Reviewing Gaps in Resource Mapping for Renewable Energy in North America

Prepared for:

The Commission for Environmental Cooperation

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with the

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Executive Summary

Context of Report

- The Commission for Environmental Cooperation's (CEC) Renewable Energy Expert Committee (REEC) has the following mandate:
  - Promote renewable energy market in North America.
  - Gather information from which to base future decisions and efforts.
  - Use available information to increase capacity.
  - Conduct policy investigation.
- Two barriers to renewable energy market penetration that relate directly to resource mapping capabilities are:
  - A general lack of awareness of regional potential for various sources of renewable energy on the part of potential energy project developers, electric utilities, and governments.
  - Risks associated to undertaking renewable energy generation projects stem from the use of relatively new and unproven technologies, the uncertainty of the long term reliability of access to energy sources (e.g., biomass supply, wind regimes etc.), and the difficulty in predicting actual power generation capacity of a given project.
- In an effort to help overcome these barriers and further promote renewable energy markets in North America, the REEC deemed it important to assess the present renewable energy resource mapping capacity in North America.
- Renewable energy resource mapping is important because:
  - Most renewable energy resources have geographically dependent potentials for generation capacity.
  - Energy project developers need to be able to narrow down the potential sights for a renewable energy development with a high degree of accuracy in order to reduce the effort and cost required during the feasibility verification phase of a project.
  - Renewable energy resource maps can allow project developers to determine expected economic returns and long-term performance of a particular renewable generation technology project sighted in a particular location before proceeding to a full feasibility study.
- The CEC engaged the Delphi Group of Canada and the *Instituto de Investigaciones Eléctricas* (IIE) of Mexico to document and assess for each renewable energy resource type:

- Efforts made to map various renewable energy resources in North America.
- Information gaps that exist in the field.
- What can be done to overcome these gaps.

➢ The report went beyond these goals in order to provide key context-setting information and allow for informed decision-making. In an effort to achieve this, the report includes the following information:

- Overview of the resource
- Methods used to map the resource
- Limitations of existing methods
- Discussion of necessary map resolution and reliability for successful feasibility study siting
- Regional coverage of existing maps
- Regional gaps
- An appendix of online resources

➢ The report covers the following renewable energy technologies: wind, geothermal, solar, biomass, small hydro and ocean (wave and tidal). The findings are summarized below.

➢ Throughout the paper, the term "renewable electricity" is used to refer to non-large hydro-power renewable electricity generating technologies. These include wind power, solar electric, small hydro power, biomass conversion to electricity, and geothermal heat conversion to electricity. Although large hydro is clearly a renewable technology, it has been excluded on the basis that it is already commercially viable, cost-effective and well-established. Unlike large hydro, other renewable electricity technologies are not yet competitively viable in all three countries and still rely on government policy drivers to a large extent. Other renewable energy applications, such as biofuels, solar thermal or geothermal heating and cooling, are outside the scope of this paper.

Wind

Overview of Findings

➢ Maps for some regions do not have key information on the location and capacity of transmission infrastructure, geographic characteristics, access to roads, land reserves, etc. This is essential to facilitate siting of potential wind projects.

➢ Some high-potential regions have not been mapped to the same standard as others.

➢ Wind resource mapping in some regions can be improved by increasing the actual measurement and monitoring capacity. Improving wind measurement and monitoring capabilities in these regions would contribute significantly to enhancing project planning capabilities.

➢ When considering the value of mapping areas with lower quality maps at a higher standard, it is important to consider the possible returns such an initiative can bring. This involves evaluating:

- Whether the region has high wind generation potential.
- For regions with poor wind regimes, whether there are more economical options for power generation in the region.

- When considering whether to make the investment to resolve any limitations associated to wind mapping, it is essential to balance the potential gains (increments in accuracy and reliability) with the unchanged requirement of siting actual wind measurement equipment at a proposed site to verify performance before proceeding to construction to satisfy the due diligence process for most financers.

Regionally Specific Findings

Canada

- Wind resource maps of 5 km resolution have been completed for all of Canada, with some provinces having mapped resources at 1 km resolution or better.

- Uncertainty associated to data in these maps is typically in the range of 7%.

- **Gap**: Province-by-province mapping initiatives to match those undertaken by Ontario, Quebec, PEI, New Brunswick and British Columbia should be undertaken. In particular, the Maritime Provinces, Alberta and Saskatchewan would benefit from such an exercise.

United States

- Better than 1 km-resolution wind resource maps have been developed for most of the United States, with the exception of several states.

- The uncertainty associated with the data is typically in the range of 10% for wind speed, and 20% for wind power density.

- Certain states have not been mapped at the same resolution as the rest of the country. These are, however, states that have shown very low potential for wind project development in early, low-resolution mapping initiatives.

  Gap: Western states have been mapped to a higher standard than the rest of the US through the use of an interactive online map tool that provides enhanced GIS details for supporting infrastructure and access information. The maps produced by the Wind Powering America program for New York, New Jersey and Ohio also contain similar details but are not available in an interactive format. This interactive mapping practice should be extended to central and eastern states that have already established promising wind regimes through prior mapping initiatives, in order to enhance national wind planning capacity. These include North and South Dakota, Michigan and the eastern seaboard states.

Mexico

- In Mexico, various governmental, educational, research and private-sector institutions have conducted wind measurements in different parts of the national territory. However, the spatial coverage of the measured area is no more than 5% of the total national area. The IIE is the only institution modeling the density of wind power in Mexico.

- Although different wind modeling has been performed in areas of Baja California, Baja California Sur, Sonora, Chihuahua, Oaxaca and the Yucatan peninsula, measurements should be taken to confirm the estimates of the models, since the implementation of power projects necessarily requires site data sufficient to characterize the resource, especially in those areas where the models indicate zones with high potential densities.

- **Gap**: Mexico as a whole would benefit from enhanced measurement capabilities, expanded data on which to base wind modeling and refined modeling capabilities using harmonized modeling practices.

Geothermal

Overview of Findings

- The Southern Methodist University (SMU) map provides sufficient detail of the entire North American continent for practical feasibility study siting of a geothermal generation project.

- **Gap**: A "sweet spot" map that shows optimal sites with shallow heat sources and terrain that permits easy siting of an electric generation or heat use facility within high geothermal resource areas would be useful to improve capacity and further narrow possible sites for an energy project prospector. Parameters related to ease of access to resources should therefore be built into ranking of sights in models/maps.

Regionally Specific Findings

- In Mexico, the national use of high-temperature geothermal resources for medium- and large-scale electricity generation is fully identified and quantified. The assessment of medium and low temperature manifestations should continue in areas where the use of this resource could be used for other purposes, as the enormous size of these reserves and their associated temperatures could trigger the economic development of several rural areas across Mexican territory.

- **Gap**: The creation of an interactive map, as has been done for the Western states, that allows a prospector to view not only the location of geothermal resource areas, but also the relative location of power transmission infrastructure, the topography, surface coverage and accessibility would be useful for Canadian resources areas, in particular British Columbia, Alberta, the Yukon and the Northwest Territories, as well as most of Mexico and some US states, such as Texas, Louisiana, Arkansas and South Dakota.

Solar

Overview of Findings

- The benefits associated of solar energy, specifically its ability to match demand and shave peak demand, needs to be communicated in order to overcome the present stigma that exists as a result of its higher cost, and addressed as a motivation to improve solar resource mapping, especially in regions where the quality of existing data is inferior.

Regionally Specific Findings

Canada

- In Canada, the market for solar energy has been slow to emerge as a result of its high price compared to more traditional sources of energy. Consequently, there has been little incentive and pressure on national or provincial governments to undertake more thorough mapping initiatives to increase the quality of existing solar resource maps.

- Natural Resource Canada has developed a statistical model based map of Canada's solar energy resources. Some provinces have developed higher resolution maps based on satellite imaging and physical models but these have not been broadly disseminated to the public.

- **Gap**: Higher resolution maps of all of Canada should be developed, especially in high population density areas where grid integrated PV applications are expected to soon be economically competitive as a result of changes in net metering laws and feed in tariffs for solar.

United States

- The Department of Energy, through the National Renewable Energy Laboratory, has developed statistical model and physical model based maps for the entire country. The physical model provides the most reliable and accurate coverage of the entire country. This is the highest standard of mapping used in North America.

Mexico

- Mexico has several solar maps, although most contain discrepancies with respect to measurement data. While available maps cover all of Mexico's territory, there are not sufficient measurements for areas removed from major cities and towns to assess the map estimates.

- A network of duly calibrated instruments is needed to correctly measure insolation, following international standards. The network would have to cover Mexican territory more homogeneously, enabling a better adjustment of models and therefore a better map quality.

- **Gap**: Access to long-term satellite weather data would allow Mexico to establish physical model based maps which allow higher resolution and accuracy and eliminate the dependence on broad distribution of properly calibrated measurement stations.

Biomass

Overview of Findings

- Few biomass energy resource maps exist within the United States, Mexico and Canada as a result of the complicating factors that exist in quantifying this resource.

- The maps that do exist typically provide estimated total (lump-sum) quantities of energy that can be produced from a compiled variety of biomass sources available within a macro region, such as a county, municipality or even a province or state.

- A more practical approach to mapping biomass resources would be to map exact locations of concentrated biomass energy sources, such as forestry product manufacturing facilities, food processing plants, farms and landfills. Combining such information with location and capacity detail of power distribution infrastructure, municipal boundaries and other supporting infrastructure details could provide a much more useful tool to a potential project developer.

Small Hydro

Overview of Findings

- Overall, small hydro is well documented in the US and Canada.
- Relatively speaking, areas that are either more remote or have low hydro potential are not as well covered as more promising populated areas.
- The maturity of small hydro mapping is representative of the maturity of the resource and its use.
- Data or equations that provide greater detail regarding flow duration would improve power generation estimates and allow for time-of-day and seasonal financial projections.
- Amounts of "available" power specified in small hydro resource maps are gross numbers that would be greatly reduced by feasibility assessments accounting for other viability factors.

Regionally Specific Findings

Canada

- Canada has an extensive database of potential sites, however, the associated map provides less detail than the US equivalent.
- The Provinces relying significantly on small hydro, namely British Columbia and Ontario, are the ones with the best mapping resources. BC has had a very thorough resource mapping undertaken, comparable to that of the US efforts. The Ontario resource map is based on the same data base used for the Canadian national resource map, but has been recently updated to provide higher resolution and more corresponding detail, such as proximity to power lines.
- **Gap**: An interactive small hydro resource map tool with full relevant geographic information representation similar to the Small Hydro Prospector in the US would be useful to develop for all of Canada.

United States

- The US has an excellent tool available publicly. Visually, the US system is more user friendly, through the use of Geographic Information System (GIS) mapping resources.

- The large population base in the US has allowed it to fund a superior GIS based survey of small hydro sites.

- Overall, mapping coverage is extensive, and the most advanced amongst the three countries.

- **Gap**: Small improvements may be made through improved use of observed data to provide information on timing and duration of flows.

Mexico

- Mexico has sufficient technical capabilities to assess small hydro resources, as several institutions have studied these resources over more than 30 years. However, it should be noted that much of the work has lacked field studies to corroborate local measurements made using indirect methods. In addition, it is necessary to have advanced tools to estimate the potential for small hydro and to identify possible areas of interest where more precise analyses may be carried out.

- **Gap**: An interactive, small hydro GIS resource map for the entire country would be useful to stimulate small hydro project development.

