# GEO Task US-09-01a: Critical Earth Observations Priorities

## *Energy Societal Benefit Area*

GROUP ON EARTH OBSERVATIONS

**User Interface Committee**

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2010

GROUP ON EARTH OBSERVATIONS

# Group on Earth Observations

## GEO Task US-09-01a:
## Critical Earth Observation Priorities for Energy SBA

## Advisory Group Members & Analyst

The following people served as expert panelists for the *ad hoc* Advisory Group for the Energy Societal Benefit Area (SBA) under GEO Task US-09-01a. The Advisory Group supported the Analyst by identifying source materials, reviewing analytic methodologies, assessing findings, and reviewing this report.

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Additionally, the following individual provided comments on draft versions of this report.

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Acknowledgment
The Analyst performed this task and prepared this report through the support of the National Aeronautics and Space Administration (NASA), 300 E Street SW, Washington, DC 20546, USA, Contract No. GS-23F-8167H.

# Group on Earth Observations

## GEO Task US-09-01a:
## Critical Earth Observation Priorities for Energy SBA

## Summary

This report is part of GEO Task US-09-01a, with the objective of identifying critical Earth observation priorities for nine Societal Benefit Areas (SBAs). This document discusses the Energy SBA, focusing on the renewable energy sources of hydropower, land-based wind power, offshore wind power, bioenergy (including biofuels for transportation), solar power, and geothermal power. In this effort, the Analyst enlisted the help of 14 expert Advisory Group members from a wide geographic distribution, including at least one member from every continent except Antarctica. The Analyst located and analyzed seventy-one (71) potentially relevant publicly available documents, reports, and websites, and determined that 54 of these documents contained information relevant to the analysis. The Analyst located the documents through literature searches and through suggestions from Advisory Group members. The Analyst analyzed the documents by searching through them for references to desired Earth observations as well as information about the adequacy of current Earth observations.

The Analyst worked iteratively with the Advisory Group to develop and refine a method of prioritization of the Earth observation parameters. Tier 1 parameters are those parameters which are key to prominent renewable energy types, and are considered to be of high priority. Tier 2 parameters are those parameters which are required across multiple renewable energy-types, offering some economy of scale, and are considered to be of medium priority:

- **Tier 1 High Priority Parameters:** Water run-off, wind speed, land cover, Normalized Difference Vegetation Index (NDVI), Net Primary Productivity (NPP), Global Horizontal Irradiation (GHI), Direct Normal Irradiation (DNI)

- **Tier 2 Medium Priority Parameters:** Elevation /topography, air temperature, surface temperature, relative humidity, and cloud cover.

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# 1. Introduction

This report articulates Earth observation priorities for the Energy SBA, based on an analysis of 71 publicly-available documents, many of which were produced by Group on Earth Observations' Member Countries and Participating Organizations.

## 1.1. GEO and Societal Benefit Areas

The Group on Earth Observations (GEO)[1] is an intergovernmental organization working to improve the availability, access, and use of Earth observations to benefit society. GEO is coordinating efforts to build a Global Earth Observation System of Systems (GEOSS)[2]. GEOSS builds on national, regional, and international observation systems to provide coordinated Earth observations from thousands of ground, in situ, airborne, and space-based instruments.

GEO is focused on enhancing the development and use of Earth observations in nine SBAs:

| | | |
|---|---|---|
| Agriculture | Biodiversity | Climate |
| Disasters | Ecosystems | Energy |
| Health | Water | Weather. |

## 1.2. Task US-09-01a

The objective of GEO Task US-09-01a is to establish and conduct a process to identify critical Earth observation priorities within each SBA and those common to the nine SBAs. Many countries and organizations have written reports, held workshops, sponsored projects, conducted surveys, and produced documents that specify Earth observation needs. Task US-09-01a focuses on compiling information on observation parameters from a representative sampling of these existing materials and analyzing across the materials to determine the priority observations.

This task considers ground, in situ, airborne, and space-based observations. The task includes both observed and derived parameters as well as model products. This task seeks to identify Earth observation needs across a full spectrum of user types and communities in each SBA, including observation needs from all geographic regions and significant representation from developing countries.

GEO will use the list of Earth observation priorities resulting from this task to determine, prioritize, and communicate gaps in current and future Earth observations. GEO Member Countries and Participating Organizations can use the results in determining priority investment opportunities for Earth observations.

[1] GEO Website: *http:// www.Earthobservations.org*
[2] GEO 10-Year Implementation Plan: *http://www.Earthobservations.org/documents.shtml*

## 1.3. Purpose of Report

The primary purpose of this report is to articulate the critical Earth observation priorities for the Energy SBA. The intent of the report is to describe the overall process and specific methodologies used to identify documents, analyze them, and determine a set of Earth observation parameters and characteristics. The report describes the prioritization methodologies used to determine the priority Earth observations for this SBA. The report also provides information on key challenges faced, feedback on the process, and recommendations for process improvements.

The primary audience for this report is the GEO User Interface Committee (UIC), which is managing Task US-09-01a for GEO. The GEO UIC will use the results of this report in combination with reports from the other eight SBAs. The GEO UIC will perform a meta-analysis across all nine SBA reports to identify critical Earth observation priorities common to many of the SBAs. Based on the nine SBA reports, the GEO UIC will produce an overall Task US-09-01a report, including the common observations and recommendations for GEO processes to determine Earth observation priorities in the future.

The report's authors anticipate that the GEO Secretariat, Committees, Member Countries, Participating Organizations, Observers, Communities of Practice, and the communities associated with the Energy SBA are additional audiences for this report.

## 1.4. Scope of Report

This report addresses the Earth observation priorities for the Energy SBA. In particular, this report focuses on the renewable energy sources of hydropower, land-based wind, offshore wind, solar, bioenergy (including biofuels for transportation), and geothermal power within the Energy SBA (see Section 3 for more details).

The report provides some background and contextual information about the Energy SBA. However, this report is not intended as a handbook or primer on the Energy SBA, and a complete description of the Energy SBA is beyond the scope of this report. Please consult the GEO website (referenced above) for more information about the Energy SBA.

The report focuses on the Earth observations within the Energy SBA, independent of any specific technology or collection method. Thus, the report addresses the "demand" side of observation needs and priorities. The report does not address the specific source of the observations or the sensor technology involved with producing the observations. Similarly, any discussions of visualization tools, decision support tools, or system processing characteristics (e.g., data format, data outlet) associated with the direct use of the observations are beyond the scope of this report.

In this report, the term "Earth observation" refers to parameters and variables (e.g., physical, geophysical, chemical, biological) sensed or measured, derived parameters and products, and related parameters from model outputs. The term "Earth observation priorities" refers to the parameters deemed to be of higher significance than others for the given SBA, as determined through the methodologies described within. The report uses the terms “user needs” and “user requirements” interchangeably to refer to Earth observations that are articulated and desired by the groups and users in the cited documents. The term “requirements” is used generally in the report to reflect users’ wants and needs; the use in this report does not imply technical, engineering specifications.

Following this introduction, the report discusses the overall approach and methodologies used in this analysis (Section 2). Section 3 describes the Energy SBA and the specific sub-areas that were part of the analysis. Section 4 articulates the specific Earth observations for each Energy sub-area, and Section 5 presents the priority observations across the Energy SBA. Sections 6 and 7 present additional findings from the analysis of the documents and recommendations for future work. The appendices include the documents cited, a list of acronyms, and a summary of the input to the Cross-SBA Analysis.

# 2. Methodology and Process

## 2.1. Task Process

The basic methodology for identifying critical Earth observation priorities within an SBA relies on an Analyst working in coordination with an Advisory Group to select the scope of the analysis, identify and analyze relevant documents, and finally extract and prioritize relevant Earth observation parameters. The GEO UIC established a general process for each of the SBA Analysts to follow in order to ensure some consistency across the SBAs. This general process for each SBA involves nine (9) steps, as summarized in the following list:

Step 1: UIC Members identify Advisory Groups and Analysts for each SBA
Step 2: Determine scope of topics for the current priority-setting activity
Step 3: Identify existing documents regarding observation priorities for the SBA
Step 4: Develop analytic methods and priority-setting criteria
Step 5: Review and analyze documents for priority Earth observations needs
Step 6: Combine the information and develop a preliminary report on the priorities
Step 7: Gather feedback on the preliminary report
Step 8: Perform any additional analysis
Step 9: Complete the report on Earth observations for the SBA.

A detailed description of the general US-09-01a process is available at the Task website *http://sbageotask.larc.nasa.gov* or the GEO website. For the Energy SBA analysis, many of these steps were conducted simultaneously. The Analyst identified existing documents (Step 3) concurrently with development of the analytic methods and priority-setting criteria (Step 4), in coordination with the Advisory Group. This allowed the methods to be tailored to the types of documents that were being identified. Also, as input was received from the Advisory Group, the Analyst continued to conduct Step 3 (document identification and analysis) iteratively throughout the process, as Advisory Group members continued to identify relevant documents.

### 2.2. Analyst and Advisory Group

The Energy SBA had an "Analyst" and an "Advisory Group" working together to identify documents, analyze them, and prioritize the Earth observations. The Analyst served as the main coordinator to manage the activities.

#### 2.2.1. Analyst

For the Energy SBA, the Analyst was Erica Zell. She holds a master's degree in Environmental Engineering, and has 12 years of experience in environmental research, including significant international experience. She has been working at Battelle for five years, currently serving as an Environmental Research Scientist. She specializes in the application of satellite data for energy and air quality applications, the impacts of electric power generation, and distributed and renewable energy technologies. She also has project management experience and has managed the production of several technical reports.

The Energy SBA Analyst served through the Battelle Memorial Institute under contract to the National Aeronautics and Space Administration (NASA).

#### 2.2.2. Advisory Group

The Analyst assembled the Advisory Group, which consisted of 14 scientific and technical experts, recognized as credible and respected in the field of renewable energy or some subset thereof (e.g., solar energy). The Advisory Group members are from both developed and developing countries, and encompass all regions of the world, representing GEO Countries and Participating Organizations, as listed in Table 1.

The Analyst developed the pool of candidates for the Advisory Group based on contacts provided by the Energy Community of Practice (COP) and identification of participants in relevant workshops and conferences. The Analyst invited each potential candidate to participate and provided each with information on the expectations for Advisory Group members. The role of the Advisory Group was to help identify relevant documents, comment on the analytic methods and priority-setting criteria utilized, and review the Analyst's findings, priorities, and reports. Communication was conducted primarily by a combination of emails and group teleconferences.

