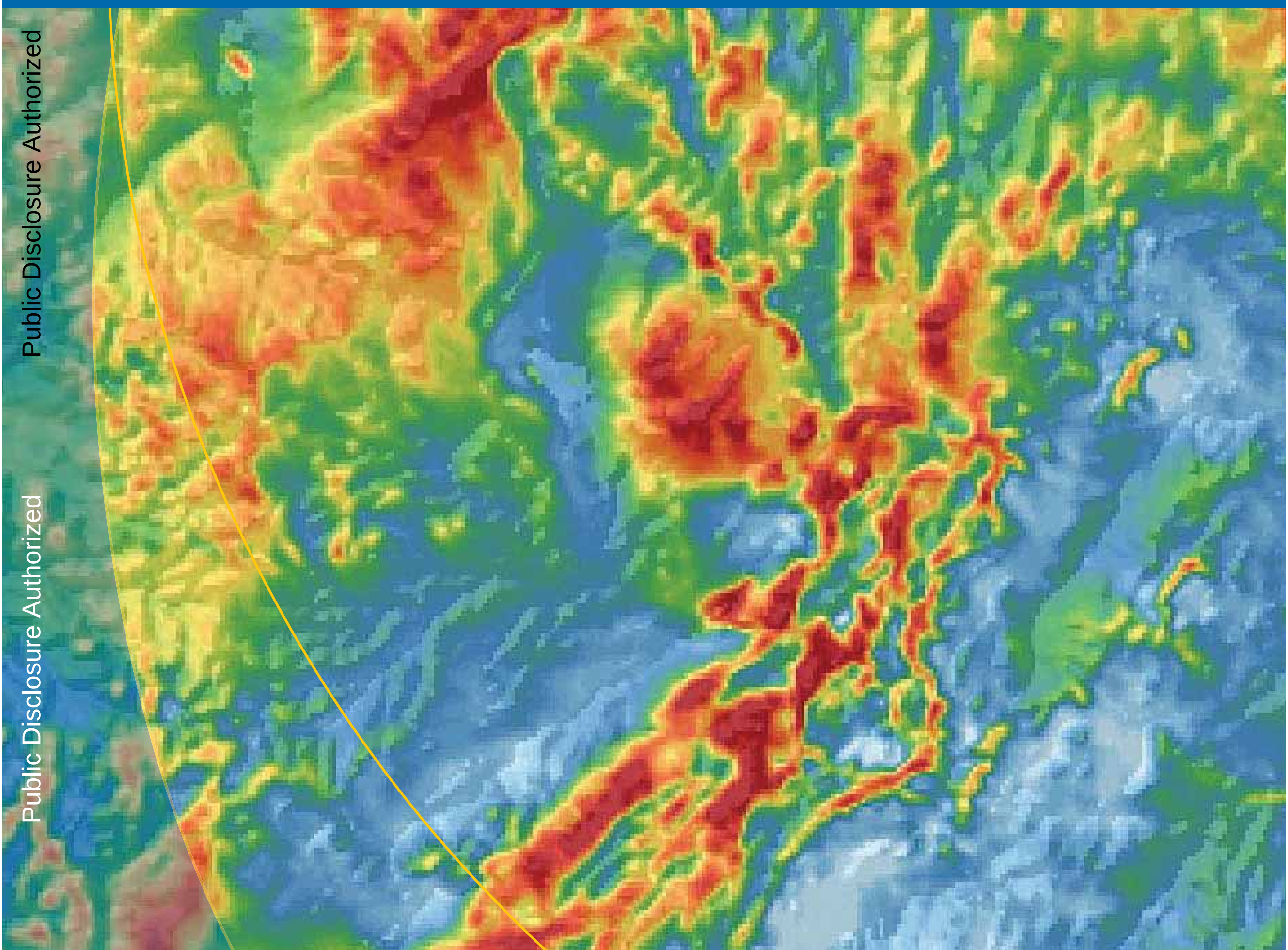


TABLE OF CONTENTS

INTRODUCTION

Understanding the location and potential of renewable energy resources is a crucial pre-requisite to their utilization, and to scaling up clean and secure sources of electricity generation such as biomass, small hydropower, solar, and wind. However many countries do not have high quality, publicly available data on renewable energy resource potential and this limits the potential for informed policy development, including zoning guidance, transmission network planning, and price regulation or incentives. It also narrows the field of potential commercial developers, and raises the cost of undertaking preliminary site identification and financial analyses.

This report draws on many years of experience within the World Bank Group and among other development partners in carrying out renewable energy resource assessment and mapping at the country level, in particular from 12 projects funded by the Energy Sector Management Assistance Program (ESMAP) under a major global initiative launched in 2012.[1] The report's purpose is to explain, for a wide range of audiences, the importance of resource assessment and mapping, key steps and good practices, methodological issues, and potential sources for further advice and support.

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 quality of the resource and the financial viability of the project, means that **understanding which renewable energy resources exist where, and to what extent, is critical to scaling up commercial development**. Renewable energy resource assessment and mapping can provide this information, both at a strategic level to inform policy, and also 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 commissioning a resource mapping study:

- Ensuring that commercial development is coordinated and focuses on the best locations from a power system perspective, taking into account the quality of the resource, proximity to demand, and potential to reduce costs through the sharing of core infrastructure (e.g., transmission lines) and streamlined permitting
- Obtaining good value for money when setting prices or incentives for renewable electricity generation, or negotiating power purchase agreements, through a better-informed regulator and off-taker
- 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 (in the case of biomass and small hydropower) and land to avoid conflicts and promote sustainable resource management
- Supporting grid stability by providing the data necessary to perform grid integration studies, which are necessary for countries to plan how they will integrate high levels of variable renewable energy capacity such as solar and wind

Renewable energy resource assessment and mapping studies provide the data needed to meet these objectives and carry out further analyses. Commercial developers are likely to benefit indirectly through well-informed government policies that support and guide investment, and directly by getting access to valuable data that can be used for initial site identification purposes or to carry out pre-feasibility analyses.[2] Placing resource maps and the underlying datasets 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.

And finally, there are likely to be a range of potential users of the data produced from the wider academic and research community, including for example 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 carrying out resource assessment and mapping, which helps to build their capacity and their ability to utilize the data that is produced.