Ocean Energy

Overview of Findings

- Resource assessments and mapping initiatives are as critical to the development of ocean energy projects as they are to other forms of renewable energies.

- There are technical and geographic limitations to ocean energy mapping in North America, including the difficulty of siting measurement equipment and the geographic factors that affect the feasibility of building and deploying wave or tidal generation technologies, even in promising resource areas.

- Funding has been very limited for ocean energy research to be conducted in parallel with the development of the wave and tidal current technologies. As these technologies progress, demand for improved information regarding the best location for ocean energy installations will increase. This trend is already underway.

Regionally Specific Findings

- Estimates of wave ocean energy have been completed at a general level for all US coasts, and in Canada for the coasts of British Columbia and Nova Scotia.

- Some site-specific tidal resource quantification efforts have been undertaken at several promising sites in the United States and Canada.

- Canadian and American efforts to map the ocean energy resources for all three coasts are underway but are in the very early stages. The lack of detailed, multi-attribute (energy, bathymetry, environmental, socio-economic) site-specific data is an important gap remaining for a better understanding of good ocean energy sites.

- Wave and tidal energy may be used at some points within Mexico. However, there are presently no estimates of its energy potential. Some research institutions are currently interested in conducting joint studies to assess resource potential.

1. Introduction

1.1 Project Background

- The Commission for Environmental Cooperation's (CEC) Renewable Energy Expert Committee (REEC) has the following mandate:
    - Promote the renewable energy market in North America
    - Gather information from which to base future decisions and efforts
    - Use available information to increase capacity
    - Undertake policy investigation
- Aware of the critical link between resource mapping and renewable energy project development, the CEC completed a wind resource mapping project in the Yucatan Peninsula, in Mexico. The project was completed by Helimax and yielded maps with resolution of 1 m^2.
- Instead of continuing its own mapping initiatives and risking duplicating efforts already made in the field, CEC deemed it to be more effective to focus on documenting what efforts have already been made to map various renewable energy resources in North America, the information gaps that exist in the field and what can be done to overcome them.

1.2 Project Objectives

- For each of the following low impact renewable energy electricity generation sources
    - Wind
    - Geothermal
    - Solar
    - Biomass
    - Small hydro
    - Ocean:
- Provide an overview of the methodologies used to map renewable energy resources.
- Establish what efforts have already been made to map renewable energy resources in North America.
- Identify which of the resulting maps or resource information are publicly accessible and which are proprietary.
- Identify limitations to mapping practices and achievable quality/reliability of mapping information (budgetary, geographic constraints and technical feasibility) and general limitations to estimating and measuring renewable resources in Canada, the United States and Mexico. Discuss what is being done to overcome limitations.

- Identify geographic regions, with emphasis on remote and complex terrain regions, that have not been mapped to the same standards as other regions, as well as document limitations to mapping in these regions.

- Discuss why mapping of resources is important and how it can be used to increase renewable energy capacity in North America (and possibly to what degree), what should be done to effectively improve the mapping information presently available and guidance for next steps.

- This study also specifically seeks to identify the existing capacities in Mexico to assess and map the country's renewable energy resources, establish the requirements and increase and strengthen such capacities, find synergies among groups to avoid duplicated efforts, optimize the scarce economic resources, and establish a consensus to homogenize assessment and mapping techniques and methods.

- This study also includes a spreadsheet appendix containing online renewable electricity mapping resources.

- Throughout the paper, the term "renewable electricity" is used to refer to non-large hydro-power renewable electricity generating technologies. These include wind power, solar electric, small hydro power, biomass conversion to electricity, and geothermal heat conversion to electricity. Although large hydro is clearly a renewable technology, it has been excluded on the basis that it is already commercial viable, cost-effective and well-established. Unlike large hydro, other renewable electricity technologies are not yet competitively viable in all three of the countries, and still rely on government policy drivers to a large extent. Other renewable energy applications, such as biofuels, solar thermal or geothermal heating and cooling, are outside the scope of this paper.

1.3 Drivers and Trends in Renewable Energy Development and Renewable Energy Resource Mapping

1.3.1 Market Overview

- Within the Organization for Economic Co-operation and Development (OECD), the production capacity from emerging sources of renewable energy increased by 24% between 1990 and 2002.

- For the three member countries of NAFTA , the figures for renewable energy capacity increases are:
  - 23% for Mexico,
  - 11% for the United States
  - and 15% for Canada **[I1]**.

1.3.2 Market Drivers in North America

- An increase in environmental concerns regarding conventional electricity production.

- Technological advances and economies of scale are allowing these sources of energy to be increasingly affordable while traditional fossil fuel based energy supply is becoming more costly and vulnerable to fluctuations in price.

- Concerns over energy reliability and security: Renewable energy increases the diversity of energy supplies and most renewable energy technologies use indigenous resources enhancing a country's independence from external supplies of primary fuels.

- Renewable sources of energy are being recognized as a key element in providing electricity to the rural poor and off-grid locations.

- Motivated by environmental, economic and energy security concerns, governments are taking action to increase the proportion of renewable energy in their energy supply mix. They are achieving this by making use of economic and tax incentives **[I1]**.

- For more information on renewable energy market, please refer to the "White Paper: *Fostering Renewable Electricity Markets in North America*" report prepared by the Institute of Engineering, National University of Mexico and the Center for Resource Solutions dated January 2006.

1.3.3 Barriers to Further Renewable Energy Market Uptake

- Limited awareness that renewables can contribute to sustainable development and energy security/reliability simultaneously.

- A general lack of awareness of regional potential for various sources of renewable energy on the part of potential energy project developers, electric utilities, and governments.

- Risks associated to undertaking renewable energy generation projects stem from the use of relatively new and unproven technologies, the uncertainty of the long term reliability of access to energy sources (e.g., biomass supply, wind regimes etc.), and the difficulty in predicting actual power generation capacity of a given project.

- The capital and/or production costs of renewable energy technologies remain too high to significantly penetrate some markets.

- The deployment of renewable energy requires appropriate economic, market and regulatory instruments, which have only recently started to be implemented in many regions of the world.

The Mexican Renewable Energy Resource Context

The use of renewable energies in Mexico is still limited. According to the 2003 Energy Report (Balance de Energía), prepared by the Secretariat of Energy (Secretaría de Energía—Sener), the annual production of primary electrical power was 2.79 PWh, of which wind power provided 14.44 GWh, geothermal energy provided 18.52 TWh, and biomass (sugarcane bagasse and wood burning) provided 96.28 TWh ***[I2]****. Knowledge of the actual potential of energy resources in Mexico is limited as well, as the majority of Mexican territory has had insufficient prospecting work and evaluation. Known potential to date and the applications thereof are summarized in the following paragraphs.*

Solar energy is used primarily in Mexico to heat water using flat solar heaters and to generate electricity using photovoltaic modules. Some estimates indicate that 75,304 m^2 of flat solar heaters were installed in Mexico during 2003, for a cumulative total of 573,919 m^2 and useful heat output of 0.77 TWh. The principal applications of flat solar heaters include water heating for pools, hotels, athletic clubs, homes and businesses. In the case of electricity generation, reports show that photovoltaic modules with a capacity of 0.950 MW were installed, for an accumulated 17.1 MW in that year. As of 2003, the total installed area of these systems was approximately 171,000 m^2.

As regards wind power, according to estimates by the Federal Electricity Commission (Comisión Federal de Electricidad—CFE), nationwide wind power potential is equivalent to 2,970 MW or 7,963 GWh/yr (considering certain areas in the states of Baja California, Hidalgo, Oaxaca, Quintana Roo, Sinaloa, Veracruz and Zacatecas). The Institute of Electricity Research (Instituto de Investigaciones Eléctricas—IIE) estimates a national probable energy of 5,000 MW (considering certain areas in the states of Baja California, Baja California Sur, Hidalgo, Oaxaca, Tamaulipas, Veracruz, Zacatecas and the Yucatan peninsula). Lastly, the US National Renewable Energy Laboratory (NREL) estimates a probable potential of 3,281 MW (considering certain areas in the states of Baja California, Baja California Sur, Hidalgo, Oaxaca, Quintana Roo, Veracruz and Zacatecas) ***[I2]****. The Canadian firm Helimax recently estimated the wind energy potential in the Yucatan peninsula. According to the company's findings, there is a potential of 1,680 MW considering three exclusion zones (roads, towns and important bird routes), 720 MW considering three exclusion zones and limiting the radius to 25 km around the electrical grid, and 7,660 MW considering two exclusion zones (roads and towns)* ***[I3]****.*

As for geothermal energy, according to CFE studies Mexico has 1,350 MW of proven reserves and 3,250 MW of probable reserves ***[I2]****.*

With respect to minihydraulic power in Mexico, studies have been conducted by CFE, the National Water Commission (Comisión Nacional del Agua—CNA) and the National Energy Savings Commission (Comisión Nacional para el Ahorro de Energía—Conae) to determine potential. Conae estimates a potential of around 3,250 MW, concentrated primarily in southern Mexico. In the states of Puebla and Veracruz alone, the estimated usable potential is 400 MW ***[I2]****.*

Mexico reports the following figures for the availability of biomass for energy production: wood fuel from natural forests, from 207 to 357 TWh/yr; wood fuel from energy plantations, 94 to 260 TWh/yr; forestry and timber byproducts, 15 TWh/yr; farming and agroindustrial byproducts, 296 TWh/yr; stockbreeding byproducts, 41 TWh/yr; energy crops, 70 PTWh/yr; and municipal byproducts, 10 TWh/yr. The overall energy potential of biomass in Mexico is between 732 and 1048 TWh/yr, of which between 20% and 40% is from wood fuels, 26% is from agrofuels, and

0.6% is from municipal byproducts. However, biomass is mostly scattered, and therefore its potential for generating electricity could be limited depending on the extent of scattering.

The potential of tidal wave energy in Mexico is practically unknown. It is thought to be an important resource, considering Mexico's 11,000 kilometers of coastline. However, until now attention has not been paid to tidal energy, and its only known application is an experimental device called Wave Energy Pumping System (Sistema de Bombeo por Energía de Oleaje—SIBEO), with a pumping capacity of 5 liters per second. The purpose of the system was to clean up water in ports and coastal lagoons, polluted by organic waste and chemicals, taking advantage of the movement of ocean waves. The equipment was set up experimentally in 1995 at the El Lagartero lagoon on the Oaxacan coast ***[I4]****.*

The Gulf of California is known to have appropriate conditions to take advantage of tides, and over the years various initiatives have been presented to build large-scale tidal power projects. One of these is the Montague project, to be set up 125 km southeast of Mexicali in the Colorado River delta. The project had a planned capacity of 800 MW, with annual output of 3.520 billion kWh. Until now, none of the proposed projects have been built.

The draft Law for the Use of Renewable Energy Sources (Ley para el Aprovechamiento de las Fuentes Renovables de Energía), recently approved by the Chamber of Deputies and awaiting review by the Mexican Senate, states that renewable energies must contribute at least 8% of Mexico's electricity-generating capacity, not including the contribution of large hydroelectric plants. ***However, the law recognizes that the lack of reliable information on the location and characteristics of each renewable energy resource is a major barrier to achieve this goal, and therefore calls for the creation of a trust to allocate funds to assess the national potentials of renewable energy sources [I5].***

To facilitate the implementation of renewable energies, since 1997 the IIE has developed the Geographic Information System for Renewable Energies (Sistema de Información Geográfico para las Energías Renovables—SIGER), intended as a powerful tool to identify projects involving the use of renewable energy resources at the national level. However, the actual usefulness of the system will depend on the quantity and quality of available information. The field assessment of resources in a country of nearly 2 million square kilometers can be slow and costly. And although measurement is indispensable at specific sites where projects of any kind are to be carried on, indirect assessment techniques and resource mapping are still valuable to help advance the understanding of these resources.