### 2.3. Methodology

#### 2.3.1. Documents

Task US-09-01a methodology required examination of a wide range of sources for potentially relevant, publicly available documents, including:

- International, regional, and national documents focused on data sources, applications, or research priorities
- Project reports (e.g., findings from major regional/national projects)
- Surveys (e.g., of users of solar resource data)
- Workshop and conference summaries
- Individual peer-reviewed journal articles.

**Table 1. Advisory Group for Energy SBA.**

| Name | GEO Country or Organization | Affiliation | Geographic Region | Area of Expertise/ Specialty |
|---|---|---|---|---|
| Charlotte Bay HASAGER | Denmark | Risoe National Laboratory, Technical University of Denmark | Europe | Wind |
| Amit KUMAR | India | The Energy and Resources Institute (TERI) | Asia/Middle East | Broad renewable energy |
| Ellsworth LE DREW | Canada | University of Waterloo | North America | Chair of GEOSS Energy COP |
| Maxwell MAPAKO | South Africa | Natural Resource and Environment, CSIR | Africa | Broad renewable energy |
| Pierre-Philippe MATHIEU | European Space Agency | European Space Agency | Europe | Broad renewable energy |
| Richard MEYER | Germany | Suntrace GmbH | Europe | Solar |
| Monica OLIPHANT | Australia | International Solar Energy Society | Oceania/Australia | Solar |
| Enio PEREIRA | Brazil | INPE (Brazilian National Agency for Space Research) | South/Central America | Broad renewable energy |
| Thierry RANCHIN | France | Ecole des Mines de Paris and Co-Chair of the GEO Energy Community of Practice | Europe | Broad renewable energy |
| David RENNE | United States | Department of Energy, National Renewable Energy Laboratory | North America | Solar and wind |
| Scott SKLAR | United States | Stella Group | North America | Broad renewable energy |
| Gerry SEHLKE | United States | Department of Energy, Idaho National Laboratory | North America | Hydropower |
| Han WENSINK | The Netherlands | ARGOSS | Europe | Ocean |
| Gu XINGFA | China | Institute of Remote Sensing Applications | East Asia | Broad renewable energy |

The Analyst used a twofold methodology for identifying potentially relevant documents: (1) literature and online searches, and (2) requests for Advisory Group members to suggest documents. The online searches conducted by the Analyst focused on the websites of international, regional, and national organizations engaged in renewable energy. The literature searches relied on standard library search tools using a variety of renewable energy key words. This approach of combining Analyst searches with suggestions from Advisory Group members helped ensure that the set of documents ultimately analyzed would have broad geographic distribution and represent both developed and developing countries. The Analyst emphasized to

Advisory Group members that any documents suggested for analysis need to be publicly available. This resulted in an initial set of potentially relevant documents.

Upon further examination by the Analyst, each document had to include one of the following for consideration in the analysis: (1) specification of Earth observation parameters *needed by users* for renewable energy applications, or (2) reference to Earth observation parameters *currently in use* for renewable energy applications, with some indication of the *adequacy* of the parameter characteristics as currently available. This latter factor provided some information on Earth observations that may need to be continued. While the Analyst focused initially on identifying the first type of document (identifying parameters needed by users), only a few of the identified documents fit neatly within this category. Thus, it was necessary to include the second type of document (focused on the adequacy of current observations) in order to have enough documents from which priorities could be derived.

A certain degree of specificity was required for the Analyst to deem a document to be relevant for analysis. That is, the document had to name the specific parameter(s) required or used, along with at least some indication of parameter characteristics (e.g., spatial resolution), in order for the document to be included in the analysis. The parameter characteristics that were sought by the Analyst are as follows:

- Coverage/Extent
- Temporal resolution (frequency)
- Spatial resolution (vertical and horizontal, as relevant)
- Timeliness (availability of measurement)
- Accuracy/Precision.

### 2.3.2. Analytic Methods

For those documents that met the criteria described in Section 2.3.1, the Analyst conducted a detailed data extraction process. This process entailed reading or skimming the document for mention of Earth observations, and recording all mentioned Earth observation parameter information in a spreadsheet organized by parameter and document. Each row in the spreadsheet represented a document, and each column represented a parameter (e.g., wind speed). Once completed, the spreadsheet facilitated a quick review of the total extracted information either by document or parameter. The Analyst recorded all relevant information provided in the document, including any mention of desired parameter characteristics.

In cases where the information in the document referred to the *adequacy* of the characteristics of a current observation rather than the *ideally required* parameter characteristics, the Analyst recorded the parameter characteristics of the current observation for reference purposes. For example, if a document indicated that current spatial resolution of wind speed data is inadequate, the Analyst recorded the spatial resolution of the current observation referenced in the document, if specified (such as on a 10 km x 10 km grid). While this information on adequacy of current observations does not provide an absolute target of ideally required parameter characteristics, this information was used to fill gaps where information was lacking on ideally required parameter characteristics. The Analyst makes a clear distinction between the information derived from these two approaches in the results section of this document.

Next, the Analyst constructed a table of priority observations for each renewable energy sub-area, as described in Section 3.2. To complete this step, the Analyst noted whether there were one or more documents for each sub-area that addressed ideally required user needs, as opposed to the adequacy of current observations. Documents addressing ideally required user needs were available for solar and wind energy, and these "primary" documents were used as an initial basis to construct a priorities table for those sub-areas. The Analyst then compared the needs in these primary documents to parameters identified in other relevant documents, and added parameters to the table in cases that did not contradict the primary sources. For the renewable energy sub-areas other than solar and wind energy, the Analyst and Advisory Group were not able to identify any clear-cut surveys or reports that focused on end user needs. Thus, the Analyst constructed a list of end user needs from the remaining relevant documents. Finally, the Analyst identified one to three key parameters for each renewable energy sub-area, based on comments from Advisory Group members and prevalence of discussion of a parameter in the documents analyzed. For this analysis, key parameters are those that are the main determinant of the renewable energy potential or output of a particular renewable energy sub-area. For example, for wind energy, the key parameter is wind speed at turbine hub height. The key parameters for each renewable energy sub-area are shown in boldface type within the table of priority observations.

### 2.3.3. Prioritization Methods

The Analyst worked iteratively with the Advisory Group to develop and refine a method of prioritization of the Earth observation parameters identified through the document meta-analysis described in Section 2.3.2. Ultimately, the Analyst grouped the Earth observation parameters into two tiers – Tier 1, indicating parameters of the highest priority, and Tier 2, indicating parameters of medium priority. The following describes how the Analyst, in consultation with the Advisory Group, selected the Tier 1 and Tier 2 parameters:

- Tier 1 Parameters: The Analyst identified the renewable energy types that are projected by experts to gain prominence over the next 20 or more years, and designated the key parameters (as described in Section 2.3.2) for each of these renewable energy types as Tier 1 parameters. For this step, the Analyst focused first on electricity generation from renewable energy, based on the International Energy Agency's (IEA) World Energy Outlook (WEO) 2008 (IEA, 2008a). The WEO draws on a worldwide body of experts to identify required actions in the energy realm for a sustainable future. The Reference Scenario presented in the WEO projects the mix of renewable energy-based electricity generation out to 2030. The Analyst also reviewed a second IEA document, Energy Technology Perspectives (ETP) 2008 (IEA, 2008b), which was suggested by an Advisory Group member for use in the prioritization.[3] The Analyst selected the top five renewable

[3] The ETP document identifies a nearly identical set of renewable energy applications as the WEO, but includes geothermal energy in the top five sub-areas in place of bioenergy. The ETP also places the renewable-energy sub-areas in a different order than the WEO.

energy types according to the terawatt-hours generated in the 2030 Reference Scenario in the WEO. These energy types are hydropower, onshore/land-based wind, bioenergy, offshore wind, and solar energy. In addition, the Analyst chose to include transportation biofuels, a subset of bioenergy, in the top five sub-areas. This is consistent with the documents analyzed, which indicate that biofuels will have continued prominence in the coming years.

- Tier 2 Parameters: The Analyst assessed which observation parameters are required, with similar scales and characteristics, across several of the six sub-areas of renewable energy analyzed in this report. The Analyst deemed that any parameters that are required for multiple types of renewable energy would have an "economy of scale" that would provide a multi-faceted return on investment. To ensure that these parameters are required with similar scales and characteristics, the Analyst checked the original literature and noted where required characteristics between renewable energy sub-areas varied significantly. However, in many cases, although the ideally required scales varied, meeting the finer scale requirement (e.g., hourly data) for one renewable energy sub-area would also allow averaging to meet a coarser scale requirement (e.g., monthly averages) for a different renewable energy sub-area.

# 3. Energy SBA

## 3.1. Description

The GEOSS 10-Year Implementation Plan notes that the Energy SBA is focused on improving management of energy resources. Section 4.1.3 of the 10-Year Implementation Plan describes the Energy SBA as follows:

> "GEOSS outcomes in the energy area will support: environmentally responsible and equitable energy management; better matching of energy supply and demand; reduction of risks to energy infrastructure; more accurate inventories of greenhouse gases and pollutants; and a better understanding of renewable energy potential."

The scope of the GEO Energy SBA includes both energy derived from non-renewable energy sources (e.g., coal, oil, and gas) and from renewable energy sources (e.g., as listed in Section 3.2). For either of these broad energy types, the Energy SBA includes aspects from exploration and production to monitoring, operation, and forecasting activities required for energy facilities. The Energy SBA also includes energy applications such as cooking, industrial processes, generating heat, and transportation fuels, rather than electricity generation applications. Further, transportation and consumption of energy falls within the Energy SBA, as does assessment of environmental impacts and reduction of weather-related and other risks to energy infrastructure. Finally, improved technologies for stabilizing or reducing greenhouse gas emissions, and the need to report energy emissions levels to bodies such as the United Nations Climate Change Convention, fall within the Energy SBA. Note that Climate is identified as a separate SBA by GEO, although closely linked with the Energy SBA.

### 3.2. Renewable Energy Sub-areas

In order to bound the Task US-09-01a analysis to a manageable scope, the Analyst made a preliminary decision in consultation with selected members of the UIC[4] to focus on renewable energy. During a teleconference in December 2008, the Advisory Group concurred that renewable energy, and all its sub-areas, is an appropriately sized subset of related topics that would lend itself well to this analysis task. As noted below, although all renewable energy areas were candidates for analysis, the Analyst and Advisory Group determined that six sub-areas of renewable energy should be thoroughly analyzed.

The Analyst evaluated both electricity generation and other applications of renewable energy (e.g., heating, transportation fuels) for inclusion in the analysis. For electricity generation, the IEA WEO (2008a) was helpful in determining which subsets of renewable energy to include. The IEA document represents a consensus document as it draws on a worldwide body of experts and presents a projection of the world energy mix out to 2030, shown in Figure 1. The Analyst used the IEA document both for scope selection and for Earth observation prioritization, as noted previously.