In summary, **assessing and mapping renewable energy resources should be seen as a classic public good**, where a relatively small up-front investment can leverage very significant and diverse economic, environmental, and social benefits. Countries are increasingly finding that carrying out such work is the logical first step in their efforts to meet Sustainable Development Goal 7[3] and the objectives of Sustainable Energy for All[4] by helping to expand the contribution of renewable energy to their electricity generation mix and increase access to electricity.

Masonry Dam of the Peramiho Small Hydropower Scheme (542 kW) in Ruvuma Region, Tanzania

IMPLEMENTING A RESOURCE ASSESSMENT PROJECT

ENTRY POINTS

The assessment and mapping of renewable energy resources is done at many levels, for many different types of users, and by a wide range of providers. However, the collective experience of the World Bank Group from over a decade of carrying out or financing projects in this area, is that **country-level mapping for strategic use by governments and other public agencies is a crucial step**, and should be carried out to a high standard.

To better illustrate the various entry points for this work, Figure 1 outlines three levels of resource assessment and mapping. Level 1 describes a wide range of global or regional resources that can be useful in understanding broad resource availability—particularly for solar and wind (IRENA 2016a, b). However, Level 1 outputs will not generally have been validated by comparing them against authoritative survey or measurement data to evaluate level of certainty of the modeled results. A Level 2 assessment improves on this by adding validation,[5] and by carrying out a bespoke, country-level[6] analysis with a level of resolution and accuracy that is sufficient for strategic planning and preliminary site identification purposes. Importantly, **a Level 2 assessment includes validation of the preliminary resource assessment using survey data or ground-based measurements**, thereby providing users with a much higher level of confidence in the final results.

Many countries inadvertently skip Level 2 in favor of a more focused Level 3 analysis that targets some already-identified sites. While Level 3 studies are an essential input to prove the commercial viability, or ‘bankability’, of any renewable energy project,

Figure 1 | Three Levels for Renewable Energy Resource Assessment and Mapping

	Level 1	Level 2	Level 3
	Preliminary	**Validated**	**Observed**
Scale	Global Regional National	National Sub-national	Areas of high potential
Purpose	Resource overview Awareness raising High-level policy development	Resource estimation Strategic planning and regulation Prospecting	Resource validation Site assessment and optimization Financial analysis
Characteristics	Based on modeling outputs using earth observation and global datasets, no/limited validation	As Level 1 but modeling outputs are informed by and validated against measurement and/or survey data	Pre-feasibility studies using industry software with site measurements and/or survey data
Main players	International organizations Regional agencies Resource assessment vendors	National governments Development agencies Universities and national labs	Commercial developers and investors Electricity off-takers/utilities
Questions	What RE resources exist where? Are they worth exploring further?	Where is the resource commercially viable? Where should development take place?	Is this site commercially viable? What will be the cost of generation?
Examples	Global Wind Atlas SWERA PVGIS	World Bank Group (ESMAP initiative) Wind Atlas for South Africa Mozambique RE Atlas	Feasibility studies undertaken by commercial developers

moving straight to this level of analysis without taking a strategic view presents a number of significant risks, including:

- The possibility that the identified sites are not optimal in terms of resource potential or other factors when compared to other possible sites
- Duplication of effort by commissioning resource assessments individually for each potential site (perhaps from multiple developers)
- An increased risk of incorrect output predictions due to shorter time series data and a lack of long-term measurements for reference purposes
- The risk of uncoordinated development of different renewable energy resources, potentially missing out on the opportunity to share infrastructure upgrade costs and to identify and benefit from synergies in resource characteristics
- An inability to consider trans-boundary or cumulative environmental and social impacts, such as those on migrating birds

For these reasons, **it is considered good practice for countries to carry out a Level 2 assessment** if they have not already, or to update an existing assessment if it is more than 10 years old or does not meet the standards outlined in this report. In some cases this may not be possible, for example as a result of funding constraints or because a very quick outcome is required. In such cases it may be possible to map high potential sections of a country based on information provided by Level 1 analyses.

THREE PHASES

When it comes to carrying out a Level 2 resource assessment, ESMAP has determined three key phases as summarized in Figure 2. Each renewable energy resource of interest (biomass, small hydropower, solar, and wind in the case of the ESMAP initiative) is usually tackled separately, although they can be coordinated to benefit from shared reporting, training, and follow-on analysis.

The precise structure and content of each phase will differ depending on the resource in question. For example, Phase 1 for wind energy resource assessment involves high resolution modeling using meteorological data from global reanalysis datasets and Numerical Weather Prediction (NWP) models, whereas for biomass the process relies more heavily upon satellite-based earth observation data, official statistics, and previous desktop studies. Phase 2 for solar involves the commissioning of ground-based meteorological stations in representative locations around the country, whereas Phase 2 for small hydropower might involve site visits, the collection of stream gauge data, and similar forms of data collection. Despite these differences, the three phases can be applied to all four renewable energy resources and are a useful way to break down the work required.

ENSURING HIGH STANDARDS

The cost of Level 2 renewable energy resource assessment and mapping is significant due to the surveys/measurements needed for validation, and can be up to $2 million per resource considered, depending on the country's size and the need for new measurement data.[7] It is, therefore, important that projects are well designed

Figure 2 | Three Phases of Renewable Energy Resource Assessment and Mapping

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 ('bankability');
- Ensuring **methodological transparency**, so that the outputs can be properly analyzed or reconfigured by others;
- Using high-quality, specially commissioned measurement or survey data to **validate the modeling results**;
- Ensuring that the outputs are **freely and widely accessible**, and adopting 'open data' principles where relevant;
- Integrating the work into ongoing **planning and policy development**, including geospatial analysis; and
- Commissioning **experienced vendors and specialists** to carry out the core technical work while building in-country capacity.

In general, sub-standard assessments stem from one or more of the above conditions not being applied. For example, when proprietary methodologies are utilized without being based on peer-reviewed techniques or being explained in the accompanying reports, confidence in the resource assessment is greatly diminished. In the worst cases, mapping outputs have been delivered as a stand-alone report based on undisclosed methodologies, with none of the underlying data made available. Similarly, restricting access to the outputs—or even worse, 'spontaneously privatizing' them by allowing their selective sale or give-away to commercial interests—severely limits the confidence of potential investors and may raise the price for commercial developments through a lack of competition and transparency.