1.3.4 The Importance of Renewable Energy Resource Mapping to Project Development

- The diffusion and deployment of newly developed renewable energy technologies into markets are particularly important. However, the actual generation capacity of these renewable energy technologies, and consequently their potential profitability, is strongly dependent on their successful location where a particular natural resource can be optimally harnessed.

- Most renewable energy resources such as wind, solar and geothermal, have geographically dependent potentials for generation capacity.

- In order to minimize the costs associated to prospecting a renewable energy project, energy project developers need to be able to narrow down the potential sites for development with a fairly high degree of accuracy in order to reduce effort and cost required during the feasibility verification phase of a project. Accurate maps illustrating exact locations of high-potential renewable energy resources can help fill this need.

- Renewable energy resource maps can also allow project developers to determine expected economic returns and long term performance of a particular renewable generation technology project sited in a particular location before proceeding to a full feasibility study.

- In addition to minimizing the risks faced by energy project developers during the pre-feasibility phase, regions with well developed renewable energy resource maps that show high project deployment potential can attract generation and support infrastructure equipment manufacturers looking to set up new production operations, leading to job creation and regional economic development.

- Enhanced resource mapping can create awareness and educate residents, governments and industry of the potential for renewable energy generation in their communities.

- Renewable energy technologies are becoming increasingly competitive with traditional energy technologies. By the middle of the 21st Century, renewable energy, in all its forms, is expected to make a large contribution to meeting energy needs. North America currently has only nine per cent of the world population, but consumes 28% of the world energy supply. Therefore, to maintain a globally competitive position while ensuring adherence to a sustainable development course, it will be important for North America to fully develop and leverage its renewable energy resources. In undertaking to do so, it is important that a clear understanding of where renewable energy technologies can be most successfully deployed be developed. High resolution renewable energy resource maps can provide this understanding [I1].

1.3.5 Challenges faced by Renewable Energy Resource Mapping Efforts

- Data access issues – by their very nature, renewable energy resources are difficult to track, document and measure. They are all intermittent to greater or lesser degrees, are influenced by complex relationships between multiple natural phenomena, and often at their highest levels far from human settlements. As a result, data collection and monitoring can be costly.

- Data sharing and ownership issues can become complex. Deciding whether information is public versus proprietary for most mapping initiatives can be controversial.

- Once a mapping resource has been developed for public consumption, a communications effort needs to be undertaken to ensure the widest possible dissemination.

- Issues around data standards can cause problems, if a lack of comparability leads to difficulty estimating the power production possibilities for a particular resource. This problem is currently challenging the ocean energy sector where the technology has not matured to the point where there is conversion on standards of measurement.

- As public agencies sponsor resource mapping initiatives, overlap between different jurisdictional efforts, integrated mapping efforts, and sensitivity to differing land use priorities and policies are issues requiring consideration.

- Integrating resource mapping outcomes into policy making processes is also key, so as to improve decision making capability.

2. Research and Analysis

2.1 Wind

2.1.1 Overview of Findings

- Maps for some regions do not have key information on the location and capacity of transmission infrastructure, geographic characteristics, access to roads, land reserves etc. This is essential to facilitating siting of potential wind projects.

- Some high potential regions have not been mapped to the same standard as others.

- Wind resource mapping in some regions can be improved by increasing the actual measurement and monitoring capacity. Improving wind measurement and monitoring capabilities in these regions would contribute significantly to enhancing project planning capabilities.

- When considering the value of mapping areas with lower quality maps at a higher standard, it is important to consider the possible returns such an initiative can bring. This involves evaluating:
    - Whether the region has high wind generation potential.
    - For regions with poor wind regimes, whether there are more economical options for power generation in the region.

- When considering whether to make the investment to resolve any limitations associated to wind mapping, it is essential to balance the potential gains (increment in accuracy and reliability) with the unchanged requirement of siting actual wind measurement equipment at a proposed site to verify performance before proceeding to construction to satisfy the due diligence process for most financers.

2.1.1.1 Canada

- Wind resource maps of 5 km resolution have been completed for all of Canada, with some provinces having mapped resources at 1km or better.

- Uncertainty associated to data in these maps is typically in the range of 7%.

- Province by province mapping initiatives to match those undertaken by Ontario, Quebec, PEI, New Brunswick and British Columbia should be undertaken. In particular Maritime Provinces, Alberta and Saskatchewan would benefit from such an exercise.

2.1.1.2 United States

- Better than 1 km^2 resolution wind resource maps have been developed for most of the US with the exception of several states.

- Uncertainty associated to data is typically in the range of 10% for wind speed and 20% for wind power density.

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2.1.1.3 Mexico

- In Mexico, various governmental, educational, research and private-sector institutions have conducted wind measurements in different parts of national territory. However, the spatial coverage of the measured area is no more than 5% of the country's total area. The IIE is the only institution modeling the density of wind power in Mexico.

- High resolution wind resource maps have been created by the US NREL for several regions of Mexico, with funding from the U.S. Agency for International Development (USAID), the U.S. Department of Energy, and in cooperation with various agencies in Mexico. These regions include the state of Oaxaca, the Baja California Norte and Sur Border Regions, Western Chihuahua Border Region, Northwestern Mexico Border Areas, Eastern Sonora Border Region, Western Sonora Border Region, the Quintana Roo Region, the Yucatan Region and the Campeche Region.

- Although different wind modeling has been done in areas in the states of Baja California, Baja California Sur, Sonora, Chihuahua, Oaxaca and the Yucatan peninsula, measurements should be taken to confirm the models' estimates, since the implementation of power projects necessarily requires site data enabling the characterization of the resource, especially in those areas where the models indicate zones with high potential densities.

- Mexico as a whole would benefit from enhanced measurement capabilities, expanded data on which to base wind modeling and refined modeling capabilities with harmonized modeling practices.

2.1.2 Wind Resource Mapping - why is it important?

- All markets for wind turbines require an estimate of how much wind energy is available at potential development sites. Correct estimation of the energy available at a given site can make or break the economics of a wind farm development.

- The first step in a wind generation project is siting the potential wind development. This can be done using wind energy resource maps provided by the models discussed above. Once a promising site has been sited it is necessary to verify its suitability with actual site measurements **[W5]**.

- Siting measurement equipment is expensive, especially in complex terrain with minimal access. In addition, validating a site is time consuming, usually a minimum one year of site measurements are required to satisfy financer requirements. Combining the cost associated and the long site validation timelines can make wind prospecting uneconomical without the ability to pinpoint reasonable starting points, as newer wind resource mapping models allow.

2.1.3 Industry mapping practices and methodologies

2.1.3.1 Characteristics of Wind Energy

- Wind is caused by uneven heating of the earth's surface by the sun. The heat absorbed by the ground or water is transferred to the air, where it causes differences in air temperature, density and pressure. These differences, in turn, create forces that push the air around **[W1]**.

- On a much smaller scale, temperature differences between land and sea and between mountains and valleys often create strong breezes. Wind direction and speed are affected by other factors, as well, such as the earth's rotation, local topographical features and the roughness of terrain **[W1]**.

- Wind power density is dependent on wind speed cubed and on the distribution of the wind speeds. This means that the power contained in the wind increases very rapidly with wind speed (e.g., if the speed doubles, the power increases by a factor of eight) **[W1]**.

- Below a certain wind speed threshold, a typical turbine does not have enough wind to generate motion in the turbine and as such to generate electricity. Above a certain speed levels, power generation performance levels off or begins to decline as a result of drag and other factors. Most wind turbines have a wind speed shut down threshold above which they are shut down to prevent damage.

- Wind speed tends to increase with height in most locations, a phenomenon known as wind shear. The degree of wind shear depends mainly on two factors, atmospheric mixing and the roughness of the terrain **[W1]**.

- With current wind turbine technology, the optimum tower height for large wind machines is approximately 70 to 80 meters.

- Wind resource characteristics can differ greatly with varying topography. Although the strongest winds can usually be found in well-exposed locations, terrain features such as hills and ridges can accelerate the wind as it passes over them. Mountainous regions can contain pockets of high wind activity resulting from the drastically varying terrain **[W1]**.

- Meteorologists have developed a variety of tools for predicting and mapping wind speeds and resulting wind power densities in complex terrain, including sophisticated computer models. Although these maps can provide enough information to make a preliminary decision as to the feasibility of developing a proposed wind power generation site, there is no substitute for direct measurement at the site.

Wind maps typically assign areas to one of seven wind classes, each representing a range of wind power densities or wind speeds at a specified height above the ground. An example of such a distribution is presented below. This table assumes a specific elevation/air density value and Weibull distribution of wind speeds.

Table 2.1.1: Sample Wind Class Divisions

	30 m Height		**50 m Height**	
Class	*Speed (m/sec.)*	*Power (W/m^2)*	*Speed (m/sec.)*	*Power (W/m^2)*
1	**0-5.1**	**0-160**	**0-5.6**	**0-200**
2	**5.1-5.9**	**160-240**	**5.6-6.4**	**200-300**
3	**5.9-6.5**	**240-320**	**6.4-7.0**	**300-400**
4	**6.5-7**	**320-400**	**7.0-7.5**	**400-500**
5	**7-7.4**	**400-480**	**7.5-8.0**	**500-600**
6	**7.4-8.2**	**480-640**	**8.0-8.8**	**600-800**
7	**8.2-11**	**640-1600**	**8.8-11.9**	**800-2000**

Source: http://www.nationalwind.org/publications/wes/wes04.htm

- By and large, the areas being developed today using large wind turbines are ranked as class 5 and above. Wind projects are being developed in class 4 areas, and even some areas considered class 3, through the use of advanced technology and tall towers (>80 m) to capture the energy from stronger winds aloft, especially in areas with large wind shear. Class I and 2 areas are not deemed suitable for large wind machines, although smaller wind turbines may be economical in areas (such as remote or off-grid communities) where the value of the energy produced is high **[W1, W6]**.

2.1.3.2 Mapping Methodology

- Siting wind characterization stations (anemometers) is costly and can only provide reliable measurements for the immediate location in which they are installed. It is therefore not economical or practical to rely on massive deployment of such stations to gain fully reliable information on the wind resources available across an entire region.
- It has therefore been necessary to develop modeling capabilities that allow wind resources in regions where little direct measurement data is available to be extrapolated in order to be able to effectively determine high potential wind resource areas.
- As a result of the rapid growth of the international wind industry in recent years, new techniques for the systematic identification and evaluation of potential wind project sites have been developed. The most prominent of these techniques is mesoscale modeling.

- Mesoscale modeling has been used extensively for weather forecasting and offers a number of advantages for wind resource mapping, such as ability to simulate with reasonable accuracy, complex wind flows in areas where surface direct measurements are not possible **[W2]**.

- Typical modern wind resource mapping models assesses wind resources over large regions at a high resolution (in some cases better than 1 km^2) using a combination of mesoscale and microscale models and weather data. These models have proven to be effective, even in complex terrain or complex wind regimes **[W2]**.

- These mapping models establish the general patterns of wind and weather in a region down to a scale of 1 to 3 km. The patterns reflect the influence of terrain, vegetation, oceans and lakes, solar heating, radiative cooling, convection, and many other factors **[W2]**.