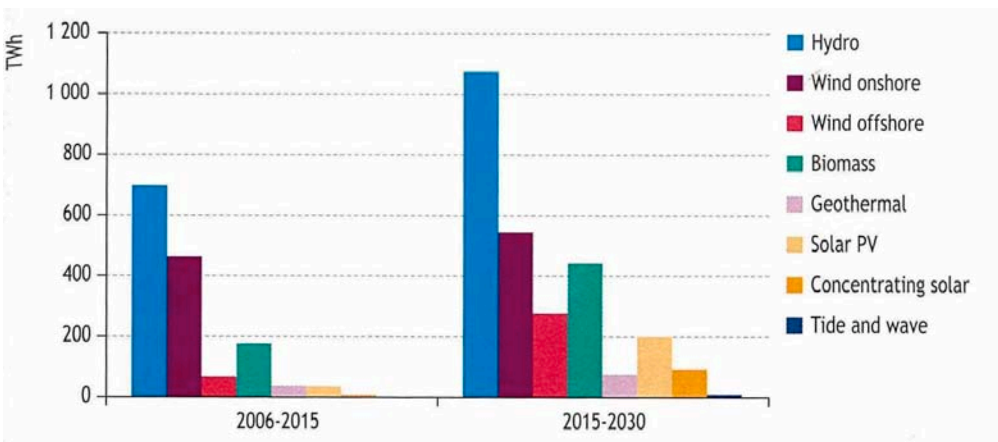


**Figure 1. Increase in World Electricity Generation from Renewable Energy in the World Energy Outlook 2008 Reference Scenario.**

Source: IEA 2008a, Figure 7.3

The Advisory Group suggested that all renewable energy sub-areas that appeared in the IEA projection would be prominent enough now and in the future that they could be included in the analysis. The Advisory Group also noted that different sub-areas are important to different regions, and certain sub-areas are especially relevant in developing countries. In particular, several Advisory Group members encouraged the inclusion of bioenergy and hydropower

[4] Personal communication with UIC contacts for Task US-09-01a, Ellsworth LeDrew, Institute of Electrical and Electronics Engineers (IEEE), and Lawrence Friedl, NASA Applied Sciences Program Manager, Washington, DC, March 2008.

(particularly micro- and small-scale) as important sub-areas for developing countries. In addition, the Analyst noted that documents describing transportation biofuels tended to focus on developing countries, and thus the Analyst included transportation biofuels in the analysis. Given limited project resources, the Analyst decided to exclude tide/wave energy because it is projected to be the smallest in both timeframes (2006 to 2015 and 2015 to 2030). Also, the Analyst chose to consider Solar Photovoltaics (PV) and Concentrating Solar Power (CSP) together in a single section of this report.

The Analyst chose to focus principally on renewable-based electricity generation because it is the primary application for most renewable energy sub-areas. Renewable-based electricity generation is projected to increase more than two-fold over the next 20-plus years. The share of total electricity output from renewable sources is anticipated to rise from 18% in 2006 to 23% in 2030, becoming the second largest source of electricity (behind coal) by 2015 (IEA, 2008a). In addition, the Analyst chose to include transportation biofuels because they are currently the fastest growing energy sector. Although transportation biofuels currently represent only 1.5% of total road transport fuel, transportation biofuels are expected to increase by a factor of 10 to 20 relative to current levels by 2030 (IEA, 2009). Additional applications of renewable energy such as solar and geothermal heating are included to the extent that the documents identified included these applications, although the Analyst did not expressly search for documents on these applications.

The six major renewable energy sub-areas included in this analysis are briefly described below. For more information on each of these sub-areas, refer to the GEOSS Energy Community of Practice website (http://www.geoss-ecp.org/) or the IEA "Renewable Energy RD&D Priorities 2006" (IEA, 2006):

- Solar Energy: The generation of electricity or heat from the sun's energy, typically accomplished by PV or CSP. PV cells convert sunlight directly into electricity and are made of semiconductors. CSP technologies use reflective materials to concentrate the sun's heat energy to drive an electric generator (IEA, 2006).

- Wind Energy (onshore or land-based): The generation of electricity from turbine facilities located on land.

- Wind Energy (offshore): The generation of electricity from wind turbine facilities located away from land on coastal or oceanic sites. (Note that onshore and offshore wind are treated jointly in Section 4.2 of this report due to their common observation needs, but are listed separately in the IEA WEO (IEA, 2008a).

- Hydropower: The generation or storage of electricity from water flow, in some cases through lakes and reservoirs. This report includes micro-hydropower (typically 300 kW or less), small hydropower (typically 10 megawatts, MW, or less), and large hydropower (typically greater than 10 to 50 MW).[5]

- Bioenergy: The generation of electricity from any plant or animal matter, typically through combustion processes, and the use of bio-based fuels for transportation. The current sources of bioenergy for electricity generation are mainly forestry, agricultural and municipal residues, and wastes, and the current sources of bioenergy for transportation fuels are mainly sugar, grain, and vegetable oil crops. This document includes both current bioenergy sources and sources under development such as grasses for transportation biofuels (IEA, 2009).

- Geothermal Energy: The generation of electricity based upon the use of heat in the Earth. Large amounts of heat at or below the surface can be used to generate pressurized steam to power electric turbines and/or heat nearby structures.

### 3.3. Documents

The Analyst and the Advisory Group identified 71 documents as being potentially relevant to Earth observation priorities for the renewable energy sectors of focus in this report. The Analyst reviewed all of these documents, and found that 54 of the 71 contain specific details regarding Earth observations, either current or desired. A list of the 54 references that the Analyst included in the analysis is contained in Appendix B; note that not every document is cited individually in the text of this report.

As described in Section 2.3.1, the Analyst sought documents from a variety of sources with the intent to be representative of both global views and regional views. Of the 54 documents included, the distribution by region and sub-area is shown in Table 2.

**Table 2. Distribution of the 54 Relevant Documents for the Energy SBA.**

| Geographic Region | Number of Documents | | Renewable Energy Sub-area | Number of Documents* |
|---|---|---|---|---|
| International | 22 | | Wind (land-based) | 16 |
| Africa | 4 | | Wind (offshore) | 19 |
| Asia | 7 | | Solar | 17 |
| Europe | 15 | | Hydropower | 13 |
| North America | 9 | | Bioenergy | 15 |
| Oceania/Australia | 5 | | Geothermal | 13 |
| Polar Regions | 0 | | | |
| South/Central America | 4 | | | |

* Many documents address multiple renewable energy types, so the column adds up to >54 documents total.

[5] Both micro- and small hydropower tend to be run-of-the-river facilities that provide renewable energy without interfering significantly with river flows, and are thus generally considered environmentally benign according to the documents analyzed. The documents indicated that large-scale hydropower has considerable environmental impacts, and is not always viewed as renewable energy. However, the documents did not provide a clear distinction among Earth observations required according to application size, and thus all application sizes are included in this analysis.

# 4. Earth Observations for Energy SBA

## 4.1. Solar Energy

The Analyst began with the 17 documents deemed relevant to Earth observation requirements for solar energy. Several organizations produced these documents, including the IEA, United Nations Environment Programme (UNEP), the European Space Agency (ESA), NASA, and the U.S. Department of Energy National Renewable Energy Laboratory (NREL). These documents included organization planning and program documents, and peer-reviewed journal articles, many with co-authors from the organizations noted above. The Analyst considered all of these types of documents valid for inclusion in the analysis, as they either represented broad consensus of an organization or included one or more authors affiliated with an internationally recognized organization.

The majority of documents (15) address the use of currently available data and indicate their adequacy in meeting user needs. The Analyst identified two documents that directly address user needs: a survey conducted by the GEO Energy COP of solar energy data end users (Huld et al., 2007), and a program description of the ESA-sponsored ENVISOLAR program (Environmental Information Services for Solar Energy Industries) (Bofinger et al., 2007). Because the COP survey and the ESA program description directly address user needs, the Analyst considered these two documents "primary" sources as described in Section 2.3.2.[6] The Analyst extracted detailed data as described in Section 2.3.2 for each of the 17 relevant documents.

Because the GEO Energy COP user survey was one of the primary analysis documents, the Analyst examined the geographic breakdown of the survey respondents. Out of 111 respondents, 85% are from Europe, and the rest are roughly equally distributed among Asia, Africa, and North America, with South/Central America being least represented, and Australia being notably absent from the survey respondents. Thus, the document offers a limited degree of global representation. The Analyst augmented this primary document with the ENVISOLAR document that includes broader geographic representation, including projects being implemented in Africa and Asia, and other documents as classified in Section 3.3.

Table 3 presents the Earth observation requirements for solar energy outlined in the documents. The Analyst constructed this table following the methodology described in Section 2.3.2. For the GEO Energy COP survey results, the Analyst chose to include in Table 3 the parameters or parameter characteristics that half or more of survey respondents ranked highly. The Analyst then supplemented these parameters with those identified in the ENVISOLAR document (Bofinger et al., 2007), and added parameters from other relevant documents. Direct normal

[6] Note that this US-09-01a document covered all uses of solar energy, including electricity and solar energy for heating and cooling. Thus, Huld *et al.*, 2007 represents the broader category of solar energy beyond electricity generation, although the remaining solar energy documents mentioned in this report focus on electricity generation alone.

irradiation (DNI) and global horizontal irradiation (GHI) are key parameters for this sub-area, based on information from the documents and input from the Advisory Group.

**Table 3. Earth Observation Parameters for Solar Energy.**

| Parameter Type | Priority Parameters |
|---|---|
| Characterization of Solar Resource | **Direct normal irradiation (DNI)**<br>**Global horizontal irradiation (GHI)**<br>Diffuse irradiation<br>Inclined plane radiation<br>Cloud cover (cloud index)<br>Circumsolar ratio |
| Meteorological Parameters | Wind speed<br>Wind direction<br>Ambient air temperature |
| Atmospheric Composition | Aerosol optical depth (AOD)<br>Water vapor content<br>Atmospheric ozone content |

Parameters listed in **boldface type** are key parameters for this subarea. Also, note that some derived parameters listed here may rely upon the measured parameters also listed in this table.

The rest of this section is a summary of all information that the Analyst found in the documents on the required parameter characteristics. This discussion includes all information from the source documents. Details of some required parameter characteristics are not included because they are not present in the source documents.