Making an early commitment to 'open data' principles[8] 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 developers to pay a reasonable fee for access to the most valuable datasets—but this should be done fairly and consistently while potentially exempting certain 'public interest' users (academia, policymakers, etc.). A further benefit of open data (particularly data that goes back many years) is that it may be utilized for multiple other purposes that were not envisaged by the commissioning entity. However, there are risks that need to be considered, in particular, the possibility of land speculation where high potential resources are discovered that are, perhaps, not known to, or understood by, the respective landowner(s).

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 specialist agencies, so that the sites are maintained and long-term reference data is generated.

Clearly, the value of high-quality reference data is in making the feasibility assessment of large-scale projects more accurate by allowing developers to calibrate site-specific measurements taken over one year to understand how 'typical' their data is. Keeping high-quality meteorological equipment operational over the longer term also helps improve the accuracy of modeling outputs for renewable energy resource assessment and forecasting purposes.

FOLLOW-ON WORK

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. While renewable energy atlases do have a value as stand-alone outputs, this value is significantly enhanced when governments use these outputs to conduct geospatial analysis—such as a Strategic Environmental (and Social) Assessment (SEA or SESA)—that can help guide development (Loayza 2012). This may be as part of a broader process of infrastructure planning, and can be used to bring in considerations such as 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 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, and another is very far from existing transmission lines and load centers, meaning that only one of these zones is really viable.

A specific area for follow-up is in the planning of transmission expansion and upgrades, and in helping to ensure long-term system stability especially as the penetration of variable renewable energy increases (IEA 2008).

The inherent spatial variability of renewable energy resources makes them particularly well suited to geospatial analysis or 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 recent example is provided by South Africa,[9] who undertook an SEA on solar and wind development following a comprehensive resource mapping exercise. For the developers themselves, having a well-informed government with clearly stated zoning guidance enhances the bankability of projects, shortens project timelines, and reduces the risk profile of the investment.

BUILDING NATIONAL CAPACITY

Although many countries are eager to develop national capacity to carry out such work, it will often be more efficient to contract out the initial work to international experts considering the fact that, when done well, the work should not need repeating for many years, if at all. The modeling work is also highly complex, involving methodologies that have been developed over many years, large volumes of data, and high capacity computers. As a one-off effort, it will often make most sense to procure the services required internationally from well-regarded experts.

Nevertheless, in-country capacity building is essential to ensuring that the data is maintained, understood, and utilized. This may be particularly important in areas such as geospatial planning, which is best seen as a continuous process that guides policy development through regular updates (for example, by using geospatial tools to track project development progress and new proposals), and therefore relies upon domestic expertise and capacity.

Student Surveying a Farmer on Crop Yields for a Biomass Mapping Activity in Pakistan

METHODOLOGICAL ISSUES

Key to commissioning high quality work will be very detailed Terms of Reference (TOR) for each assignment, with appropriate technical specifications for any measurement campaign. Template TOR are made available by ESMAP to support countries or development partners looking to commission such work, but these will need to be tailored to each country's requirements. More detailed guidance, drawing on the latest research, may be available via sources such as the International Energy Agency's Energy Technology Initiatives (also referred to as Implementing Agreements),[10] and the World Energy & Meteorology Council, which holds a biennial international conference.[11]

Below is an outline of a typical scope of work for such assignments, by renewable energy resource.

BIOMASS

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

Each biomass type requires a specific methodological approach. As documented by the Food and Agriculture Organisation (FAO) of the United Nations, 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).

A typical scope of work will involve the following steps:

Phase 1

- Identification and specification of biomass resources to be assessed, considering the specific context being analyzed
- Based on this, 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 develop a plan for data gathering (existing and foreseen land use plans can be consulted, as well)

Phase 2

- A combination of field surveys, site visits, questionnaires, and consultative events to verify any data gaps in existing national or local datasets 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 datasets and ultimately a Biomass Atlas, as shown in Figure 3.

In order to understand the real resource availability it is important to gain a clear understanding of local uses of biomass, 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 has adopted is commissioning domestic universities for the 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.