- There are typically two parts to the development of a wind resource map, creation of the meso- climate model and refinement of this model to create the micro- climate models.

- The size of an element of a typical "mesomodel" is in the range several km to hundreds of km. Conversely, the size of an element of a micro-model can be less than 1 km.

- The key meteorological inputs to creating mesomodels are derived from data from a global climate database produced by US National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR). The data available from these sources provides a 3D representation of atmospheric state based on a 2.5 degree (latitude by longitude) resolution snapshot every 6 hours around the world. The database covers a 43 year period from 1958-2000 **[W2, W3 and W4]**.

- Typically, elements of the mesomodel are established by correlating them to elements of the NCEP/NCAR meteorological database, which are classified using key wind characterization parameters including: geostrophic wind direction, geostrophic wind speed and geostrophic wind shear. The wind is considered geostrophic when it blows parallel to isobars (constant pressure geographic lines). Using established ranges of these characterization parameters, a range of combined climate states are defined. Based on the data from the 43 year coverage of the database, a climate state distribution and frequency is determined for each element of the NCEP/NCAR meteorological database and in turn translated to the mesomodel elements **[W2, W3 and W4]**.

- The outputs from this mesomodel are then used to drive a mass-conserving wind flow model which serves to sharpen the picture created by the mesomodel to account for the localized effects of terrain and surface roughness variations. This allows the achievement of wind flow spatial resolutions of up to 200 m or finer, or "microscale" models. When the runs are finished, the results are compiled to produce maps of mean wind speed and wind power density as well as data bases containing wind speed and direction distributions **[W2, W3 and W4]**.

- Independent validation with data from over 1000 stations worldwide has established a typical uncertainty range of 5-7% in mean speed for these models at the turbine hub height. This is comparable to the error margin associated with one year of measurement from a 50 m mast **[W2]**.

- The following figure is a sample high resolution (better than 1km^2) mesomap of the wind resources in Washington State.

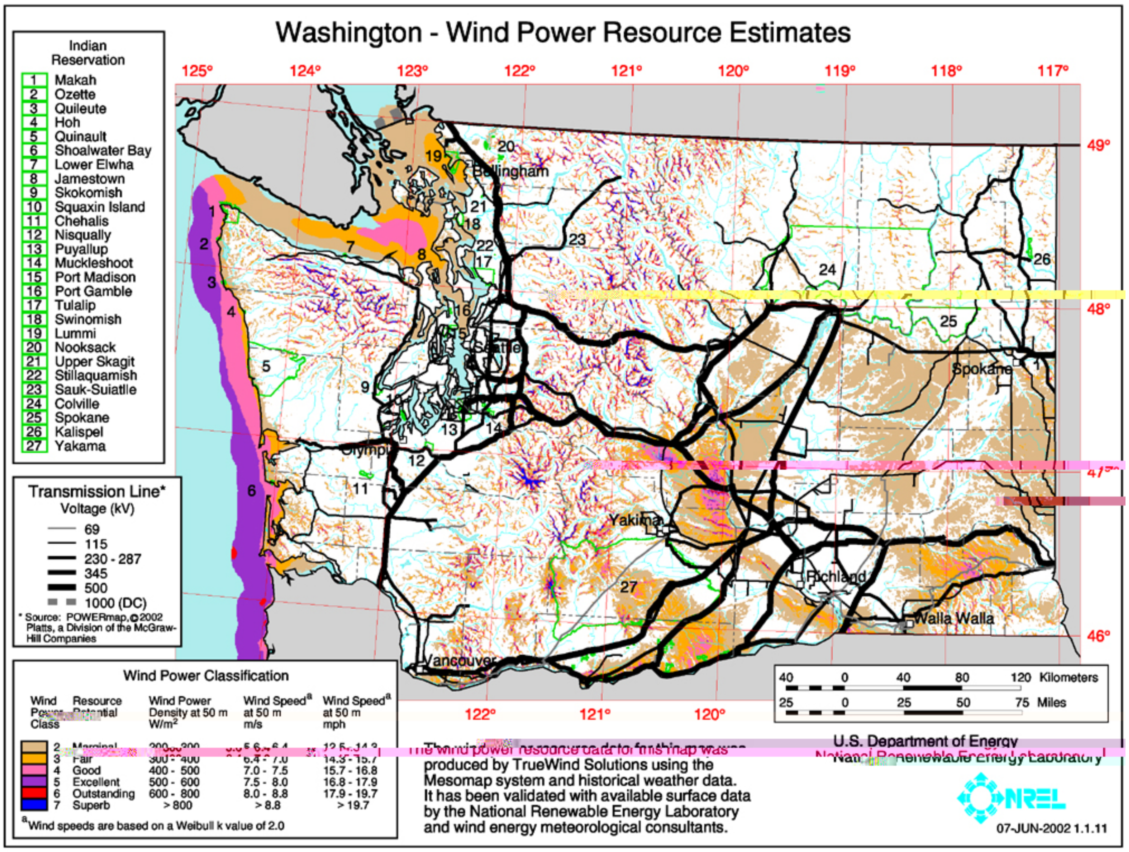

Figure 2.1.1: Washington Wind Resource Map; Source: (http://www.eere.energy.gov/windandhydro/windpoweringamerica/maps_template.asp?stateab=wa)

- In Mexico, the IIE is the only national institution that models the density of wind potential. To do so, it uses information collected from wind stations installed by the IIE itself, measuring the average wind speed and associated direction in 10-minute intervals, with readings every two seconds. The modeling is done using the WAsP program, developed at RISØ Laboratories in Denmark.

- Some satellite based mapping initiatives are being undertaken in order to provide real time monitoring of wind patterns which should allow established wind generation projects to predict outputs more reliably, which in turn should result in better cost performance for these projects.

2.1.4 Limitations to mapping wind energy resources

2.1.4.1 Technical

- Typical model error for mesoscale mapping is in the range of 5-7% of the mean wind speed at a 50 m height. Due to the cubic relationship between wind speed and wind power, an error of this magnitude implies a 16-22% error in available energy. However, because wind turbines do not convert all of the available energy to electricity, the error in wind turbine output is actually somewhat smaller – about 10-15%. This represents a significant uncertainty for financial evaluation of wind projects. Consequently, wind resource maps are typically used to approximate the local resource in a given region or even a precise micro region but a professional assessment of local meteorological conditions and technical feasibility is still generally required before proceeding with an actual wind turbine installation project. As previously stated, wind statistics provided in the resource maps are generally verified by a wind resource assessment program which involves the use of wind monitoring towers at the site of interest for a minimum of 1 year.

- The leading sources of error for modern mapping methodologies include:
  - Grid resolution of the mesoscale and microscale runs: data is averaged across a given grid element and over the time span of the data set. Smaller fluctuations within an element can therefore be lost;
  - Uncertainty in land cover and surface roughness: essentially a compounded error from source data used to create the models.
  - Sparse meteorological data in some regions: for some regions it is necessary to extrapolate data over broader areas to develop a model resulting in loss of nuances within these regions.
  - Atmospheric stability in the lower boundary layer.
- Solutions to these technical problems can include:
  - Employing higher resolution in both the mesoscale and microscale models, which involves more time and enhancing existing processing capabilities.
  - Increasing data points within the source data set to reduce extrapolation of data within and between grid elements.
  - Increasing site measurement points to reduce dependence on modeling.
- All of these solutions represent significant cost increases which may not be justified by the potential economic gains.
- In Mexico, the main limitation in wind mapping is the lack of anemometric data to validate the model-derived maps, as Mexico has a very low density of currently installed instruments.
- Mexico has the capacity to conduct atmospheric dynamics modeling studies in various research centers. However, to date, such work has not been linked with the estimated potential of wind in regions of interest.
- The current measurement network in Mexico comprises observatories and the automatic weather stations of the National Meteorological Service (Servicio Meteorológico Nacional—SMN) and provides information on wind speed and direction, regularly obtained at a height of 10 meters. However, as the network was not conceived for purposes of estimating wind energy, some stations do not adequately meet the sensor exposure requirements to obtain reliable estimates of the wind's energy potential.

2.1.4.2 Geographic

- Models partially rely on density of measurement points available for tracking meteorological data. More remote and less populated regions have fewer of these measurement points, affecting the quality of the data. These regions are often less suitable for larger scale generation projects because integration into the power distribution grid cannot be easily or economically achieved. However, these regions can be suitable for smaller, stand alone power applications and the lower quality modeling may affect the ease with which a planner can properly project a suitable site for such a development.

- Geographic information pertinent to siting a wind development is not always presented or considered in wind resource mapping. Examples of information that can affect pursuit of a more thorough potential wind site assessment include:

    - Accessibility
    - Proximity to power distribution infrastructure and constraints of the transmission capacity needed to carry wind power to population centers
    - Terrain that is difficult to site a measurement tower on
    - Conflicts with bird habitats and migration routes
    - Land allotment

2.1.4.3 Budgetary

- Associated to the resolution of any technical limitation to modeling accuracy is a cost. When considering whether to make the investment to resolve these limitations it is essential to balance the potential gains (increment in accuracy and reliability) with the unchanged requirement of siting actual wind measurement equipment at a proposed site to verify performance before proceeding to construction.

- A threshold value for acceptable error, and development risk associated to this error, for a model for wind resource mapping may eventually be established by project financers as modeling capabilities improve.

2.1.5 Typical data quality (resolution) and reliability

- Better than 1 km resolution for most of the US with the exception of several states (as indicated in table).

- 5 km resolution for all of Canada, with some provinces (as indicated in Table 2.2) having mapped resources at 1km or better.

- As previously stated, uncertainty associated to wind speed data is typically in the range of 10%.

2.1.6 Discussion of required data quality for practical energy project planning

(This is covered in the Limitations section.)

2.1.7 Regional mapping and data gathering initiatives and capacity (including an analysis of mapping capacity in remote areas)

Table 2.1.2: Regional Wind Mapping and Data Gathering Initiatives and Capacity

	Map Title (Source)	Resolution/Uncertainty	Public Access/ Proprietary	Available Information
Global	NASA Surface Meteorology and Solar Energy Data Set (NASA's and Earth Science Enterprise program (RETScreen International-NRC))	Resolution: 1° by 1° (longitude by latitude) grid system representing average condition within a grid element are provided. Uncertainty: ~20-25%.	Publicly accessible once online registration is filled in.	Average, maximum and minimum wind speeds, wind speed distribution information (% of time at each level) and wind direction at 50 m and wind speed at 10 m.
North America	Assessment of global wind power in North America (Stanford University)	Resolution: N/A - does not provide full geographic coverage, only data for specific measurement/monitoring points.	Public	Average wind speeds calculated at 80 m height. Data from 7753 surface stations and 446 sounding stations. Results of extrapolations are color categorized by range of average wind speed and are represented as colored dots sited at the locations of the particular measurement point.