DNI and GHI are derived parameters calculated with a radiative transfer equation that incorporates the measurements of the cloud index and atmospheric composition, according to several documents. Thus, although the GEO Energy COP survey document did not explicitly identify parameters such as cloud index, AOD, atmospheric ozone content, and water vapor content as of interest to end users, the Analyst included these parameters in Table 3 as priority observations (on which other priority observations rely). The need for DNI, GHI, or both depends upon the specific solar technology under consideration by the user (Cogliana et al., 2008). Furthermore, the required parameter characteristics of DNI and GHI, and other parameters listed in Table 3, depend upon the intended use of the data, such as the stage of the application (site selection vs. planning vs. operation). The documents indicated that, in general, earlier stages, such as resource assessment of a country, require relatively coarse spatial and temporal resolution data, while individual project planning and operation require increasing degrees of resolution. Note, however, that the GEO Energy COP survey requested the desired parameter characteristics (e.g., spatial resolution) in a separate section from the desired parameters, making it difficult for the Analyst to connect parameters with precise desired characteristics. Thus, the discussion below applies generally to the solar energy parameters as listed in Table 3.

In terms of temporal resolution and timeliness, the documents indicated a wide range of needs for solar resource information, depending upon the intended use of the information. For resource assessments and trend analysis, there is more end user interest in long-term averages (annual or monthly) than in very short-term averages (less than 1 hour). However, for solar technology simulations during project planning and for reliability checks during plant operation, users are interested in GHI or other solar parameters in 5-minute to hourly resolution (for example, see Bofinger et al., 2007). Similarly, the documents indicated that users need information used for plant operation in near-real time, while other applications require only archived data.

In terms of spatial resolution, the documents indicated that the highest end user interest is in data on a scale of 1 $km^2$ to 10 $km^2$. In the absence of additional information on ideally required spatial resolution, the Analyst referred to other documents that address spatial resolution relative to currently available data. These other documents noted, for example, that users need an unspecified increase in concentration of DNI measurements in India, Italy, and Spain (above an unspecified current level), and that underdeveloped regions such as parts of Africa lack single-point data entirely. Only one document provided quantification of the need for higher spatial resolution, noting that, in Germany, the density of ground stations is one per 8500 $km^2$, which the document stated is inadequate (Bofinger et al., 2007).

In terms of accuracy, the documents presented a wide range of information, augmented by input from the Advisory Group. The information on accuracy was limited to the adequacy of current information rather than the absolute quantitative terms of accuracy required by end users. With the possible exception of GHI, the documents and Advisory Group generally indicated that the accuracy of currently available solar data is inadequate. GHI accuracy currently ranges from 5 to 20% relative root mean square error (rRMSE), and DNI accuracy currently ranges from 15 to 35% rRMSE (Bofinger et al., 2007). Although no documents quantified the desired improvement in accuracy, one document noted that end users especially require increased accuracy of DNI, because the current inaccuracy in highly variable DNI calculations hinders private investment in CSP.

Several documents indicated that forecasted parameters, such as GHI and DNI, are required for efficient operation of a facility and planning for grid integration, anywhere from hours to months in advance (Huld et al., 2007 and Bofinger et al., 2007). The documents indicated that forecasted parameters are typically derived from forecast models that rely upon inputs of current and historical parameters, such as meteorological observations. The need for forecasted parameters gives added importance to the need for observation of meteorological parameters, along with development and refinement of appropriate models. However, the documents did not provide specifics on the parameter characteristics required for such models to meet end user needs.

**Summary of Solar Energy Parameters Required by End Users**
DNI and GHI are key parameters required by end users for solar energy applications. These derived parameters rely upon several other parameters, as detailed above. Depending upon the application, users need temporal resolution of 5 minutes to annual averages, and spatial resolution of 1 $km^2$ to 10 $km^2$. The limited available information on required accuracy indicates that the accuracy needs to be improved above that of current solar resource data (e.g., 15 to 35% rRMSE currently for DNI). Forecasts of DNI and GHI, from hours to months in advance, are particularly important.

## 4.2. Wind Energy (Land-based and Offshore)

The Analyst began with the 25 documents deemed relevant to Earth observation requirements for wind energy. Several organizations produced these documents, including the IEA, UNEP, NASA, and NREL. These documents are either official reports of the agency or online documentation of data needs and uses related to wind energy. These documents included six peer-reviewed journal articles that describe current applications of Earth observations with respect to wind energy and any noted shortcomings. The journal articles typically have multiple authors and often include representatives from the organizations noted above.

The majority of documents (23) address the use of currently available data and indicate its adequacy in meeting user needs. Similar to the solar energy documents discussed in the previous section, the Analyst considered all of these types of documents valid for inclusion in the analysis. The Analyst identified two documents that directly address user needs: a survey conducted by the GEO Energy COP of wind energy data end users (Ranchin et al., 2007), and a European Wind Energy Association prioritization of strategic wind energy research needs (EWEA, 2005). Because these two documents address user needs, the Analyst considered these documents to be “primary” sources as described in Section 2.3.2. The Analyst extracted detailed data as described in Section 2.3.2 for each of the 25 most relevant documents.

Because it was used as one of the primary documents for analysis, the Analyst examined the geographic breakdown of the GEO Energy COP user survey respondents. The survey respondents are primarily from Europe (75%), with 13% from North America, 8% from Oceana, and 4% from Africa. The Analyst augmented this primary document with the EWEA document, also biased toward Europe, and brought in other documents where available to provide geographic diversity, as classified in Section 3.3.

Table 4 presents the Earth observation requirements for wind energy outlined in the documents. The Analyst constructed this table following the methodology described in Section 2.3.2. For the GEO Energy COP survey results, the Analyst chose to include in Table 4 the parameters ranked highly by half or more of the survey respondents. The Analyst then supplemented these parameters with those identified in the EWEA document (EWEA, 2005), and added parameters from other relevant documents to this list. Wind speed at turbine hub height (30 m to 200 m for utility-scale power) is the key parameter for this sub-area, based on information from the documents and input from the Advisory Group.

**Table 4. Earth Observation Parameters for Wind Energy.**

| Parameter Type | Priority Parameters |
|---|---|
| Meteorological Parameters | **Wind speed**<br>Wind direction<br>Vertical wind profile<br>Turbulence<br>Wind shear<br>Relative humidity<br>Ambient air temperature<br>Atmospheric pressure |
| Land Parameters | Topography/elevation<br>Land cover<br>Surface roughness |
| Offshore Environment Information | Wave height<br>Current speed<br>Tides<br>Bathymetry<br>Sea surface temperature |

Parameters listed in **boldface type** are key parameters for this subarea. Also, note that some derived parameters listed here may rely upon the measured parameters also listed in this table.

The rest of this section is a summary of all information that the Analyst found in the documents on the required parameter characteristics. This discussion includes all information from the source documents. Details of some required parameter characteristics are not included because they are not present in the source documents.

Earth observation parameters are required for assessing wind resources and assessing the environment (onshore or offshore) where a wind energy facility may be located. In addition, facility operation and maintenance, cost assessment, grid integration, and energy trading are among the other user applications of Earth observation data (Ranchin et al., 2007). The required parameter characteristics depend upon the intended use of the data. The Analyst tried to capture the broad range of potential uses in the following discussion.

Most of the documents that address wind energy end user needs focus on the required characteristics of the meteorological parameters listed in Table 4, and specifically on wind speed, direction, and vertical wind profile. Thus, the following discussion focuses primarily on these three parameters, including specification of the exact parameter referenced when available. The discussion concludes with the limited information that the Analyst found in the documents on required characteristics of the other meteorological parameters, land parameters, and offshore environment information included in Table 4.

The documents indicate a broad range of end user needs in terms of horizontal spatial resolution of data. For applications such as system design and operation, the documents indicate end user needs on the order of 100 $m^2$ to 1 $km^2$. For applications such as feasibility studies, site selection, and investment decisions, the documents indicate end user needs on the order of 10 $km^2$ to 25 $km^2$, and even up to 400 $m^2$. The Analyst inferred that the 100 $m^2$ to 400 $km^2$ scale state-of-the-art products from programs such as SWERA (Solar and Wind Energy Resource Assessment) are meeting current user needs (potentially distinct from ideally required user needs).

One primary document by the EWEA addresses horizontal spatial coverage, noting that there is a need for mapping wind speed and direction for many offshore areas, including 5 to 50 km offshore where many wind facilities are likely to be located. The EWEA document recommends mapping of the Baltic, North, and Black Seas (EWEA, 2005). The need for more mapping of offshore areas was confirmed by many other documents, highlighting the inadequacies in coverage of wind speed and direction measurements.

The documents indicate the importance of vertical wind profiles to end users, without providing specifics on height ranges needed. In addition to profiles, the documents noted that wind speed, direction, and turbulence measurements are needed at wind turbine hub height, which has generally been increasing over the years. Hub height varies from 10 to 30 m for land-based rural power, to 30 to 80 m for land-based utility scale power, to 100 to 200 m for offshore wind facilities (Barthelmie et al., 2005 and Ranchin et al., 2007).

In terms of temporal resolution, the documents indicate a very wide range of user needs. While the documents identify hourly average data as the most important to end users, the documents also identify a wide range of temporal resolutions (seconds, to 5 minute, to annual averages) as high priority (Ranchin et al., 2007). End users need hourly or finer data for near-ground level historical data used to plan a wind generation facility, and hourly data for vertical wind profiles that support wind modeling (U.S. NASA, 2008). Data as fine as several seconds is needed for understanding turbulence for wind facility design. For annual average data, such as that which might be derived from a long-term record of scatterometer data, end users need better (unspecified) diurnal variation to capture different parts of a day with varying wind speeds.

Several documents address the required timeliness of wind resource data, which again highlights the differences in end user needs depending on the application. The EWEA document indicates that near real-time (“immediately available”) data are particularly relevant for operators of large wind farms and for wind forecasting (EWEA, 2005). Other documents note that end users require historical data (several days to several years old) for wind-based electricity generation facility planning.

A majority of the documents note that an improvement in accuracy over that of current wind resource information is needed. The need for improved accuracy is prioritized as an urgent “show stopper” by the EWEA document (EWEA, 2005). The EWEA document notes that, especially for short-term averages, an error of 10% between measured and actual wind speed is “too much” for financiers, insurers, and project developers. However, for longer term annual averages, a U.S. NREL document notes that wind speed within 10% is adequate to stimulate the development of wind energy in a study region (U.S. NREL, Undated). For reference purposes, the documents note that the current accuracy of satellite-based wind resource data, for example, is within “a few meters per second” for wind speed and approximately 20 degrees for wind direction (Mathieu, 2005).

As for the other required meteorological, land, and offshore environment parameters and parameter characteristics, the documents provide limited information. The documents indicate topography as being a priority parameter for end users but do not provide the ideally required parameter characteristics. The Analyst inferred some information on required spatial resolution of topography by referencing the adequacy of the spatial resolution of current topography data. The documents indicate that current topography data at 1 $km^2$ resolution is adequate for regional but not local wind resource assessments, and that finer gridded data are needed to improve the accuracy of wind model outputs (Elliott et al., 2001 and U.S. NREL, Undated). The required spatial resolution also depends on the relief in the area, and contour maps of 5 to 10 m elevation intervals are being used for wind facility planning studies.