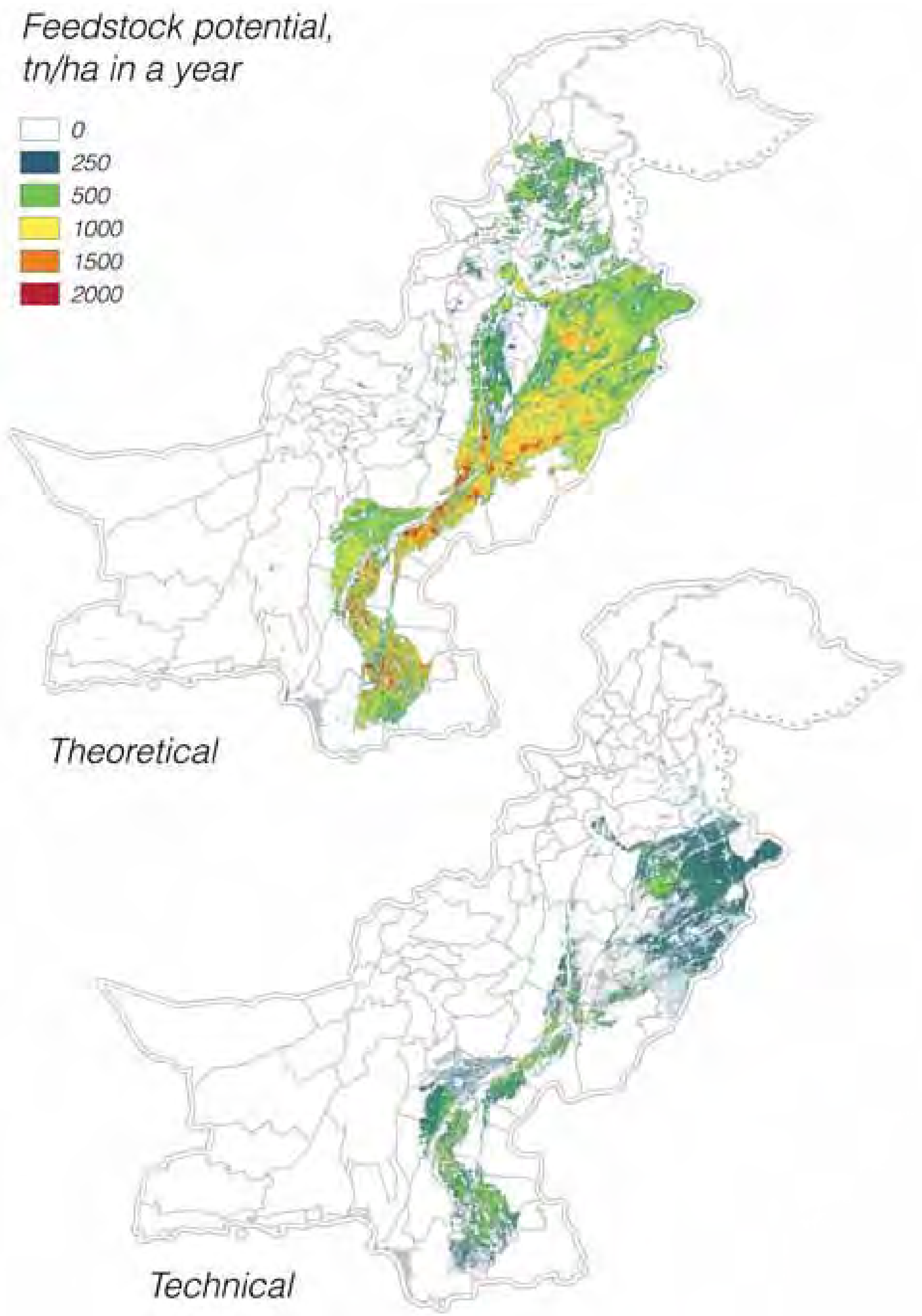
SMALL HYDROPOWER

Assessing and mapping small hydropower resources is 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 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 currently being seen in Liberia, Madagascar, 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 GW compared to 75 GW currently installed (Liu, Masera and Esser 2013).

Phase 1

Small 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

Figure 3 | Estimated Theoretical and Technical Potential of Biomass in Pakistan



Source: Full Advantage and Simosol (2016), under contract to The World Bank site visits to properly identify the potential. The basis for small hydropower mapping is to map slopes and flow data for the river systems, which is usually conducted through GIS modelling 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 is scarce, a hydrological model, using rainfall records, may be required. Figure 4 provides an example of an interim small hydro mapping output from Madagascar.

Phase 2

However, the suitability of a location for small hydropower is very dependent on site-specific factors, such a 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 small hydropower mapping is likely to involve site visits by hydropower experts. These site visits would include visual assessment of site specific key factors, and limited measurement of stream flow, soil, and riverine sediment transport. The combination of measured and modeled data for the potential small hydropower sites provide a better estimation of the resource minimum and maximum levels in the mid to long term.

Installing stream gauges as part of a 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 assessments and detailed design to be carried out by potential developers.

Phase 3

In Phase 3, as for biomass mapping, the various data sources are brought together to produce an integrated Small 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 more in-depth prefeasibility analysis to provide public authorities and commercial developers with the data needed to further investigate, and potentially develop, the highest priority sites.