Canada	Canadian Wind Energy Atlas (Environment Canada, Projet Eole)	Resolution: 5 km. Uncertainty: ~10%.	Public	Average wind speed, average wind power density, wind rose, and wind distribution histogram at 30, 50 and 80m; surface roughness, topography, power lines, roads, cities etc.
Quebec	Wind Potential Maps of Quebec (Speed & Density) (Ressources naturelles et Faune QC/Helimax/AWS Truewind)	Resolution: 200m and 3 km display formats. Uncertainty: ~10%.	Public	Average wind speed and power density at 65, 80,100m heights.
Ontario	Ontario Wind Atlas (Ontario Ministry of Natural Resources/Helimax/AWS Truewind)	Resolution: 1 km^2 Uncertainty: ~5-7%	Public	Average wind speed and wind power density at 10 m, 30 m, 50 m, 80 m, and 100 m, vegetation coverage, power lines, towns, municipalities, roads, topography etc.
British Columbia	British Columbia Predicted Wind Speed Map (BC Hydro/AWS Truewind)	Resolution:1 km^2 Uncertainty: ~10%	Public	Average wind speed for 65m height.
Prince Edward Island	Prince Edward Island Wind Atlas (PEI Provincial Government/PEI Energy Corporatrion/Universite de Moncton)	Resolution: 200 m Uncertainty: ~10%	Public	Average wind speed at 30m, 50m and 80 m, power lines, power generation infrastructure, topography, surface roughness, protected nature areas etc.
New Brunswick	Atlas Elolien du Nouveau Brunswick (Centre de Genie Eolien and Universite de Moncton)	Resolution : 1 km Uncertainty : N/A	Public	Average wind speed at 10 m and 50 m, streams and power line locations.

Gap Regions not yet Mapped at Higher Resolution	Manitoba	N/A	N/A	Some wind resource mapping has been undertaken by Manitoba Hydro based on results from 7 monitoring sites, but results have not yet been published.
	Nunavut	N/A	N/A	Some territorial wind resource mapping efforts have been started by little information is presently available.
	Nova Scotia, Newfoundland, the Yukon, the Northwest Territories, Saskatchewan and Alberta	N/A	N/A	No provincial mapping efforts to date.
United States	US Wind Resource Maps (NREL (National Renewable Energy Laboratory) - National Wind Technology Center)	Resolution: 1km² or better Uncertainty: ~10%	Public	Average wind speed and wind power density at 50 m, power lines, and Indian reservations. This data has been enhanced with other key project planning infrastructure geographic information for the Western States of Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming in the Renewable Energy Atlas of the West.
United States	Wind Energy Resource Atlas of the United States (NREL)	Resolution: 1/3 degree of longitude by ¼ degree of latitude. Roughly 25 km x 25 km, though varies with latitude. Uncertainty: Not available (high due to low resolution)	Public	Average wind speed and wind power density at 10 m and 50 m heights. Information is based on 1986/1980 map.
United States	The Spatial and Temporal Distributions of U.S. Wind and Windpower (Standford University)	Resolution: N/A - does not provide full geographic coverage, only data for specific measurement/monitoring points.	Public	Average wind speeds calculated at 80 m height. Data from 1587 surface stations & 97 sounding stations. Results of extrapolations are color categorized by range of average wind speed and are represented as colored

				dots sited at the locations of the particular measurement point.
Regions that Have Been Mapped at Higher Resolutions but Not Validated by the NREL	Texas	Not available	Public	Not available
	Oklahoma	Resolution: 372 m Uncertainty: ~10%	Public	Quality of wind resource at 10 m and 50m.
	Kansas	Resolution: ~1km^2 Uncertainty: ~10%	Public	Average wind speed at 50m.
	New York	Resolution: ~1km^2 Uncertainty: ~10%	Public	Average wind speed at 30m, 50m, 70m and 100m and average wind power density at 50m.
	Iowa	Resolution: ~1km^2 Uncertainty: ~10%	Public	Average wind speed at 50m.
	Minnesota	Resolution: 750 m (square cell) Uncertainty: ~10%	Public	Average wind speed and wind power density at 50m and 70m.
	Alaska	Not available	Public	Not available
	Wisconsin	Resolution: ~1km^2 Uncertainty: ~10%	Public	Average wind speed at 30m, 60 m and 100 m
Gap Regions not yet Mapped at Higher Resolution	Louisiana, Mississippi, Tennessee, Kentucky, Alabama, Georgia, South Carolina, Arkansas and Florida	N/A	N/A	Based on earlier lower resolution maps these states are not projected to have significant wind resources and may not be worth mapping at a higher resolution.

Mexico	Wind Energy Resource Atlas of Oaxaca, Baja California Norte Border Region, Western Chihuahua Border Region, Northwestern Mexico Border Areas, Eastern Sonora Border Region, Western Sonora Border Region, the Quintana Roo Region, the Yucatan Region and the Campeche Region. (Renewables for Sustainable Village Power – NREL)	Resolution: 1km² or better Uncertainty: ~10%	Public	Average wind speed and wind power density at 50 m, power lines.
Mexico	The wind measurements currently taken in Mexico are from research organizations, educational institutions, government agencies and private businesses. IIE (GEF-UNDP program)	Not available Not available	Not available Not available	The IIE is the only institution that models the density of wind potential. To do so, it uses information collected from wind stations installed by the IIE itself, measuring the average wind speed and associated direction in 10-minute intervals, with readings every two seconds. The modeling is done using the WA^{s}P program, developed at RISØ Laboratories in Denmark. IIE is measuring wind speed and direction at Corredor La Paz-Cd. Constitución, Baja California Sur; Cd. Cuauhtémoc and Samalayuca, Chihuahua.; Barra de Coyuca, Guerrero.; Alchichica, Puebla; Los Mochis, Sinaloa; San Fernando and La Pesca, Tamaulipas; Perote and Punta Delgada, Veracruz and Zacatecas, Zacatecas. Prior initiatives have measured and modeled wind in the North Pacific region of Baja California Sur; Isla del Carmen, Campeche; Pachuca, Hidalgo; the border region in the state

				of Nuevo León; Playa Paraíso and Chetumal, Quintana Roo; Moroncarit, Sinaloa; Laguna Verde, Veracruz; Holbox, Yucatán and La Virgen, Zacatecas.
Tamaulipas border region	(The Universidad Autónoma de Tamaulipas)	Not available	Not available	Has recently begun a measurement program in the Tamaulipas border region, with the support of the North American Development Bank (NADB). According to preliminary results, the area has winds of regular intensity that suggest the feasibility of installing wind electric stations.
Baja California, Baja California Sur, Chiapas and Oaxaca	(Private Companies)	Not available	Proprietary	Some private companies are measuring wind at sites located in the states of Baja California, Baja California Sur, Chiapas and Oaxaca, but no information is publicly available.
Chihuahua, Hidalgo and Veracruz	(State Governments)	Not available	Not available	The governments of the states of Chihuahua, Hidalgo and Veracruz are funding the assessment of wind to implement electricity generation projects in areas of interest.

2.1.8 Regional information gaps

- See Table 2.1.1 above.
- In Mexico, the area currently being studied is not more than 5% of the total national territory.

2.1.9 Summary

2.1.9.1 What is missing?

- Maps for some regions do not have key information on the location and capacity of transmission infrastructure, geographic characteristics, access to roads, land reserves etc. This is essential to facilitating siting of potential wind projects.

- Without adequate validation, there may be significant discrepancies along state borders and increased uncertainty by users if available high-quality measurement data does not agree with the map estimates **[W6]**.

- Wind resource mapping in some regions can be improved by increasing the actual measurement and monitoring capacity. Ground measurement stations are located throughout the world, but they are situated mainly in populated regions. In more remote areas and less developed nations, where renewable energy technology projects are often implemented, measurement stations are limited. Improving wind measurement and monitoring capabilities in these regions would contribute significantly to enhancing project planning capabilities.

- Development of short-term and real time forecasting/mapping tools will help energy producers proceed with new wind farm projects and avoid the penalties they must pay if they do not meet their hourly generation targets **[W5]**.

2.1.9.2 What should be done to improve capacity?

- Canada: Province by province mapping initiative to match initiative those undertaken by Ontario, Quebec, PEI, New Brunswick and BC should be undertaken. In particular Maritime Provinces, Alberta and Saskatchewan would benefit from such an exercise.

  United States: Certain states have not been mapped at the same resolution as the rest of the country. These are, however, states that have very low potential for wind project development in early, low resolution mapping initiatives. Western states have been mapped to a higher standard than the rest of the US through the use of an interactive online map tool developed using enhanced GIS details related to supporting infrastructure and access information. The maps produced by the Wind Powering America program, for New York, New Jersey and Ohio, also contain similar details but are not available in a interactive format. This interactive mapping practice should be extended to the central and eastern states that have established promising wind regimes through mapping initiative in order to enhance national wind planning capacity. These states include North and South Dakota, Michigan and the eastern seaboard states.

2.2 Geothermal

2.2.1 Overview of Findings

- The Southern Methodist University (SMU) map provides sufficient detail of the entire North American continent for practical feasibility study siting of a geothermal project.
- A "sweet spot" map that shows optimal sites with shallow heat sources and terrain that permits easy siting of an electric generation or heat use facility within high geothermal resource areas would be useful to improve capacity and further narrow possible sites for an energy project prospector. Parameters related to ease of access to resources should therefore be built into ranking of sights in maps.
- In Mexico, the national use of high-temperature geothermal resources for medium- and large-scale electricity generation is fully identified and quantified. The assessment of medium and low temperature manifestations should continue in areas where the use of this resource could be used for other purposes, as the enormous size of these reserves and their associated temperatures could trigger the economic development of several rural areas across the Mexican territory.
- The creation of an interactive map, as has been done for the Western states, that allows a prospector to view not only the location of geothermal resource areas, but also the relative location of power transmission infrastructure, the topography, surface coverage and accessibility would be useful for Canadian resources areas, in particular British Columbia, Alberta, the Yukon and the Northwest Territories as well as Mexico and some US states, such as Texas, Louisiana, Arkansas and South Dakota.

2.2.2 Geothermal Resource Mapping -- why is it important?

- Like all other renewable resources, high resolution/high reliability geothermal resource maps are important to minimize energy project prospecting risks by minimizing feasibility study costs during final, exact location of a facility.
- It is also important in providing preliminary estimates of power or heat generation potential for a project and assessing potential rates of return for projects during the pre-feasibility assessment.
- Increasing modeling/mapping capacity will also increase understanding of geothermal resources and improve our ability to successfully harness them.

2.2.3 Industry mapping practices and methodologies

2.2.3.1 Characteristics of Geothermal Energy

- Geothermal energy is natural heat from the Earth's interior where temperatures reach more than 3500 ^{o}C. This heat energy comes from the decaying of naturally occurring radioactive elements within the Earths' crust.

- The heat flow of an area is determined by measuring the geothermal gradient in a borehole and the thermal conductivity of the rock drilled **[G1]**.

- As heat energy is transferred through the Earth it comes into contact with other substances, such as water. This water is then heated by the radioactivity to elevated temperatures and brought to the Earth's surface as steam or hot water.

- Another way for geothermal energy to be provided is that magma rising through the crust will heat any nearby groundwater. This groundwater can then escape to the surface to give such features as geysers, hot springs and boiling mud puddles **[G1]**.

- Only two resources can presently be used commercially to generate energy with today's technologies: hydrothermal fluids and earth energy **[G2]**.

- Hydrothermal fluid resources are reservoirs of steam or hot water (>200 ^{o}C) that are formed by water seeping into the Earth, collecting in, and being heated by fractured or porous hot rock. These reservoirs are tapped by drilling wells to deliver hot water to the surface for generation of electricity or direct use **[G2]**.

- Earth energy is the heat contained in soil and rocks at shallow depths. This form of low and moderate temperature resources is tapped for direct use and ground source heat pumps.

- Direct-use projects generally use resource temperatures of 40°C-150°C **[G2]**.