The documents provide limited information on the parameter characteristics of the required offshore environment information, including wave height, tides, currents, bathymetry, and sea surface temperature. End users need wave height information in a wide range of temporal resolutions, primarily in hourly to monthly averages (but with moderate interest in data down to 15-minute averages) (Ranchin et al., 2007). End users also require forecasts of wave heights from a few hours to a few days in advance for operation and maintenance of offshore wind facilities. The documents do not specify the underlying Earth parameters required for such forecasts (e.g., Boud, 2003).

Several documents discuss the need for meteorological parameters such as dew point, ambient air temperature, and atmospheric pressure for inputs to wind resource models. These documents do not specify required parameter characteristics, but note that such meteorological parameters are increasingly needed in higher temporal and spatial resolution to keep pace with improving models. For reference purposes, one document indicates that the current temporal resolution of wind resource models is hourly, and that increased (unspecified) spatial resolution is needed to correspond with each node of the high voltage grid (Lange et al., 2006).

Several documents address land parameters needed for wind resource models and for micro-siting of facilities, without specifying required parameter characteristics. The land parameters include classified land cover (including tree cover density) for use in calculating surface roughness. Also, end users need improved methods of interpreting surface reflectance data to differentiate snow cover from clouds (U.S. NASA, 2008).

**Summary of Wind Energy Parameters Required by End Users**

Wind speed at turbine hub height (30 m to 200 m for utility-scale power) is the key parameter for this sub-area, based on information from the documents and input from the Advisory Group. Other parameters of high priority are wind direction, vertical wind profiles, and topography. Depending upon the application, users need a wide range of temporal resolutions, from several seconds, to 5-minutes, to annual averages, and horizontal resolutions ranging from 100 $m^2$ to 25 $km^2$. Both near-real time availability of data and historical archives are important. Improving accuracy above the current level of 10% error between measured and actual wind speed is critical for short-term data (e.g., hourly). End users particularly require the mapping of wind resources in near-shore areas (5 to 50 km offshore).

## 4.3. Hydropower

For the following analysis, the Analyst relied upon 13 documents that address application of Earth observations for hydropower. These documents provide information on the adequacy of current observations rather than ideally required user needs. The 13 relevant documents include two IEA documents, seven peer-reviewed journal articles, one government report, and the website of the U.S. Department of Agriculture (USDA), Foreign Agricultural Service. The documents provide reasonably broad geographic coverage, including Asia, Africa, Europe, and North America, and address both developed and developing countries. The Analyst extracted detailed data as described in Section 2.3.2 for each of the 13 most relevant documents.

Table 5 presents the Earth observation requirements for hydropower as outlined in the documents. The Analyst constructed this table following the methodology described in Section 2.3.2. Water run-off is the key parameter for this sub-area, based on information from the documents and input from the Advisory Group.

**Table 5. Earth Observation Parameters for Hydropower.**

| Parameter Type | Priority Parameters |
|---|---|
| Water Parameters | **Water run-off**<br>Stream/river flow<br>Lake/reservoir height<br>Snow water equivalent<br>Groundwater storage<br>Near-surface water and sea-surface temperature (for large lakes) |
| Meteorological Parameters | Precipitation<br>Air temperature<br>Wind speed<br>Relative humidity<br>Pressure<br>Cloud cover |
| Land Parameters | Topography/elevation<br>Land cover<br>Snow cover<br>Synthetic aperture radar images |

Parameters listed in **boldface type** are key parameters for this subarea. Also, note that some derived parameters listed here may rely upon the measured parameters also listed in this table.

The rest of this section is a summary of all information that the Analyst found in the documents on the required parameter characteristics. This discussion includes all information from the source documents. Details of some required parameter characteristics are not included because they are not present in the source documents.

Similar to other renewable energy types, different stages of hydropower assessment, development, and operation require different sets of Earth observations. Earth observations are needed for hydropower projects to identify and develop potential sites, conduct site management and operations, and conduct historical analysis on the performance of hydropower projects. End users involved with different scales of hydropower require different parameters (e.g., stream flow, reservoir height) at different spatial resolution (e.g., ranging from meters to kilometers).

For example, micro-scale hydropower is derived from several meter-wide streams whereas reservoir hydropower is derived from bodies of water that can be tens of kilometers across.

The key parameter for hydropower, water run-off, is over-land flow of water resulting from either precipitation or melting of snow, glaciers, or ice. The calculation of water run-off requires hydrology and meteorology data as well as snow cover and numerical weather prediction (NWP) models. Water run-off is a modeled parameter that can be calculated in historical or near-real time, or forecasted. One document mentioned a need for hourly water run-off information, while another document mentioned a need for monthly water run-off information for historical analysis. Since water run-off is a modeled parameter, its characteristics depend upon the characteristics of the input parameters. In fact, many parameters listed in Table 5 are inter-related. For example, snow cover and snow water equivalent are based on underlying parameters of topography, synthetic aperture radar (SAR) images, cloud cover, and land cover classification (a derived parameter) (Larsen et al., 2005). Evaporation is based on wind speed, near-surface and sea-surface temperature, humidity, and pressure. The rest of this section summarizes the limited information provided in the documents on user needs for these interrelated parameters.

The documents indicate that end users need a snow water equivalent product at a finer spatial scale than that which is currently available (7 $km^2$ scale, for one particular product) for operational deployment. The documents also note that hydropower companies are currently using snow cover at 250 $m^2$ spatial resolution, and snow water equivalent at 375 $m^2$ spatial resolution, as provided by the EO-Hydro Service within the ESA Earth Observation Market Development (EOMD) Program (Larsen et al., 2005). The Analyst did not identify any further indication of adequacy of currently available information.

For precipitation and water run-off, the required spatial resolution can be as small as several square kilometers, and varies with the watershed catchment size. The documents note that current coverage of ground-based rain gauges for large-scale hydropower projects is inadequate. The documents only indicate that such gauges are sparse without providing an ideal target. The documents also note that precipitation data are currently available on a spatial resolution of 0.25 by 0.25 degrees for tropical regions (from the Tropical Rainfall Measuring Mission [TRMM], in a data product that integrates ground-based rain gauge data), without any indication of adequacy.

Similarly, the Analyst did not identify any information on the adequacy of the spatial resolution of current data on lake/reservoir heights or groundwater storage. For reference purposes, lake or reservoir heights are currently available as an average lake-height along a satellite track, from every 350 m to 580 m (as provided by satellite altimeters such as the NASA/Centre National d'Etudes Spatiales (CNES) Topex/Poseidon and Jason-1 and Jason-2 satellites). Groundwater storage is currently available on the spatial scale of a few hundred kilometers or greater (e.g., from the Gravity Recovery and Climate Experiment, GRACE), although the Analyst did not identify any indication of adequacy.

In terms of spatial coverage, the documents did not address ideally required information, but did give some indication of currently available coverage. For example, lake or reservoir heights provided through the USDA Global Reservoir and Lake Monitor project cover approximately

100 lakes worldwide, and other services (e.g., from the French space agency CNES) include a broader set of lakes (Swenson and Wahr, 2009 and U.S. Department of Agriculture, 2009). The precipitation data provided by TRMM covers the tropics between 35 degrees north and south. One document notes that classification of satellite imagery is needed for identification of potential small and micro-hydropower resources in complex terrain (e.g., in mountainous areas of India) (Dudhani et al., 2006).

In terms of temporal resolution of lake and reservoir height data, the documents do not provide any indication of adequacy. For reference purposes, lake and reservoir height data are available every 10 to 35 days, approximately 7 to 10 days after satellite overpass. Timeliness is also addressed in terms of the adequacy of some current methods of data collection (Dudhani et al., 2006). Topographical surveys that are 8 to 10 years old are considered too old for small-hydropower and micro-hydropower project implementation, implying a need for topographical data that are updated in a more timely fashion. Finally, the timeliness of the EO-Hydro Service water run-off product is characterized as near-real time, and designed as such to meet hydropower company needs.

Temporal resolution is also an issue for measurement of elevation/topography. One Advisory Group member noted that repeated monitoring (at an unspecified interval) is needed to monitor land subsidence related to large reservoirs, and glacier height.

In terms of accuracy, several documents address the adequacy of the accuracy of currently available information, although primarily in a qualitative manner. Lake or reservoir heights (provided through the USDA Global Reservoir and Lake Monitor project) have accuracy to within 10 cm root mean square (RMS), or 3 to 4 cm RMS for large lakes, which is considered "excellent" and is adequate for estimating lake discharge (Swenson and Wahr, 2009 and U.S. Department of Agriculture, 2009). Groundwater storage information from GRACE has accuracy, for example, over the Caspian Sea of approximately 5 cm RMS, indicated as "quite consistent," on seasonal and inter-annual timescales (Swenson and Wahr, 2009). Precipitation data from TRMM, when compared to rain gauges in Ethiopia near Lake Victoria, show errors of about 25% RMS, and biases of about 10%, although the documents do not address adequacy of this accuracy. One Advisory Group member noted a need for water run-off with an accuracy of 3% or more. The accuracy of the snow cover and snow water equivalent parameters provided by the EOMD program is not currently publicly available because the parameters are based on comparison with ground-based observations that are the property of hydropower companies. However, the accuracy is reported to be satisfactory to the end users (Tampellini et al., 2007). A separate document on snow water equivalent in Norway notes that the product is averaged to a 7 km by 7 km grid to obtain "sufficient accuracy," without providing further quantification.

**Summary of Hydropower Parameters Required by End Users**
Water run-off is the key parameter for this sub-area, based on information from the documents and input from the Advisory Group. Because water run-off is a modeled parameter, its characteristics depend upon the characteristics of the hydrological and meteorological input parameters. Such parameters include snow water equivalent, precipitation, and lake/reservoir height. The required temporal resolution of water run-off and the associated input parameters is hourly to monthly averages. Because the scales of hydropower vary widely, the required spatial resolution ranges from a few hundred meters to tens of kilometers. Similarly, the required timeliness of data ranges from forecasted and near-real time information to archived historical data.

### 4.4. Bioenergy

This analysis is based upon the 15 identified documents that indirectly address user needs for bioenergy-related Earth observations, focusing on the level of adequacy of currently reported observations. The 15 relevant documents include reports from the IEA and peer-reviewed journal articles. The geographic area of interest across the 15 documents has a strong focus on Asia, and also includes South America, North America, and Europe. The Analyst extracted detailed data as described in Section 2.3.2 for each of the 15 most relevant documents. As discussed in Section 3.2, this section includes both the generation of electricity from bio-based sources, and bio-based transportation fuels.