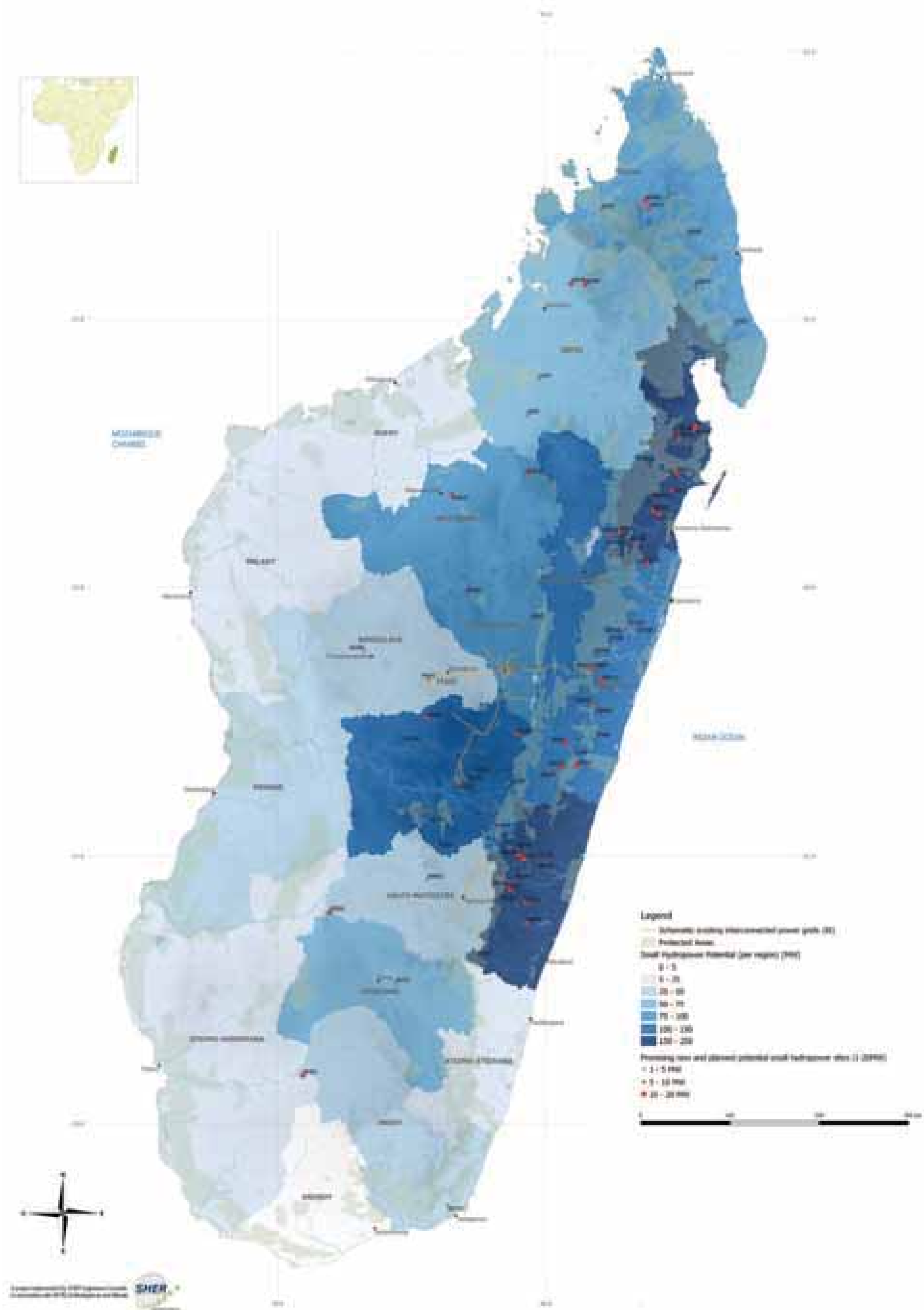
SOLAR

Solar resource assessment and mapping is increasingly a high priority for countries that want to take advantage of ongoing cost reductions in solar photovoltaic technologies. 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 absolute impact on cashflow projects for the largest projects. Conversely, accuracy is less of an issue for solar home systems or mini-grids, where the economics are dictated more by balance-of-system costs and other factors than the amount of sunlight available.

Phase 1

For solar, Phase 1 involves modeling solar irradiance levels using earth observation and global atmospheric datasets, including cloud cover, aerosols, water vapor, land use, and other relevant factors. The model should cover a minimum of 10 years of historical gridded data with spatial resolution of 5 km or more, available at a frequency of 10 to 30 minutes. Results are produced for global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal irradiance (DHI), the first

Figure 4 | Small Hydropower Mapping Output from a Project in Madagascar



Source: SHER (2015), under contract to The World Bank being a combination of the latter two. GHI is the resource relevant for power generation using solar photovoltaics, whereas DNI is the value needed to calculate the potential for concentrated solar power (CSP). In the case of long-term estimates of GHI, the preliminary results at this stage may have a ±6% to ±10% margin of error, but this can be reduced to around ±3% by validating the solar modeling using high quality ground-based measurements. Figure 5 shows typical solar mapping outputs from a project in Zambia.

Phase 2

The uncertainty of Phase 1 data is typically calculated from a validation process based on limited or very distant measurements. Hence, Phase 2 is required to obtain high-accuracy measurements from across the country over a period of at least one year, with two or more years preferred. This will usually require installation of dedicated solar measuring stations, some of which look very much like standard meteorological stations except with extra equipment added. The number of stations required depends on a number of factors, but in general the objective is to take measurement from at least one location within each identified 'climatic zone', which can be identified through the Phase 1 modeling. In many medium-sized countries, this might mean around 7 to 10 measurement stations, the number strongly depending on the country's geography and available budget.

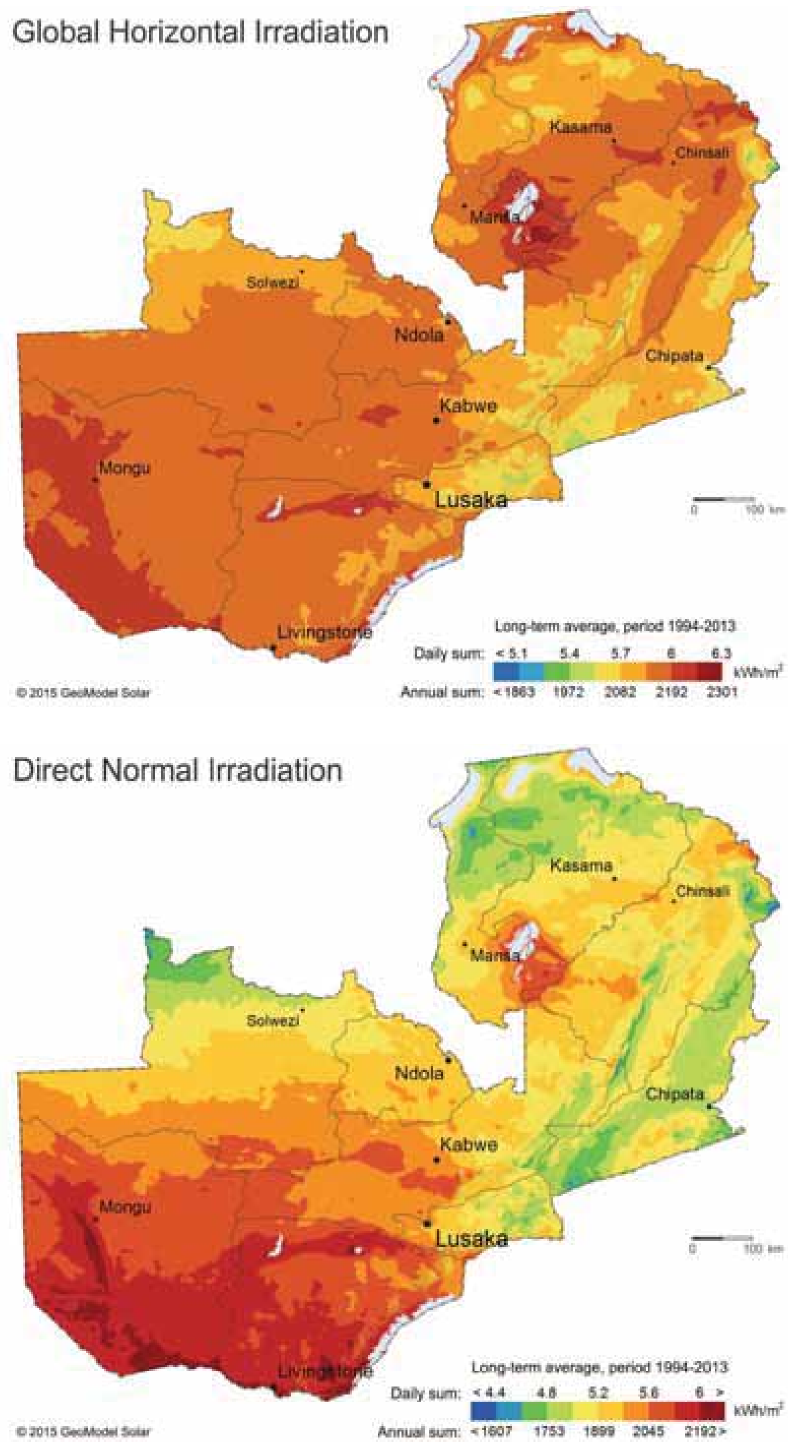
A number of options exist in terms of equipment specification and configuration, from high accuracy thermopile radiometers (preferred in locations where daily cleaning is possible), to rotating shadowband radiometers (preferred in more remote locations where daily cleaning is unlikely), to more simple GHI-only sensors (an option for extending the measurement campaign, or potentially taking solar measurements from already existing meteorological sites). Further technical details and guidance can be found in *Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications*—a very helpful report produced by the US National Renewable Energy Laboratory (2015).