- In a typical direct-use application, a well brings heated water to the surface; a mechanical system—piping, heat exchanger, controls—delivers the heat to the space or process; and a disposal system either injects the cooled geothermal fluid underground or disposes of it on the surface. The most rapidly growing use for geothermal energy is geothermal heat pumps, which use earth or low-temperature groundwater as a heat source in the winter and a heat sink in the summer **[G2]**.

- The areas with highest underground temperatures are in regions with active or geologically young volcanoes. These "hot spots" occur at plate boundaries or at places where the crust is thin enough to let the heat through **[G3]**.

- These regions are also seismically active. The many earthquakes and the movement of magma break up the rock covering, allowing water to circulate. As the water rises to the surface, natural hot springs and geysers occur. The water in these systems can be more than 200 ^{o}C **[G3]**.

- Geothermal energy resources are typically represented in terms of heat flow per unit area (mW/m^2) or temperature range at a certain depth.

2.2.3.2 Mapping Methodology

- The most recent and most complete map (see Figure 2.2.1 below containing the US portion of the map) of the geothermal energy resources in North America utilized extensive industry oriented thermal data sets as well as heat flow data from various research initiatives **[G4]**.

- Access to previously proprietary industry oriented thermal data in recent years has allowed for a substantial increase in the number of data points available for geothermal resource modeling, allowing for higher resolution and more reliable maps to be developed.

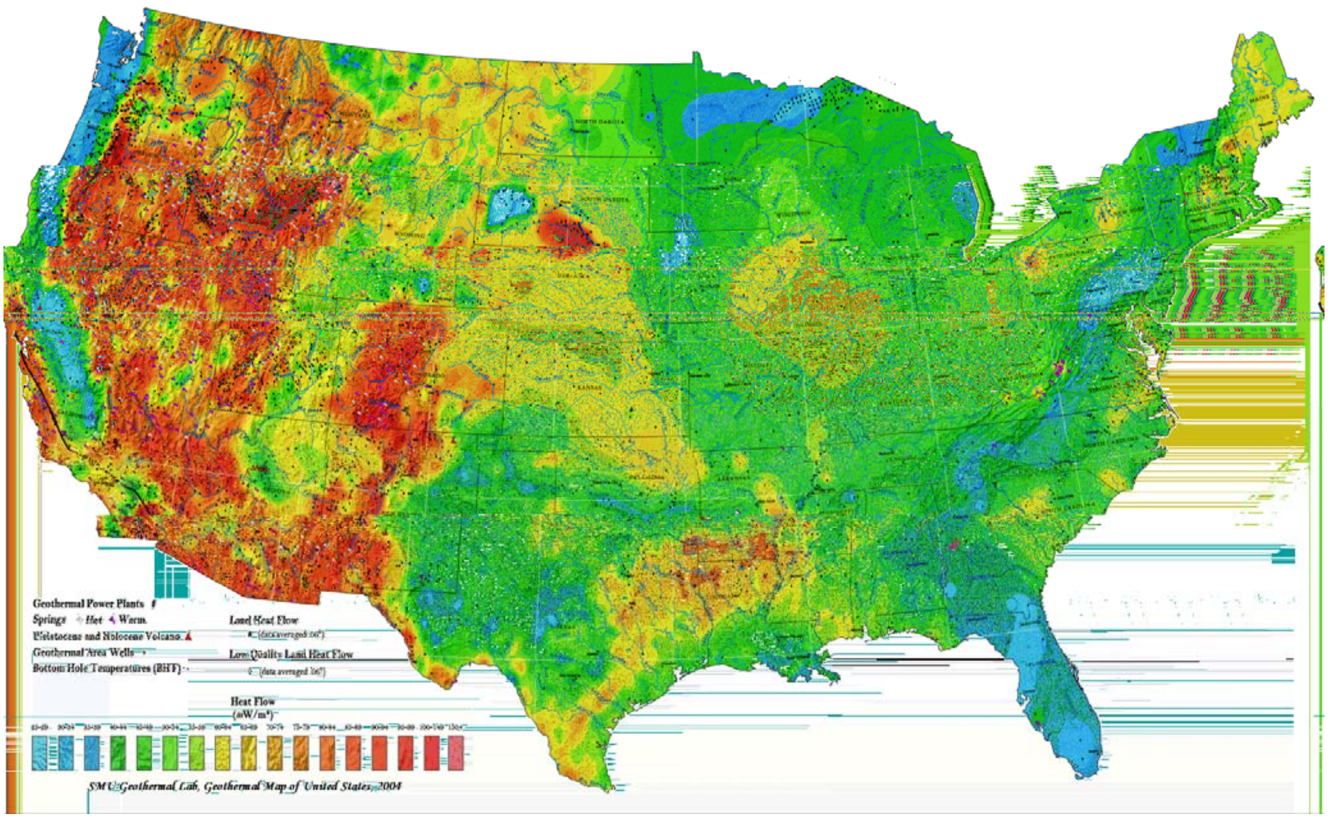

Figure 2.2.1: US Geothermal Resource Map; Source: http://www.smu.edu/geothermal/heatflow/geothermal_all_us_clipped_150dpi_pagesize_legend.gif

- For some newer sources of data used, heat flow values were not available. Heat flow values were therefore calculated for as many wells as possible using raw temperature-depth and gradient information as well as derived thermal conductivity and rated quality **[G4]**.

- For other sources of data, data points were corrected to compensate for variations between data sets **[G4]**.

- Sites (data points) were assigned a quality ranking based on the drilled depth and the quality of the data. The deeper wells receive the higher quality rankings. Wells with “geothermal” scale gradients/heat flow or those drilled within a known geothermal area are given a separate ranking. A cut off heat flow of 120 mWm^{-2} is typically used to differentiate sites with electric generation potential from strictly thermal sites **[G4]**.

- Once a completely ranked data set is derived, data points were contoured using a minimum curvature algorithm over a fine grid interval. The achievable resolution with such a model is constrained primarily by the number and quality of data points **[G4]**.

- Other versions of geothermal resources maps, such as that used by the US Department of Energy (DOE) are based on broad regional divisions, usually differentiated by color coding, based on the estimated subterranean temperatures at a depth of 6 kilometers. The basis for these estimated subterranean temperatures is provided by extrapolation/interpolation of actual bore hole measurement sites. To determine the Earth's internal temperature at any depth below the capabilities of normal well drilling, multiple data sets were synthesized. The data typically used include: thermal conductivity, thickness of sedimentary rock, geothermal gradient, heat flow, and surface temperature **[G5]**. These maps are less precise and less reliable. The DOE map is presented in Figure 2.2.2 below.

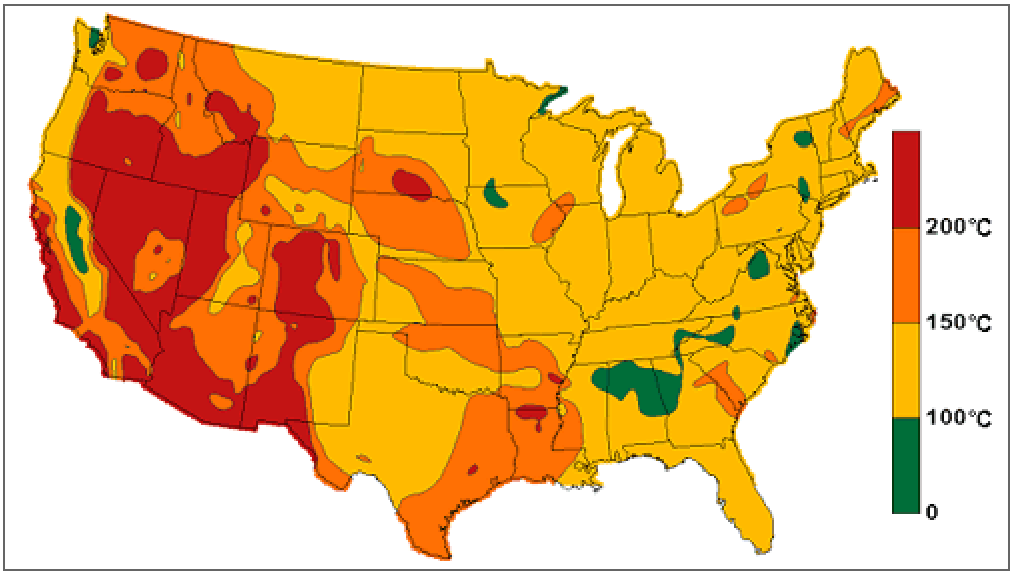

Figure 2.2.2: US Geothermal Resource Map (Temperatures at a depth of 6 km); Source: http://www.eere.energy.gov/geothermal/geomap.html

2.2.4 Regionally Specific Mapping Methodologies

- The best geothermal resource map presently available is the North American map described above, completed by the Southern Methodist University (SMU) Geothermal Research Lab. This map covers all of North America in an equal level of detail and is based on the largest data set of any map (more than 24,000 data points) **[G4]**.

- The recognition and inventory of thermal areas in Mexico resulted in the identification of around 1,380 points with thermal potential, in 1987 **[G6]**.

- The IIE has estimated Mexico's geothermal reserves at intermediate to low temperatures (< 200 °C). The results of these estimates include approximately 30% of all identified geothermal manifestations. In performing these estimations, the volume method was used, complemented with simulations using the Montecarlo method, to quantify the inherent uncertainties **[G7]**.

2.2.5 Limitations to mapping geothermal energy resources

2.2.5.1 Technical

- There is generally little consistency in drill site characteristics, such as bore hole depth, measurement depth and type, and geological structure. This necessitates substantial extrapolation and correction of available data for existing sites to develop a coherent and reliable model.

2.2.5.2 Geographic

- Although an area may appear to be promising based on a geothermal resource model/map, other geological and engineering factors can affect the feasibility of a geothermal generation project. The depth of the resource and the geological structure and the terrain above it can greatly affect the feasibility of siting an electric generation or heat use facility.
- Although there are many ocean data points, the amount of scatter in ocean heat flow and large areas lacking data still makes it difficult to interpolate regional phenomena according to actual available data points for the two oceans surrounding North America. However, these resources are not expected to be viably accessible in the near future.

2.2.5.3 Budgetary

- Improving the resolution or reliability of geothermal resource maps is particularly difficult, as it relies on increasing the number of data points used to create a regional resource model. Data points used are based on test drilling sites, which are expensive to develop, especially to the depth of some resources (several kilometers). Furthermore, little financial incentive exists to undertake such drilling in regions of known or projected poor geothermal resources.
- Mexico's geothermal development has focused on using high-temperature geothermics to produce electricity. However, it is also possible to locate sites with lower-temperature thermal waters that could be used for recreational and therapeutic purposes, although there is no coordinated effort to promote such uses, available information, or investor interest.

2.2.5.4 What is being done to overcome limitations?

- By increasing the number of heat flow measurement points used to generate a map for a given region, the knowledge on heat flow contouring, and consequently the interpolation of geothermal trends between measurement points, continues to be improved. This increased detail has amplified the information available and enhanced reliability of the map for North America as a whole, but some regions may still benefit from an increase of data measurement points.

- Conversely, in regions where the geothermal resource is low, which are coincidentally the areas where mapping quality is inferior, there is little economic incentive to improving the data pool.

2.2.6 Discussion of required data quality for practical energy project planning

- The SMU map provides ample detail for feasibility study siting of a geothermal project. At a resolution of 0.1°, combined with locations of actual well measurement sites on which the maps are based, risk of miss-siting is greatly reduced. In addition, the geological formations that drive the geothermal process typically cover large areas making it fairly easy to center a feasibility analysis on a high resource zone. Furthermore, the decrease in geothermal energy potential is very gradual as one gets further from the center of a higher-potential geographic zone.