The key determinant of the Earth observation parameters required for bioenergy is the source of the biomass. The three major categories of biomass are:

- Residues (e.g., from forestry and agriculture activities, or industrial facilities)
- Organic waste streams (e.g., methane from landfills)
- Purpose-grown energy crops (e.g., grass production on pasture land, wood plantations and sugar cane on arable land).

The documents that the Analyst and Advisory Group identified address purpose-grown energy crops and forestry and agricultural residues; no documents were identified that address organic waste streams. The documents indicate that specific crops and residues which may be used for electricity generation or transportation fuels vary by region, and are strongly influenced by market conditions and agricultural policies. The field of bioenergy is evolving such that new feedstocks are constantly being explored. A crop-specific or residue-specific analysis of Earth observation parameters for bioenergy would be speculative at best. However, the Analyst identified some common Earth observation needs across multiple types of bioenergy feedstocks in the documents.

Table 6 presents the Earth observation requirements for bioenergy as outlined in the documents. The Analyst constructed this table following the methodology described in Section 2.3.2. Land cover and vegetation indices (NDVI and NPP) are the key parameters for this sub-area, based on information from the documents and input from the Advisory Group.

**Table 6. Earth Observation Parameters for Bioenergy.**

| Parameter Type | Example Parameters |
|---|---|
| Land Information | **Land cover (including ecosystem type and identification of specific crops)**<br>Elevation/topography<br>Texture |
| Vegetation and Soil Information | **Normalized Difference Vegetation Index (NDVI)**<br>**Net Primary Productivity (NPP)**<br>Evapotranspiration<br>Soil Moisture<br>Soil carbon content<br>Groundwater storage |
| Meteorological Parameters | Precipitation<br>Air temperature<br>Relative humidity<br>Surface temperature |
| Characterization of Solar Resource | Direct normal irradiation (DNI)<br>Global horizontal irradiation (GHI)<br>Spectral distribution<br>Cloud cover (cloud index) |

Parameters listed in **boldface type** are key parameters for this subarea. Also, note that some derived parameters listed here may rely upon the measured parameters also listed in this table.

Earth observation parameters can be applied to both identify locations for potential new bioenergy crops, and to monitor and predict yields for crops already being grown and residues being harvested. Unlike other renewable energy sub-types covered in this report, the documents addressing bioenergy particularly focus on its environmental impacts, as a major driver of future bioenergy practices. For example, many documents discuss land use change, noting that transportation biofuels produced from crops grown on converted forest land strongly impacts land cover, and subsequently, reduces terrestrial carbon sequestration and contributes to climate change.

The rest of this section is a summary of all information that the Analyst found in the documents. This discussion includes all information from the source documents, which in the case of bioenergy, was limited to addressing the adequacy of current observations. Details of some required parameter characteristics are not included because they are not present in the source documents.

In terms of spatial resolution, the documents indicated user needs ranging from 15 $m^2$ to 10 $km^2$. The documents noted that Earth observations on a 1-$km^2$ scale, for example, of NPP, lend themselves to provincial- and country-level analyses (Elmore et al., 2008). On the other hand, identification of specific crops (e.g., African Palm for biodiesel) for assessment of land-use impacts of biofuels was conducted on a 15$m^2$ scale; the Analyst inferred that this 15$m^2$ scale served end users well who are interested in such local studies (Santos and Messina, 2008).

In terms of temporal resolution, the documents noted a wide range of user needs. Some users required annual averages (for example, of vegetation indices) while others required single snapshots in time (for example, of texture from SAR, to identify African Palm plantations). The

Analyst did not find any additional information on the ideally required user needs, or adequacy of current information, in terms of coverage, resolution, and accuracy.

**Summary of Bioenergy Parameters Required by End Users**

Land cover, NDVI, and NPP are the key parameters for this sub-area, based on information from the documents and input from the Advisory Group. The Analyst found very limited information on ideally required user needs in terms of parameter characteristics, and therefore inferred required parameter characteristics based on statements of adequacy of current observations. The spatial scales of interest are 15 $m^2$ to 10 $km^2$; temporal resolution varies, ranging from single snapshots in time to annual averages.

## 4.5. Geothermal Energy

For the following analysis, the Analyst relied upon 13 documents that address application of Earth observations for geothermal energy. These documents provide information on both the adequacy of current observations and the ideally required user needs. The 13 relevant documents include peer-reviewed journal articles focused on Oceana and Europe, peer-reviewed and gray literature articles describing state-of-the-art geothermal applications, and a report by the U.S. Department of Energy. The Analyst extracted detailed data as described in Section 2.3.2 for each of the 13 most relevant documents.

Table 7 presents the Earth observation requirements for geothermal energy as outlined in the documents. The Analyst constructed this table following the methodology described in Section 2.3.2. Temperature of a geothermal fluid and the rate of change of temperature as depth increases (geothermal gradient), groundwater chemistry, and surface deformation are the key parameters for this sub-area, based on information from the documents and input from the Advisory Group.

**Table 7. Earth Observation Parameters for Geothermal Power.**

| Parameter Type | Example Parameters |
|---|---|
| Characterization of Geothermal Resource | **Temperature of geothermal fluid (at depth)**<br>Fluid pressure<br>**Water Chemistry**<br>Rock Permeability |
| Land Information | Elevation/topography and **surface deformation** (change in elevation)<br>Land cover<br>Land surface temperature |

Parameters listed in **boldface type** are key parameters for this subarea. Also, note that some derived parameters listed here may rely upon the measured parameters also listed in this table.

Surface deformation occurs as a result of the production of geothermal fluids. The documents indicate that surface deformation is needed at a vertical resolution on the scale of millimeters (less than 1 cm) (e.g., Aines et al., 2008). The Analyst did not find any information on the required horizontal spatial scale, but includes the following for reference information. The horizontal spatial resolution, for example, of Interferometric Synthetic Aperture Radar (InSAR), which can be used to measure surface deformation, is 20 to 40 $m^2$. The Analyst infers that this spatial resolution is generally adequate, because the areas of need highlighted in the documents relate to better interpretation of surface deformation rather than increased horizontal spatial resolution. The Analyst did not find any other information in the documents on required accuracy or temporal resolution.

The Analyst did not identify any documents addressing ideal user needs with regard to geothermal gradient, land surface temperature, water chemistry, or the other parameters listed in Table 7. The following references to the adequacy of current observations of these parameters are included for reference information. The documents noted that the evaluation of groundwater chemistry, such as for the presence of borates, can indicate potential sites for development of geothermal power. This is currently being performed using data from ASTER (Advanced Spaceborne Thermal and Emitted Reflectance Radiometer), with a spatial resolution of 15 to 90 $m^2$. ASTER is also being used to measure land surface temperature. The documents did not provide information on the adequacy of this resolution.

**Summary of Geothermal Energy Parameters Required by End Users:**
Temperature of a geothermal fluid and the rate of change of temperature as depth increases (geothermal gradient), groundwater chemistry, and surface deformation are the key parameters for this sub-area, based on information from the documents and input from the Advisory Group. Limited information is available in current documents on the ideally required characteristics of the key parameters. For reference, the horizontal spatial resolution of currently available information is on a scale of 15 to 90 $m^2$, with no information on the adequacy of this scale in the documents analyzed.

## 5. Priority Observations

Given the various forms of renewable energy that were examined in this analysis, the Analyst and the Advisory Group had to both incorporate the diversity of Earth observation needs of different renewable energy types and focus on the highest overall priorities. In doing so, the Analyst followed the methodology detailed in Section 2.3.3.

Tier 1 parameters are those parameters that are key for renewable energy types projected to be prominent according to the IEA WEO (2008a). Figure 2 (identical to Figure 1 earlier in this document) shows the increases from 2006 of each type of renewable energy.

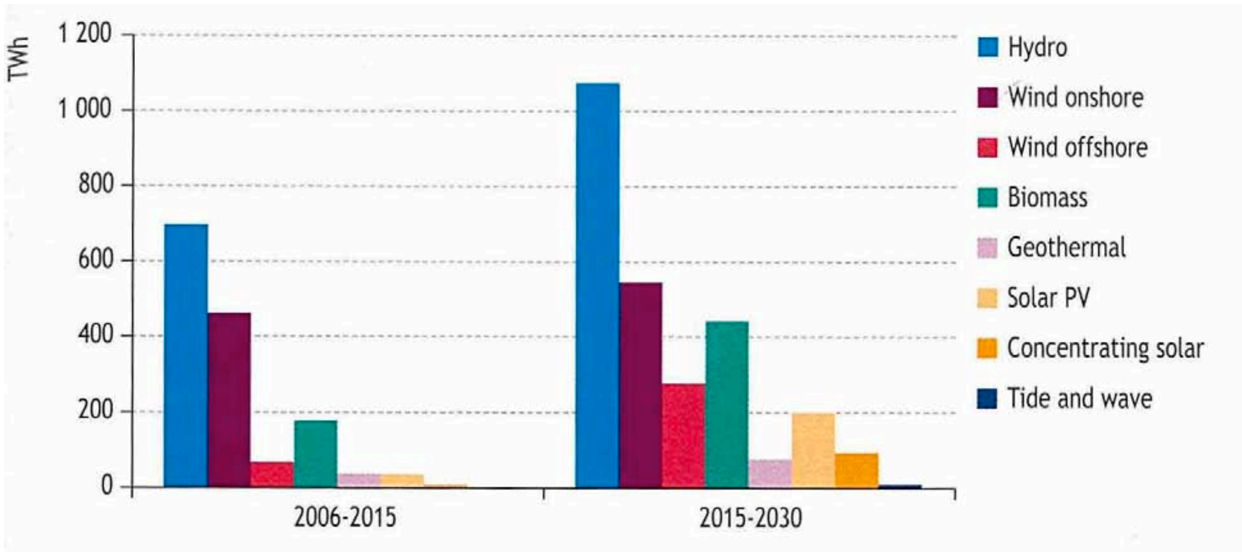


**Figure 2. Increase in World Electricity Generation from Renewable Energy in the World Energy Outlook 2008 Reference Scenario.**

Source: IEA 2008, Figure 7.3 (IEA, 2008a)

Based on analyses by the IEA (IEA, 2008a), in the medium term (2006-2015), hydropower will increase the most, followed by onshore wind, and distantly by biomass. In the long term (2015-2030), hydropower will also increase the most, followed by onshore wind, biomass, and offshore wind. Solar power is of minor prominence in the medium and long term. Table 8 lists the key parameters, as previously identified, for each of these priority renewable energy types. In Table 8, the highest ranked renewable energy types appear first.