Data will usually be transmitted using mobile phone networks (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 then for this data to be published or made easily accessible on an ongoing basis—for example, monthly during the measurement campaign.

Phase 3

Once the measurement campaign is completed, or sufficient data exists for validation purposes, Phase 3 begins with a validation exercise to compare the modeling results against the more accurate ground-based measurement data. The conclusions from this can be used to refine and improve the model to account for regional or local phenomena, and then the model is re-run to produce a final Solar Atlas. The Solar Atlas will usually consist of high resolution GIS layers for publication via a web-based GIS platform, plus an accompanying report describing the process and providing a summary of the results. In addition, it is desirable for the client to obtain (although not necessarily publish, for commercial reasons) the complete modeling output for each grid cell, plus a summary of this in the 'typical meteorological year' (TMY) format, to allow the data to be used in follow-on analysis that requires hourly data, such as with commercial project development or grid integration studies.

Figure 5 | Maps Showing Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) in Zambia



Source: GeoModel Solar (2015), under contract to The World Bank

WIND

Wind resource assessment and mapping is arguably the most methodologically developed of the four resources covered here, 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. The objective of Level 2 wind mapping is to develop a mesoscale map of the wind resource where such local factors are stripped out, allowing project developers to then carry out more microscale analysis by adding these factors back in at a more granular level (ESMAP 2016). This approach is intended to consider regional weather systems and larger land features to produce a 'generalized wind climate' for each cell in a country, from which more detailed estimations can be performed. Without such data, each project developer must obtain such mesoscale data independently, resulting in duplication of effort to obtain lower quality, unvalidated data, because no one developer is in a position to make the country-wide investment required.

Phase 1

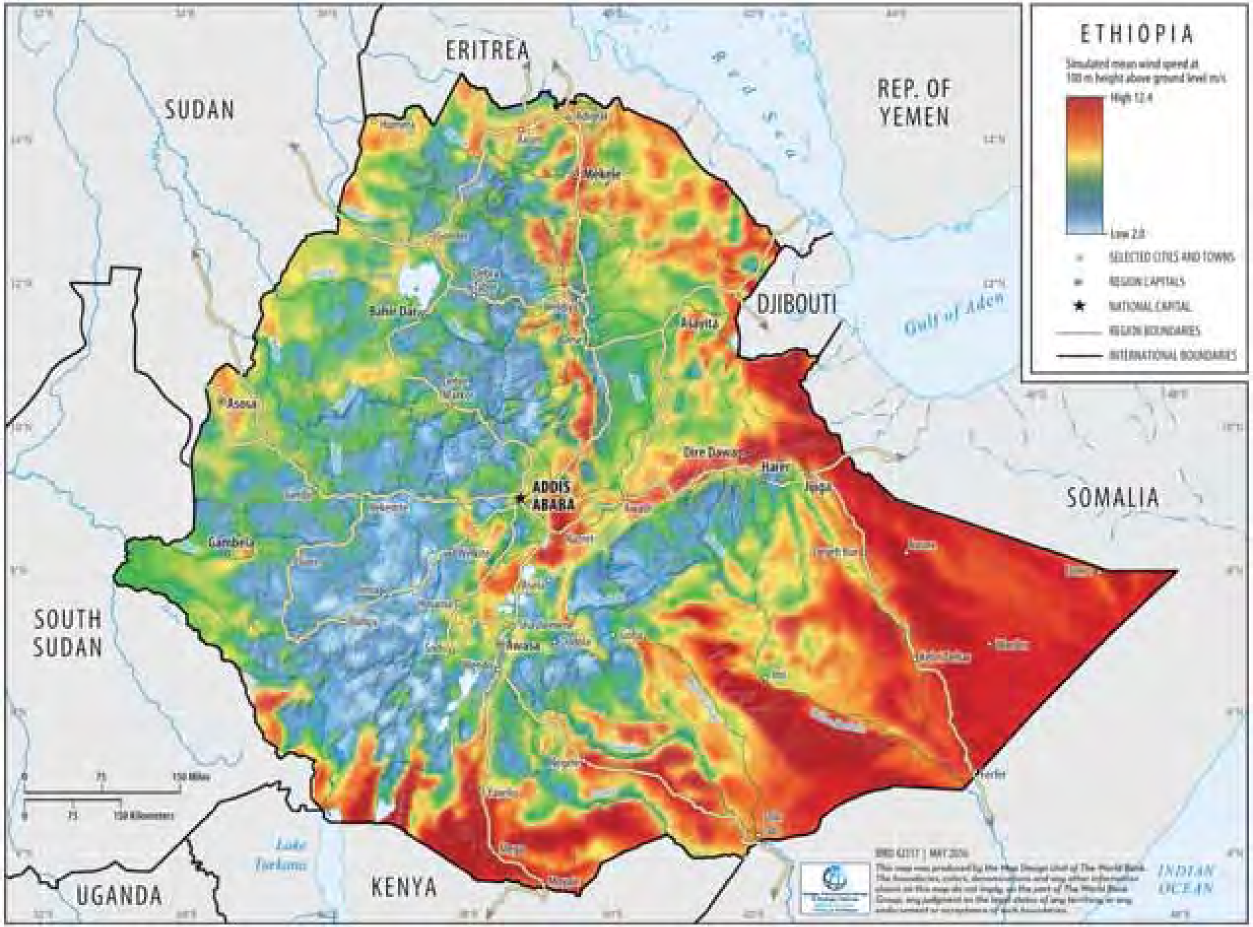
As with solar mapping, wind mapping follows a similar approach characterized by model-measure-remodel. The initial mesoscale modeling in Phase 1 draws upon existing and freely available global meteorological reanalysis data such as Modern-Era Retrospective Analysis for Research & Applications (MERRA)[12] provided by the US National Aeronautics and Space Administration (NASA), and then carries out a series of nested modeling runs at progressively higher levels of resolution. This ensures that climatic effects outside the country of interest, such as trade winds, are incorporated, while achieving the required resolution without excessive computing power. The final modeling run will usually cover a minimum of 10 years of historical wind data for each grid cell in the country, at multiple heights, down to a frequency of 10 minutes. From this, GIS layers showing average wind speeds and wind power density can be generated, as shown in Figure 6. The data itself is usually made available via one large dataset, which can then be conveniently processed to summarize the data for each grid cell. One common format is the .lib file, which is compatible with most mainstream microscale wind modeling software.