- Some additional value may be derived if maps can highlight easily accessible and shallow high geothermal resource potential "sweet spots", to further narrow appropriate locations for site feasibility investigation.

- In Mexico, there is sufficient information to plan medium- and large-scale power generation projects. In the case of other productive uses or micro- and small-scale electricity generation, temperature and output information on potentially usable small deposits is required.

2.2.7 Regional mapping initiatives and capacity (including an analysis of mapping capacity in remote areas)

2.2.7.1 What has been done? Where? What is the resolution/reliability of the information?

Table 2.2.1: Regional Geothermal Mapping Initiatives and Capacity

	Map Title (Source)	Resolution/Uncertainty	Public Access/ Proprietary	Available Information
North America	2004 Geothermal Map of North America (Southern Methodist University (SMU) Geothermal Lab Research)	Resolution: ~0.1° Uncertainty: Not available	Public (at a cost of ~US$ 60)	Heat Flow ranging from 25 to >150 mW/m^2. Map also shows location of geothermal power plants, hot springs and geothermal wells.

Canada - British Columbia	Green Electricity Resources of British Columbia (BC Hydro/Canadian Cartographics)	Resolution: Not available Uncertainty: Not available	Public	Color categorization into three ranges of geothermal potential: low (not significant), moderate (gradient heat with temperatures up to 200 ^{o}C) and high (presence of hot fluids often in excess of 200 ^{o}C), location of temperature readings are provided, as is the potential for development in GWh/year.
United States	Geothermal Map of the United States (Southern Methodist University (SMU) Geothermal Lab Research)	Resolution: ~0.1^{o} Uncertainty: Not available	Public	Based on the North American Map listed above.
United States	US Geothermal Resource Map (DOE)	Resolution: Not available Uncertainty: Not available	Public	Broad regional divisions based on estimated subterranean temperatures at a depth of 6 kilometers presented in a ranges from 0 to > 200 ^{o}C.

Western United States (Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming)	Renewable Energy Atlas of the West (Land and Water Fund of the Rockies, Northwest Sustainable Energy for Economic Development (SEED), Green Info Network and Integral GIS)	Resolution: $\sim 0.1^{o}$ Uncertainty: Not available	Public	One set of maps depicts regions of strong geothermal potential and another set of maps depicts estimated temperatures in degrees centigrade, at depths of 3, 4, 5, 6 and 10 km on a state by state basis. An interactive version of this map is available with capability of illustrating location of power transmission infrastructure and capacity details, roads, county boundaries, etc. is also available. These maps are base on the model developed by SMU for the North American Map listed above.
Mexico	(IIE, Sponsored by SENER)	N/A	Not available	IIE has been conducting studies on the potential of intermediate- and low-temperature geothermal reserves.

- In the United States, the hottest (and currently most valuable) resources are in the western states, Alaska, and Hawaii. In Canada, British Columbia contains the hottest geothermal resources. This has driven efforts to thoroughly map these areas **[G2]**.

- In Mexico, the IIE, sponsored by Sener, has been conducting studies on the potential of intermediate- and low-temperature geothermal reserves for several years.

- Mexico has the capability to estimate geothermal resources. However, given the preference for high-temperature geothermics for medium- and large-scale electricity generation, due regard has not been given to other possible applications, such as intermediate- and low-temperature geothermal resources. This field may be attractive because many production processes, especially in rural areas, can be powered by low-temperature thermal sources, including micro- and small-scale electricity generation.

2.2.7.2 Public versus proprietary mapping initiative information

- See Table 2.2.1 above.

2.2.8 Regional information gaps

2.2.8.1 Where is there missing information or lower quality/reliability?

- Canada does not presently have its own geothermal resource map, however, the SMU North American map provides very high resolution coverage over the entire country.

- The creation of an interactive map, as has been done for the Western states by the Land and Water Fund of the Rockies, Northwest Sustainable Energy for Economic Development (SEED), Green Info Network and Integral GIS in the United States, that allows a prospector to view not only the location of geothermal resource areas, but also the relative location of power transmission infrastructure, the topography, surface coverage and accessibility would be useful for Canadian resources areas, in particular British Columbia, Alberta, the Yukon and the Northwest Territories as well as Mexico and some US states, such as Texas, Louisiana, Arkansas and South Dakota.

- In Mexico, the information obtained to date from studies conducted at high-temperature deposits is reliable. However, there is still much work to be done to study potential areas to use this resource for purposes other than medium- and large-scale electricity generation.

2.2.8.2 Why? (remote location, funds, complex terrain, etc.)

- The main reasons for the lack of effort in Canada to map geothermal resources is likely due to the relatively low quality of the resource across the majority of the country with the exception of British Columbia, which has mapped its resources through the efforts of BC Hydro and Canadian Cartographers, the Yukon, the Northwest Territories and Alberta. With the existence of the SMU map, there is little incentive to duplicate their efforts to create a Canadian version of the map.

2.3.9 Summary

2.3.9.1 What is missing?

- An interactive full GIS map of Canadian and Mexican geothermal resource areas. Certain US states would also benefit from such a map.

- A “sweet spot” map that shows optimal sites with shallow heat sources and terrain that permits easy siting of an electric generation or heat use facility within high geothermal resource areas.

- In general terms, there is an acceptable coverage of information on national high-temperature geothermal resources in Mexico. However, as mentioned above, the potential of usable low- and medium-temperature resources needs to be quantified. This kind of information is necessary to identify heat-powered projects and micro- and small-scale electricity generation projects, especially in rural areas.

2.3.9.2 What should be done to improve capacity?

- Although existing capacity appears to be adequate, it can be improved by increasing the number of drilled test sites, establishing universal drill site testing and reporting parameters (such as geological structure, measurement depth etc.) and adding mapping parameters in the ranking of sites that correspond to ease of electric generation or heat use facility installation and operation.

2.3 Solar

2.3.1 Overview of Findings

- The benefits associated of solar energy, specifically its ability to match demand and shave peak demand, needs to be communicated in order to overcome the present stigma that exists as a result of its higher cost, and addressed as a motivation to improve solar resource mapping, especially in regions where the quality of existing data is inferior.

2.3.1.1 Canada

- In Canada, the market for solar energy has been slow to emerge as a result of its high price compared to more traditional sources of energy. Consequently, there has been little incentive and pressure on national or provincial governments to undertake more thorough mapping initiative to increase the quality of existing solar resource maps.
- Natural Resource Canada has developed a statistical model based map of Canada's solar energy resources. Some provinces have developed higher resolution maps based on satellite imaging and physical models. Details of Canadian solar resource maps are presented below.
- Higher resolution maps of all of Canada should be developed, especially in high population density areas where grid integrated PV applications are expected to soon be economically competitive as a result of changes in net metering laws and feed in tariffs for solar.

2.3.1.2 United States

- The Department of Energy, through the National Renewable Energy Laboratory, has developed statistical model and physical model based maps for the entire country.

2.3.1.2 Mexico

- Mexico has several solar maps, although most contain discrepancies with respect to measurement data. While available maps cover all of Mexico's territory, there are not sufficient measurements for areas removed from major cities and towns to assess the map estimates.
- A network of duly calibrated instruments is needed to correctly measure insolation, following international standards. The network would have to cover Mexican territory more homogeneously, enabling a better adjustment of models and therefore a better map quality.
- Access to long-term satellite weather data would allow Mexico to establish physical model based maps which allow higher resolution and accuracy and eliminate the dependence on broad distribution of properly calibrated measurement stations.

2.3.2 Solar Resource Mapping - why is it important?

- To minimize the economic risk of implementing solar energy conversion technologies. In order to do this, data must accurately represent the spatial (geographic), temporal (hourly, daily and seasonal), and spectral (wavelength distribution) variability of the solar radiation resource at different locations.

- By continuing the long-term measurement or monitoring of solar radiation at numerous sites, it is possible to assess changes in climate and add new data to existing databases and consequently improve their reliability and their adaptability.

2.3.3 Industry mapping practices and methodologies

2.2.1.1 Characteristics of Solar Energy

- Solar radiation is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and converted into several forms of energy, such as heat and electricity, using a variety of technologies. The technical and economic feasibility of actually using these technologies to generate useful energy at a specific location depends on the available solar radiation or solar resource **[S1]**.

- The amount of usable solar radiation that reaches any one "spot" on the Earth's surface is affected by:

  - Geographic location
  - Time of day
  - Season
  - Local landscape
  - Local weather.

- Due to the spherical shape of the planet, the sun strikes the surface at different angles ranging from 0º (just above the horizon) to 90º (directly overhead) depending on latitude and time of the year. The closer the incident sun rays are to being parallel with the earth's surface, the longer they travel through the atmosphere, becoming more scattered and diffuse, resulting in a lower amount of energy available. Consequently, the Earth's polar regions remain cooler and have a lower potential for solar based energy generation since they never get a high sun. Contrarily, equatorial region remain warm and have a high solar energy generation potential, as a result of the constant direct incidence of the sun (90^o angle to the earth's surface) **[S1]**.

- Due to the rotation of the planet, hourly variations in sunlight intensity occur. In the early morning and late afternoon, the sun is low in the sky and its rays travel further through the atmosphere than at noon when the sun is at its highest point. On a clear day, the greatest amount of solar energy reaches a solar collector around solar noon (the highest point of the sun in the sky) **[S1]**.

- When entering the Earth's atmosphere, solar radiation undergoes complex interactions of reflection, scattering and absorption by atmospheric components and the planets surface.

- Clouds, atmospheric gases and particles and surfaces reflect about 30% of the radiation incident at the top of the atmosphere. The remaining 70% are absorbed, heating the system and causing water evaporation (latent heat) or convection (sensible heat) **[S2]**.

- Solar radiation that enters the earth is partially scattered by atmospheric components and planet surfaces, such as vegetation, snow etc. This is called diffuse solar radiation. The solar radiation that reaches the Earth's surface without being diffused is called direct beam solar radiation. Direct solar radiation is typically the most useful and reliable for usable energy generation **[S1]**.

- Measurements of solar energy are typically expressed as total radiation on a horizontal surface, or as total radiation on a surface tracking the sun.

- Radiation data are usually presented in kilowatt-hours per square meter (kWh/m^2) or mega joules per square meter (MJ/m^2) on a daily average for a given period, either annual or monthly **[S1]**.

2.3.3.2 Mapping Methodology

- Various computational models have been developed to obtain solar radiation estimates reaching the surface. These models can be classified under two main categories, statistical models and physical models **[S2]**.

- Statistical models make use of empiric formulations between incident solar radiation measurements sourced from actual surface measurement sites and local conditions. These models therefore provide restricted validity to the studied region and for the period of the year of validation. The density of measurement sites available with a region within a given amount of time can have a significant impact on the quality of the information available from the model **[S2].** Figure 2.3.1 provides an example of a statistical model.

Figure 2.3.1: Statistical model of the Average Daily Solar Radiation in the United States; Source: http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/serve.cgi

- Physical models are valid for any region of the planet because they are based on the solution of the radiative transfer equation (or energy balance) for the atmosphere. All radioactive processes that occur in the atmosphere are described mathematically by the radiative transfer equation. The parameterization of radiative processes depends on the knowledge of atmospheric data such as the cloud coverage and the profile of atmospheric constituents like aerosols, water vapor, ozone and other gases. This atmospheric data is generally sourced from satellite imaging **[S2]**. Figure 2.3.2 provides an example of a physical model-based map of solar radiation.