**Table 8. Key Parameters for Priority Renewable Energy Types.**

| Priority Renewable Energy Type | Top Parameters Required |
|---|---|
| Hydropower | Water runoff |
| Onshore wind power | Wind speed |
| Bioenergy | Land cover, NDVI, NPP |
| Offshore wind power | Wind speed |
| Solar PV and CSP | DNI, GHI |

Tier 2 parameters are those that are required across multiple types of renewable energy. Table 9 combines the parameters listed for each renewable energy type in Tables 3 through 7 of this document. The check marks indicate that a given parameter is required for a given renewable energy type.

**Table 9. Analysis of Parameters across All Renewable Energy Types.**

| Parameter Type | Parameter | RE Type: Solar | RE Type: Wind | RE Type: Geothermal | RE Type: Hydropower | RE Type: Bioenergy | Total # of RE Types |
|---|---|---|---|---|---|---|---|
| **Solar Resources** | Direct normal irradiation (DNI) | ✓ | | | | ✓ | 2 |
| | Global horizontal irradiation (GHI) | ✓ | | | | ✓ | 2 |
| | Diffuse irradiation | ✓ | | | | | 1 |
| | Inclined plane radiation | ✓ | | | | | 1 |
| | Spectral distribution | | | | | ✓ | 1 |
| | Circumsolar ratio | ✓ | | | | | 1 |
| **Meteorological Parameters** | Air temperature | ✓ | ✓ | | ✓ | ✓ | **4** |
| | Surface temperature | | ✓ | ✓ | ✓ | ✓ | **4** |
| | Wind speed | ✓ | ✓ | | ✓ | | **3** |
| | Relative humidity | | ✓ | | ✓ | ✓ | **3** |
| | Cloud cover (cloud index) | ✓ | | | ✓ | ✓ | **3** |
| | Wind direction | ✓ | ✓ | | | | 2 |
| | Air pressure | | ✓ | | ✓ | | 2 |
| | Precipitation | | | | ✓ | ✓ | 2 |
| | Turbulence | | ✓ | | | | 1 |
| | Wind shear | | ✓ | | | | 1 |
| | Evaporation | | | | ✓ | | 1 |
| **Atmospheric Composition** | Atmospheric ozone content | ✓ | | | | | 1 |
| | Aerosol optical depth (AOD) | ✓ | | | | | 1 |
| | Water vapor | ✓ | | | | | 1 |
| **Land Parameters** | Elevation/topography | | ✓ | ✓ | ✓ | ✓ | **4** |
| | Land cover | | ✓ | ✓ | ✓ | ✓ | **4** |
| | Surface roughness/texture | | ✓ | | | ✓ | 2 |
| | Snow cover | | | | ✓ | | 1 |
| | Synthetic aperture radar images | | | | ✓ | | 1 |
| | Surface deformation | | | ✓ | | | 1 |
| **Offshore Environment** | Wave height | | ✓ | | | | 1 |
| | Tides | | ✓ | | | | 1 |
| | Bathymetry | | ✓ | | | | 1 |
| | Current speed | | ✓ | | | | 1 |
| **Vegetation and Soil** | Normalized Difference Vegetation Index (NDVI) | | | | | ✓ | 1 |
| | Net Primary Productivity (NPP) | | | | | ✓ | 1 |
| | Evapotranspiration | | | | | ✓ | 1 |
| | Soil carbon content | | | | | ✓ | 1 |
| | Soil moisture | | | | | ✓ | 1 |
| **Water** | Lake/reservoir height | | | | ✓ | | 1 |
| | Snow water equivalent | | | | ✓ | | 1 |
| | Near-surface water and sea-surface temperature | | ✓ | | ✓ | | 2 |
| | Stream/river flow | | | | ✓ | | 1 |
| | Water run-off | | | | ✓ | | 1 |
| **Geologic Properties** | Groundwater storage | | | | ✓ | ✓ | 2 |
| | Temperature of geothermal fluid (at depth) | | | ✓ | | | 1 |
| | Water chemistry | | | ✓ | | | 1 |
| | Fluid pressure at depth and rock permeability | | | ✓ | | | 1 |

The parameters that rank the highest based on this Tier 2 analysis are those parameters (shaded in gray in Table 9) that are required for three or four renewable energy types: the meteorological parameters of wind speed, relative humidity, cloud cover, air temperature, and surface temperature, and the land parameters of elevation/topography and land cover. The Analyst deemed that parameters that qualified as both Tier 2 from the analysis in Table 9 and Tier 1 (from the analysis in Table 8) should default to the highest priority (Tier 1).

The resulting tiered list of Earth observation parameters required by end users for renewable energy is presented in Table 10. Tier 1 parameters are of highest priority (roughly in order of importance), and Tier 2 parameters are of medium priority (also roughly in order of importance).

**Table 10. Tiered List of Earth Observation Requirements for Renewable Energy.**

| Tier | Parameter | Required Characteristics of the Observations Parameters | | | | |
|---|---|---|---|---|---|---|
| | | Coverage/ Extent | Spatial | Temporal | Accuracy | Latency |
| **1** | Water run-off | Global land surface | A few hundred meters to tens of kilometers | Hourly to Monthly | Within 3% | Ranges from years old to needed in advance (forecast) |
| **1** | Wind speed | Global land surface and marine coastal zone (5-50 km offshore) | 100m$^2$ to 25 km$^2$ horizontal, 10 to200m+ vertical | From seconds to annual averages | Within 10% of annual average, <<10% for hourly | Ranges from several years old to needed in advance (forecast) |
| **1** | Land cover | Global land surface | 80m$^2$ to 10 km$^2$ | Single measurements to annual averages | Not specified | Not specified |
| **1** | Normalized Difference Vegetation Index (NDVI) | Where bioenergy production is evaluated | 15 m$^2$ to 10 km$^2$ | Single measurements to annual averages | Not specified | Not specified |
| **1** | Net primary productivity (NPP) | Where bioenergy production is evaluated | 15 m$^2$ to 10 km$^2$ | Single measurements to annual averages | Not specified | Not specified |
| **1** | Global Horizontal Irradiation (GHI) | Not specified | 1 km$^2$ to 10 km$^2$ | 5 minutes to annual averages | << 5-20% rRMSE | Ranges from several years old to needed in advance (forecast) |

| Tier | Parameter | Required Characteristics of the Observations Parameters | | | | |
|---|---|---|---|---|---|---|
| | | Coverage/ Extent | Spatial | Temporal | Accuracy | Latency |
| **1** | Direct Normal Irradiation (DNI) | Not specified | 1 $km^2$ to 10 $km^2$ | 5 minutes to annual averages | << 15-25% rRMSE | Ranges from several years old to needed in advance (forecast) |
| **2*** | Elevation / topography | Global to site level | 1 $km^2$ to m-scale (5-10 m vertical contours) | Repeated measurements (unspecified) | Scale of mm | Not specified |
| **2*** | Surface temperature | Not specified | Not specified | Hourly or finer | Not specified | Not specified |
| **2*** | Air temperature | Not specified | Not specified | Hourly or finer | Not specified | Ranges from several years old to needed in advance (forecast) |
| **2*** | Cloud cover (cloud index) | Not specified | Not specified | Not specified | Not specified | Not specified |
| **2*** | Relative humidity | Not specified | Not specified | Not specified | Not specified | Ranges from several years old to needed in advance (forecast) |

* The documents did not often include the required characteristics of Tier 2 parameters, because they were only of modest importance to any single type of renewable energy. Refer to the Analyst's recommendations for filling this gap in Section 7.

# 6. Additional Findings

In the course of conducting this analysis, the Analyst identified some common themes and additional findings which are detailed below. This information relates to the natural endowment of renewable resources, the need for forecasts and long-term records, identification of gaps in the available literature, and the scope of this report. This section also highlights input from Advisory Group members regarding key documents and prioritization methodologies.

The endowment of renewable energy resources varies by continent, region, country, and even sub-regions within a country. As such, parameters that support a specific type of renewable energy (e.g., solar) may be useful in one location and useless in another. In addition, whether driven by natural resource endowment or other political or economic considerations, the Analyst noted that certain regions of the world have pursued specific renewable energy types more than other regions. For example, purpose-grown energy crop activity has historically been focused in Europe, the U.S., and Brazil (Faaij, 2006). Some of the main growth areas for bioenergy are Asia and South and Central America. Thus, the interests of individual nations and regions may drive them to focus on Earth observations that support one or more types of renewable energy. Also, different Earth observation monitoring technologies lend themselves to different scales. Thus, an organization looking to obtain data for a single state or province would not likely select or have the resources for a satellite-based technology option. Although a single set of Earth observation priorities has been identified by this US-09-01a analysis, the complete analysis results in this report may help individual organizations match their monitoring resources with observation needs.

Several documents and Advisory Group members noted that historical records and forecasts of a given parameter are equally important as near-real time measurement of Earth observation parameters. Historical records of parameters are required for understanding trends in renewable resource availability (e.g., DNI) for large-scale resource assessments down to project planning scales. Forecasted parameters are often required for operation of a facility and planning for grid integration, typically on a scale of hours to days ahead. For example, several documents noted that financing of renewable energy projects such as CSP is hindered by the high inter-annual variability of DNI. For CSP projects, at least 10 years of historical data on DNI are required, and 20 years of historical data would be preferable. However, for PV projects, several documents indicated that 3 to 5 years of historical GHI is sufficient, since variability from year to year is low. Similarly, for wind energy, annual average wind speeds can vary up to 10% or more from the long-term means, and annual wind power densities can vary up to 30% or more from the long-term means (UNEP, undated). Thus, one year of anemometer data at a potential wind facility site leaves uncertainty in the expected power output, giving added importance to longer-term satellite-based and/or modeled wind resource data sets.

The documents and Advisory Group members also highlighted the growing role of forecasting, particularly for solar and wind resources. The need for forecasted parameters gives added importance to the need for observation of meteorological parameters that drive the forecast models, along with development and refinement of appropriate models. The characteristics of the forecasted output parameters, such as spatial scale, are dictated by refinements in the model and its input parameters. As an example, wind forecasting relies on NWP models, artificial neural networks, and near-real time wind power measurements. The current time horizon of wind forecasts ranges from 5 minutes to days ahead forecasts of wind power production. The documents noted that unspecified higher spatial resolution of NWP forecasts (to correspond with each grid node of the high voltage grid) is desired (Lange et al., 2006). With regard to accuracy, the current uncertainty of power output is 15% to 20% for forecasting of 6 to 48 hours ahead, and improvements to reduce this uncertainty to 5 to 10% are desired (IEA, 2006). Improvements in wind forecasting are especially needed in complex terrain and for offshore sites (EWEA, 2005). The Analyst found that discussions such as this one on parameter forecasting were prevalent in the literature reviewed.