Phase 2

To validate the modeling outputs, ground-based wind measurement data is needed from across the country at multiple heights. It is often the case that some wind data from 10m masts is available from existing weather stations or other sources, but this is of very limited use for validation purposes. In some countries, data does exist from specialized, tall wind masts erected for the purposes of wind power, but it is essential that this data is accompanied by all the relevant metadata, including full site reports, installation reports, photographs, and other supporting evidence that will enable the mesoscale modelers to determine the characteristics and quality of the data being provided. Without this, such data may also have limited value for validation purposes. Furthermore, such data is likely to come from sites of high interest to developers, which most likely means there will be large gaps in the geographical coverage.

In many cases, it is necessary to commission a series of wind measuring sites specifically to validate the mesoscale modeling, either because high quality data does not exist, or because it is compromised or does not cover the entire country. This would comprise Phase 2 of such a project. Collecting wind data to the required standards is

Figure 6 | Wind Mapping Output from a Project in Ethiopia



Note: Shows simulated wind speed at 100m above ground level (Phase 1 output, unvalidated).

Source: 3E and DTU Wind (2016), under contract to The World Bank an expensive exercise, at least twice as costly per site as for solar data. It is also very easy to get wrong, as a result of suboptimal equipment specifications, poor siting or installation, vandalism, and the effects of extreme weather. Because of the need for validation data over a period of at least one year (and two years or more), and the desirability of reference data for a much longer period, it is important to design, plan and implement a wind measurement campaign with sufficient due diligence, and without compromising on quality. If done correctly, a successful wind measurement campaign will provide planners and project developers with an important source of high quality reference data, plus a validated Wind Atlas that they can use to estimate the wind potential at any point in the country with a known level of certainty.

A standard wind measurement site will consist of a lattice or tubular tower, upon which wind speed measurements (using 'anemometers') will be taken at vertical intervals of 20m above ground level. The current industry standard height is 80m (with anemometers at 20m, 40m, 60m and 80m), although taller masts are now being used by some developers, and shorter masts may be more appropriate in certain circumstances (for example, 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, and 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 anti-climbing 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.

Phase 3

When sufficient data is gathered to enable validation, Phase 3 is similar to the solar modeling whereby a validation exercise is carried out, followed by a fresh mesoscale modeling exercise that is used to produce the final Wind Atlas, including a summary report and the full package of GIS layers and modeling data. This data will replace the outputs generated in Phase 1. During Phase 3, it may also be desirable to carry out a microscale modeling exercise, whereby topography and surface roughness are added back into the model to produce a higher resolution mapping output that can also be part of the final Wind Atlas.

Close-up of a Wind Measuring Mast

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 specialist 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,[13] 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. As a result of this work, ADB has produced a guide to undertaking 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 partners, has developed a Support Package to Decision-Making for Sustainable Bioenergy.[14] The package includes different elements which can be used independently or together in relation 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,[15] 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. **Contact details: BEFS-support@fao.org**

INTERNATIONAL RENEWABLE ENERGY AGENCY

One of the flagship initiatives of the International Renewable Energy Agency (IRENA)[16] is their Global Atlas for Renewable Energy.[17] This has brought together a large number of mainly solar and wind resource assessment studies—at Levels 1 and 2—and provides free and easy access via a web-based user interface and accompanying smartphone app (IRENA 2014). While IRENA does not directly fund or carry out resource assessment studies, it provides a natural home for the outputs of work commissioned by countries or other agencies where these can be shared publicly. **Contact details: potentials@irena.org**

NATIONAL RENEWABLE ENERGY LABORATORY

The National Renewable Energy Laboratory (NREL)[18] of the United States has been supporting and carrying out renewable energy resource assessment and mapping for over three decades, both within the United States and internationally. Jointly with the United Nations Environment Program (UNEP) they implemented the Solar and Wind Energy Resource Assessment (SWERA) program,[19] which carried out mainly Phase 1, Level 2 mapping in over 10 countries from 2005 to 2010. More recently NREL has carried out a Phase 1, Level 2 solar mapping of North and South America (available from the NSRDB portal)[20] and India (available from the RReDC portal).[21] NREL has active programs in this area, primarily supported by the US Department of Energy and sometimes supported by the US Agency for International Development (USAID). NREL also produces useful guidance documents and other relevant publications. **Contact details: nsrdb@nrel.gov**

WORLD BANK GROUP

The World Bank[22] and the International Finance Corporation (IFC)[23]—collectively the World Bank Group (WBG)—have supported many countries with renewable energy resource assessment and mapping studies, as part of lending operations and also via grant-funded technical assistance. More recently, the Energy Sector Management Assistance Program (ESMAP) has established a **global initiative on Renewable Energy Resource Mapping,** providing a combination of technical support and grant funding for WBG-executed, Level 2 projects.[24] Under this initiative, ESMAP has invested heavily in standardized TORs, involving contributions from a range of international experts and service providers, and in the information and technology solutions needed to store and serve the data outputs to users. These TORs are freely shared by ESMAP via their website along with the outputs from country projects, and WBG client countries are welcome to request ESMAP technical support, including for projects being undertaken without direct WBG involvement or with other development partners. **Contact details: esmap@worldbank.org**

ENDNOTES

[1] Further details can be found on the ESMAP website. The initiative covers biomass, small hydropower, solar, and wind resources.

[2] In some cases, such as smaller solar photovoltaics plants, the data provided may be sufficient for full project planning and financing purposes.

[3] http://www.un.org/sustainabledevelopment/energy/

[4] http://www.se4all.org/

[5] For solar and wind, this is generally carried out over a broader area that includes neighboring countries, where data exists.

[6] While a Level 2 analysis could conceivably be carried out at a regional or continental level, our experience so far is that the process of carrying out surveys and/or ground-based data collection will necessarily require a country-by-country approach due to the governmental coordination, field work, and permissions that are required to make this a success.

[7] Wind resource assessment and mapping tends to be the highest cost, with biomass and small hydropower up to 50% less than the equivalent cost for wind. In general it should be possible to map all four resources for less than $5m in a medium-sized country. Regional, multi-country approaches may allow that cost to be substantially reduced.

[8] http://opendefinition.org/

[9] https://redzs.csir.co.za/

[10] http://www.iea.org/techinitiatives/

[11] http://icem2015.org/

[12] http://gmao.gsfc.nasa.gov/research/merra/

[13] http://www.adb.org/sectors/energy/programs/clean-energy-program/wind-energy

[14] http://www.fao.org/energy/82318/en/

[15] http://www.fao.org/energy/befs/en/

[16] http://www.irena.org/

[17] http://globalatlas.irena.org/

[18] http://www.nrel.gov/international/

[19] http://en.openei.org/apps/SWERA/

[20] http://nsrdb.nrel.gov/

[21] http://rredc.nrel.gov/solar/new_data/India/

[22] http://www.worldbank.org/energy

[23] http://www.ifc.org/

[24] http://esmap.org/re_mapping

REFERENCES

ADB [Asian Development Bank]. 2014. *Guidelines for Wind Resource Assessment: Best Practices for Countries Initiatiating Wind Development.* Manila: Asian Development Bank. Available at: http://www.adb.org/publications/guidelines-wind-resource-assessment-best-practices-countries-initiating-wind-dev.

ESMAP [Energy Sector Management Assistance Program]. 2016. *Best Practice Guidelines for Wind Mapping.* Washington, DC: The World Bank. Available at: http://www.esmap.org/sites/esmap.org/files/Guidance_Mesoscale-Wind-Mapping_WBG-ESMAP_2015.pdf.

FAO [Food and Agricultural Organisation]. 2010. *Bioenergy and Food Security: The BFES Analytical Framework.* Rome: Food & Agricultural Organisation. Available at: http://www.fao.org/3/a-i1968e.pdf.

IEA [International Energy Agency]. 2008. *Empowering Variable Renewables: Options for Flexible Electricity Systems.* Paris: International Energy Agency. Available at: https://www.iea.org/publications/freepublications/publication/Empowering_Variable_Renewables.pdf.

IRENA [International Renewable Energy Agency]. 2016a. *Investment Opportunities in Latin America: Suitability Maps for Grid-Connected and Off-Grid Solar and Wind Projects.* Abu Dhabi: International Renewable Energy Agency.

IRENA. 2016b. *Investment Opportunities in the GCC: Suitability Maps for Grid-Connected and Off-Grid Solar and Wind Projects.* Abu Dhabi: International Renewable Energy Agency.

IRENA. 2014. *Global Atlas for Renewable Energy: Overview of Solar and Wind Maps.* Abu Dhabi: International Renewable Energy Agency. Available at: http://www.irena.org/DocumentDownloads/Publications/GA_Booklet_Web.pdf.

Liu, H., D. Masera, and L. Esser. 2013. *World Small Hydropower Development Report 2013.* International Center on Small Hydropower Power, Hangzhou: United Nations Industrial Development Organisation. Available at: http://www.smallhydropowerworld.org/fileadmin/user_upload/pdf/WSHPDR_2013_Final_Report-updated_version.pdf.

Loayza, Fernando. 2012. *Strategic Environmental Assessment in the World Bank: Learning from Recent Experience and Challenges.* Washington, DC: The World Bank. Available at: http://documents.worldbank.org/curated/en/2012/01/16768818/strategic-environmental-assessment-world-bank-learning-recent-experience-challenges.

NREL [National Renewable Energy Laboratory]. 2015. *Best Practices Handbook for the Collection and Use of Solar REsource Data for Solar Energy Applications.* Boulder, CO: National Renewable Energy Laboratory. Available at: http://www.nrel.gov/docs/fy15osti/63112.pdf.

ACRONYMS AND ABBREVIATIONS

ADB	Asia Development Bank
BEFS	Bioenergy and Food Security
DHI	Diffuse horizontal irradiance
DNI	Direct normal irradiance
FAO	Food and Agriculture Organisation
GHI	Global horizontal irradiance
GSM	Global System for Mobile (communication)
GW	Gigawatt
SEA or SESA	Strategic environmental (and social) assessment
TOR	Terms of Reference
WBG	World Bank Group

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

Written by | Oliver Knight, Sr. Energy Specialist, ESMAP

Photo Credits

Cover: ©DNV GL | World Bank
Table of Contents: ©SESI Pakistan | World Bank
Page 1, 21: ©Soren Krohn
Page 2, 11: ©National University of Science and Technology (NUST), Islamabad
Page 5: ©SHER | World Bank

Production Credits

Production Editor | Heather Austin

Typesetting | Shepherd, Inc.

THE WORLD BANK
IBRD • IDA | WORLD BANK GROUP

ESMAP
Energy Sector Management Assistance Program

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 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, Switzerland, and the United Kingdom, as well as The World Bank.

For more information about ESMAP's Clean Energy program and renewable energy resource mapping activities, please visit us at http://www.esmap.org/re_mapping.

Energy Sector Management
Assistance Program
The World Bank
1818 H Street, NW
Washington, DC 20433 USA
email: esmap@worldbank.org
web: www.esmap.org