The Analyst noted that, in general, there are limited documents available that address Earth observation needs for renewable energy. On the contrary, there are many documents available (particularly peer-reviewed journal articles, and also government-generated documents) that discuss state-of-the-art applications of Earth observations for renewable energy. Such documents often focus on a particular technology or current application of data, but do not fit into this US-09-01a analysis because they do not address user needs. For example, several documents focused on the wind measurement technologies of sonic detection and ranging, or SoDAR, and light detection and ranging, or LiDAR, and discussed required accuracy improvements. Also, the U.S. Climate Change Science Program produced a document in 2008 entitled “Uses and limitations of observations, data, forecasts, and other projections in decision support for selected sectors and regions” which includes a section on state-of-the-art wind and solar applications. As further discussed in Section 7 of this report, documents that address research needs often fail to include the specifics needed for this analysis (e.g., the document says “better information” is required on wind speed without specifying the required accuracy or resolution).

There is one scope exclusion in this report worth noting. The Analyst initially examined Earth observations required for ocean energy (including tidal energy and wave energy) as part of this analysis. However, because projections indicated that this type of energy is not likely to play a large role in renewable energy through at least 2030 (IEA, 2008a), the Analyst decided to exclude ocean energy from the final document. No Advisory Group members objected to the exclusion of ocean energy in the final document.

# 7. Analyst Comments and Recommendations

The nine-step process (detailed in Section 2.1) that was outlined by the UIC for Task US-09-01a proved to be effective. The Analyst reflects on the process, challenges faced, and recommendations for future iterations of Task US-09-01a in this section.

Based on interaction with Analysts for other SBAs on Task US-09-01a, the Analyst has inferred that each SBA faced unique challenges in implementing the nine-step process. Also, the degree of resources available to the Analyst somewhat determined the extent to which each of the nine steps could be thoroughly completed. The underlying premise of relying on existing documents and drawing upon the expertise of an Advisory Group is sound. For SBAs such as the Energy SBA, the application of Earth observations to renewable energy seemed to be less well studied than for other SBAs. There is a fair amount of current work on renewable energy, although user needs appear to be evolving slowly and needs are not particularly well documented. This is evidenced by the fact that only 54 documents were found to be relevant across all types of renewable energy, and many of these documents contained few specifics on required Earth observations. This gap in documents was supposed to be covered by the “additional analysis” as part of Step 8, following the preliminary draft. In reality, the gaps in documentation of required Earth observations for renewable energy were larger than originally anticipated by the Analyst. Thus, actions that the Analyst could have taken to fill the gaps, such as conducting a survey of user needs or contacting individual document authors for additional feedback, were not performed. The analysis as it stands reflects currently documented (published) information and expert Advisory Group input, but could be strengthened by further primary research.

The identification of Advisory Group members representative of GEO participating countries and organizations was relatively straightforward. The challenge, however, was that some Advisory Group members were less engaged than others. Future iterations of this task should include a larger Advisory Group (perhaps 20 to 22 instead of 14) to ensure an even broader set of input than that received for this report. In addition, to increase the engagement of Advisory Group members, it would be helpful to have the UIC send an official letter explaining the importance of the task early in the process (the Energy SBA analysis was already underway before such a letter was sent). Also, although there may be logistical issues, another idea would be to provide a small honorarium in recognition of sufficient involvement by the Advisory Group member throughout the process. This may be especially helpful in obtaining increased involvement from experts in developing countries.

The methodology used to recruit Advisory Group members (Section 2.2.2) was successful at identifying participants from developing countries. To the extent that the Advisory Group could be larger in a future iteration of this task, even more participation from developing countries could be achieved. The UIC may also consider conducting a follow-on task in a local language for a topic of particular interest to that region. For example, the bioenergy analysis in this report could be augmented by a Spanish/Portuguese sub-task focused on South and Central America. On a related note, although the Analyst did allow for Advisory Group members to provide relevant documents in languages other than English, the Advisory Group did not provide any such documents. The Analyst does not see this as a major gap because the regional and international agencies (e.g., IEA) that tend to have the most relevant documents typically prepare a version in English.

As for the actual meta-analysis of the documents and prioritization, the Analyst received input from the Advisory Group and revised the methods accordingly. Specifically, Advisory Group members noted that key or enabling parameters need to be identified for each renewable energy type. As one Advisory Group member noted, the key parameters (e.g., wind speed for wind energy) dominate the annual yield, and the other auxiliary parameters typically have only less than 1% impact on annual yield. The Analyst suggests that this method worked well and should be considered by future Analysts for other SBAs. The only drawback was in attempting to find common parameter characteristics to report as priorities of end users. In reality, spatial and temporal resolution required by end users is dictated by the type of end user (e.g., researcher versus wind facility operator) and ranges widely. End users in operation typically require very high spatial and temporal resolution, at a level that would not sensibly be collected globally. Researchers such as those performing a renewable energy resource assessment of a region may require only moderate spatial and temporal resolution. Blurring this distinction into a single set of parameter characteristics does not seem helpful, and thus the Analyst often included broad ranges in the final tiered priority list in Table 10. Also, the documents did not often include the required characteristics of parameters that were deemed important because of their cross-cutting nature (the Tier 2 meteorological and land parameters). This omission is likely because these Tier 2 parameters are not highly important to any one renewable energy types, but rather of modest importance to many types. The documents tended to focus on a single renewable energy type, and thus did not detail the required characteristics of these modestly important parameters. The UIC may wish to address this with primary research such as a survey on meteorological and land parameters that are likely to cross-cut many SBAs.

Another finding of the Analyst is that future iterations of Task US-09-01a could be performed. Beyond renewable energy, future analyses could focus on the following topics:

- Oil, gas, and coal
- Energy efficiency
- Electricity production, generation, and load balancing
- Energy-related climate change concerns (e.g., carbon sequestration, measuring greenhouse gases).

This list is not all-inclusive, and the number of topics to be included in a “single” US-09-01a analysis would need to be carefully considered, as certain topics are broader in scope and more dependent upon Earth observations than others. Potential Advisory Group members are likely to be relatively distinct between these different subtopics, as are the documents that would be reviewed. However, coordination between energy subtopic analyses would be useful.

# Appendix A: Abbreviations

| | |
|---|---|
| AOD | Aerosol optical depth |
| ASTER | Advanced Spaceborne Thermal and Emitted Reflectance Radiometer |
| CNES | Centre National d'Etudes Spatiales (French Space Agency) |
| COP | Community of practice |
| CSP | Concentrating solar power |
| DNI | Direct normal irradiation |
| ENVISOLAR | Environmental Information Services for Solar Energy Industries |
| ETP | Energy Technology Perspectives |
| EWEA | European Wind Energy Association |
| EOMD | Earth Observation Market Development |
| ESA | European Space Agency |
| GEO | Group on Earth Observations |
| GEOSS | Global Earth Observation System of Systems |
| GHI | Global horizontal irradiation |
| GRACE | Gravity Recovery and Climate Experiment |
| IEA | International Energy Agency |
| INPE | Instituto Nacional de Pesquisas Espaciais (Brazil) |
| InSAR | Interferometric Synthetic Aperture Radar |
| LiDAR | Light Detection and Ranging |
| MW | Megawatt |
| NASA | National Aeronautics and Space Administration (USA) |
| NDVI | Normalized Difference Vegetation Index |
| NPP | Net Primary Productivity |
| NREL | National Renewable Energy Laboratory (USA) |
| NWP | Numerical weather prediction |
| PV | Photovoltaic |
| RMS | Root mean square |
| rRMSE | Relative root mean square error |
| SAR | Synthetic aperture radar |
| SBA | Societal Benefit Area |
| SoDAR | Sonic Detection and Ranging |

| | |
|---|---|
| SWERA | Solar and Wind Energy Resource Assessment |
| TERI | The Energy and Resources Institute (India) |
| TRMM | Tropical Rainfall Measuring Mission |
| UIC | User Interface Committee |
| UNEP | United Nations Environment Programme |
| USDA | United States Department of Agriculture |
| WEO | World Energy Outlook |

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# Appendix C: Input to the Cross-SBA Analysis

At the conclusion of the individual SBA priority-setting analysis, the Energy Analyst provided input on the overall critical Earth observation parameters for the Energy SBA for inclusion in the Cross-SBA meta-analysis. Upon receiving input from the SBA Analysts, the Cross-SBA Analyst reviewed the priorities and combined observation parameters that are the same or very similar but have different names (e.g., precipitation intensity and precipitation duration). In some cases, the Cross-SBA Analyst extracted observation parameters from aggregated observation categories that were identified as priorities by individual SBAs and included these observation parameters as input to the Cross-SBA analysis. As a result, the number of observation priorities identified by individual SBAs may vary from the number of observations that were included in the Cross-SBA analysis. To the extent possible, the Cross-SBA Analyst focused on retaining the observation parameter terminology employed by the majority of the SBAs, in order to minimize regrouping and splitting of observations.

The Energy SBA Analyst determined the overall critical Earth observation priorities for the Energy SBA by using a method to rank the observation categories, as described in Sections 2.3.3 and Chapter 5. Based on the results of the prioritization analysis, the 12 observations listed below have the highest rankings and thus are considered to be the observation priorities for the Energy SBA. The Cross-SBA Analyst included these 12 observations in Methods 1-3 of the Cross-SBA analysis. Accounting for differences in observation terminology across the SBAs, the Energy Team effectively contributed 15 observation parameters to Methods 1-3 of the Cross-SBA analysis. The Energy Analyst divided the 12 observations into the three tiers representing "High," "Medium," and "Low" priority observations for numerical weighing in Cross-SBA Methods 2 and 3.

For Method 4, the Cross-SBA Analyst included all of the "High," "Medium," and "Low" priority observations, plus the additional observation parameters of Temperature of Geothermal Fluid at Depth, Surface Deformation, and Groundwater Chemistry, as the "15 Most Critical" observations. These additional observation parameters are applicable for geothermal energy, a sub-area that the Energy Team did not consider to be prominent out to 2030 based on IEA 2008, and were not among the priorities for Methods 1-3. However, the Energy Team added these observation parameters to round out the "15 Most Critical" list, in accordance with the Cross-SBA methodology. Accounting for differences in observation terminology across the SBAs, the Energy Team effectively contributed 17 observation parameters to Method 4 of the Cross-SBA analysis.

| **High** | **Medium** | **Low** |
|---|---|---|
| Water Run-Off | Global Horizontal Irradiation (GHI) | Surface Temperature |
| Wind Speed | Direct Normal Irradiation | Relative Humidity |
| Land Cover | Elevation/Topography | Cloud Cover |
| NDVI | Air Temperature | |
| Net Primary Productivity | | |