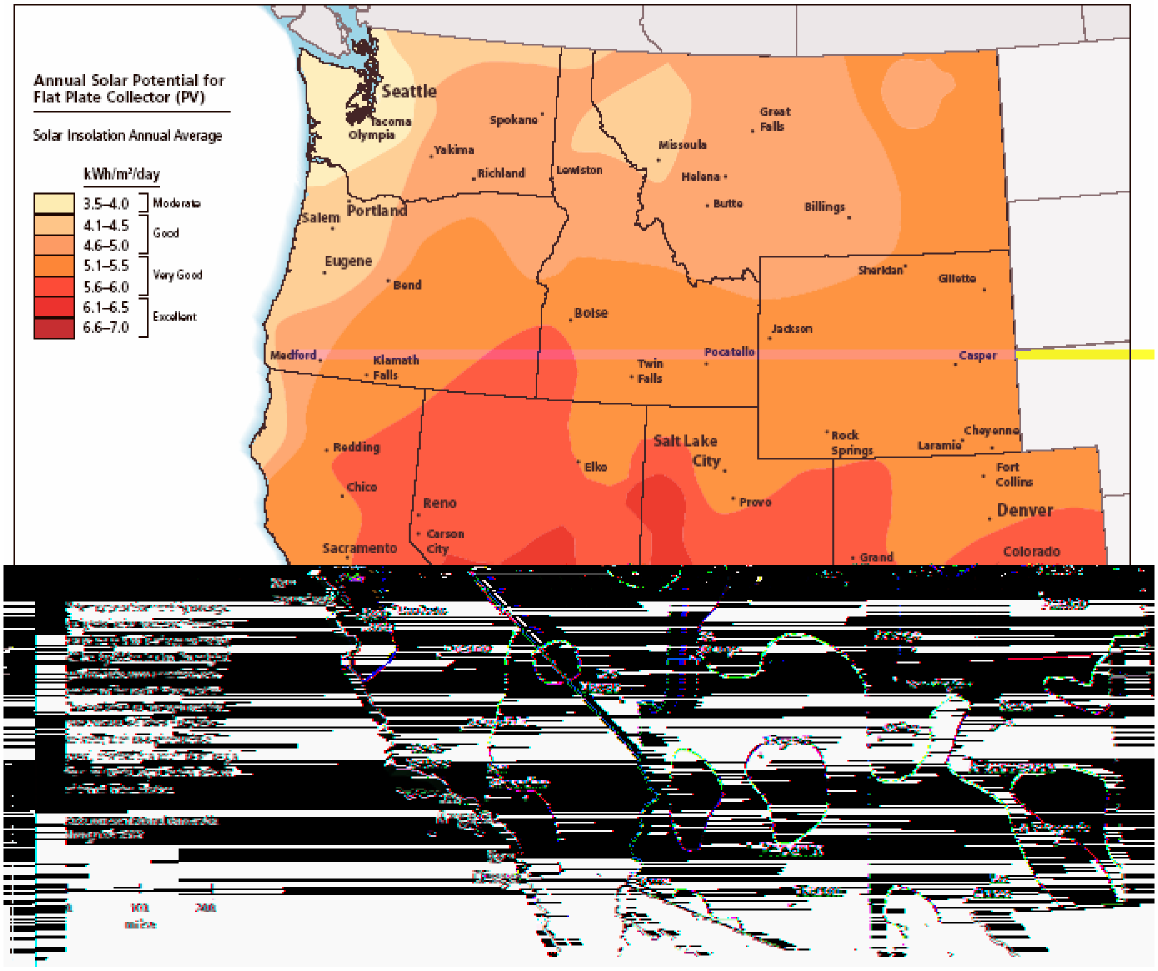

Figure 2.3.2: Average Daily Radiation for the Western United States; Source: The Renewable Energy Atlas of the West

- The main impacting factor for solar radiation on the surface, besides geographic location on the planet, is the cloud coverage.

2.3.4 Regionally Specific Mapping Methodologies

- Canadian national solar resource maps are based on a statistical model which uses data from 54 measurement stations. Most of these measurement stations are in the southern part of the country. This data was combined with simulated data based on a numeric model for an additional 93 locations **[S3]**.

- Earlier versions of the United States solar resource map showed general trends in the amount of solar radiation received in the country and its territories. It was based on a spatial interpolation (statistical model) of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB) which contained data from 239 measurement sites of the NSRDB **[S4]**.

- The more recent version of the United States solar resource map were developed using the Climatological Solar Radiation (CSR) Model (a physical model). The National Renewable Energy Laboratory for the U.S. Department of Energy developed the CSR model. This model uses information on cloud cover, atmospheric water vapor and trace gases, and the amount of aerosols in the atmosphere, to calculate the monthly average daily total insolation (sun and sky) falling on a horizontal surface. Where possible, existing ground measurement stations were used to validate the model **[S5]**.

- There are several studies on the potential of solar energy in Mexico, using different prediction techniques. The Atlas of Solar Radiation for Mexico, containing 12 charts showing the global solar radiation isolines in MJ/m^2 and height about mean sea level, was prepared using data from the GOES satellite and the Tarpley statistical model.

- The Solar Atlas of the Mexican Republic lists average actual exposure, average daily global solar irradiation in $cal/cm^2 \cdot day$, average daily direct solar irradiation in $cal/cm^2 \cdot day$, and average daily, monthly, seasonal and annual diffuse solar radiation in $cal/cm^2 \cdot day$. These maps were prepared using the monthly regional cloud percentages obtained from the NIMBUS III and ESSA-8 satellites, covering all territory divided into a network of 117 squares of approximately 130 km per side, using the Angstrom approximation **[S6]**.

- The IIE, in Mexico, prepared maps of global, direct and diffuse solar radiation, measured monthly and annually in $Wh/m^2 \cdot day$, using the RADIAC model and information on sky cover observed at 2900 weather stations over a period of 10 years **[S7]**.

2.3.5 Limitations to mapping solar energy resources

2.2.5.1 Technical

- Availability of data, especially for statistical models, can be a significant limitation to reliability and achievable resolution of a given model.

- Unusual weather phenomena, such as El Nino, or unusual micro climatic condition, caused by large bodies of water for example, can cause cloud cover, and consequent solar radiation values, to vary significantly from models in a given region.

- In Mexico there are various research institutions and government agencies measuring solar radiation at different sites within national territory. However, there are deficiencies in the calibration and maintenance of the equipment, due to the lack of budgetary and economic support. The Solar Radiation Observatory at the Institute of Geophysics at the UNAM Mexico City campus measures the parameters of global radiation, diffuse radiation, ultraviolet radiation and the duration of insolation with duly calibrated high-quality instruments. This observatory offers referencing services for solar radiation measuring equipment, using instruments referenced every five years with patterns from the World Radiation Center at Davos, Switzerland.

2.2.5.2 Geographic

- Although not as sensitive as wind to the effects of variations in terrain, some deviations can still occur.

- Abrupt changes occur in the amount of solar radiation received on surfaces in mountainous regions as a result of significant variations of elevation, aspect and slope, over short distances.

- In areas of more regular terrain, because of constraints on isarithmic interpolation imposed by the uneven and often sparse distribution of climate stations, the density of the station network can be used as an index of isoline reliability **[S3]**.

2.3.5.3 Budgetary

- Cost per watt for most solar energy generation technologies compared to traditional sources of energy or even other renewable sources of energy such as wind and hydro, is (often) prohibitive in North America (meaning a reliance on subsidies, or specific tax incentives can be required) (when benefits – environmental, distributed power – are not considered) .

- Financing for solar resource mapping is directly tied to the perceived potential for economic solar energy generation within a region or country. In Canada for example, where solar energy has been slow to emerge as a potentially viable source of energy, relatively very little has been done to enhance solar resource mapping capabilities. Conversely, in the United States significantly more effort has been put in to improve solar resource maps.

- For statistical models, the cost of siting measurement stations is a significant limitation to increasing reliability.

2.3.5.4 What is being done to overcome limitations?

- The trend has been to move towards maps based on physical models which provide greater reliability and enhanced resolution as a result of their use of satellite imaging as their source data.

- This modeling eliminates the dependence on density of ground measurement stations for increasing model reliability.

2.3.6 Typical data quality (resolution) and reliability

- Typical resolution for physical model based maps is in the range of 40 km x 40 km with an associated uncertainty of ~10%.

- Resolution is difficult to assess for statistical model based maps. These maps only illustrate average trends within largely divided geographic regions, without discerning for micro-climatic or topographic features. The associated uncertainty for such maps is expected to be in the range of 16-20%.

- Most solar measurement equipment in Mexico is not regularly calibrated in accordance with World Meteorological Organization (WMO) recommendations, which suggests that most available measurements are not entirely reliable.

2.3.7 Discussion of required data quality for practical energy project planning

- Because variation in insolation rates is so gradual, varying primarily with location on the planet, resolution is less important than with wind resource mapping (as an example).
- The two main factors that can affect micro-regional deviations from a modeled average macro-regional insolation rate are cloud cover and drastic changes in topography.
- Cloud cover variations in micro-regions are not easily captured and there is no guaranty that higher resolution maps can provide a greater guaranty of expected power generation estimates.
- Current solar maps give only a general idea as to the distribution of solar energy; for large-scale commercial projects measurements must be taken at the site where the station would be set up.
- Shaded sides of mountains are obviously not desirable for siting solar technologies, so providing the capability to discern such regions would be redundant and excessive.

2.3.8 Regional mapping initiatives and capacity (including an analysis of mapping capacity in remote areas)

2.3.8.1 What has been done? Where? What is the resolution/reliability of the information?

Table 2.3.1: Regional Solar Radiation Mapping Initiatives and Capacity

	Map Title (Source)	Resolution/Uncertainty	Public Access/ Proprietary	Available Information
Global	NASA Surface meteorology and Solar Energy Data Set (NASA's and Earth Science Enterprise program (RETScreen International-NRC))	Resolution: 1° by 1° (longitude by latitude) grid system representing average condition within a grid element are provided. Uncertainty: ~16%.	Public	Provides parameters for solar cookers, sizing and pointing of solar panels and for solar thermal applications, solar geometry, parameters for tilted solar panels, parameters for sizing battery or other energy-storage systems, parameters for sizing surplus-product storage systems, meteorology (temperature), and diurnal cloud Information. Key parameters include: Average Monthly Insolation (kWh/m^2/day) for flat and angled panels, minimum available insolation and hours of daylight. Other information includes: insolation on horizontal surface (kWh/m^2/day), midday insolation (kWh/m^2/day), clear sky insolation (kWh/m^2/day), clear sky days (days), diffuse radiation on horizontal surface (kWh/m^2/day), direct normal radiation (kWh/m^2/day), insolation averages at available (0, 3, 6, 9, 12, 15, 18, 21) GMT times (kWh/m^2/day), insolation clearness index, clear sky insolation index, clear sky insolation normalized clearness index, radiation on equator-pointed tilted surfaces (kWh/m^2/day), equivalent sun hours radiation for equation-pointed tilted surfaces (kWh/m^2/day) and minimum available insolation as % of average values over consecutive-day period (1, 3, 7, 14 and 21 days).

Global	Solar Energy - Measuring Solar Insolation (World Energy Council, Environment Canada & Nasa Center)	Resolution: 40 km Uncertainty: Not available	public	Average monthly solar insolation for the months of January and April based on Earth Observatory data from NASA for the years 1984-1993. The data in presented as color coded ranges 0 to 8.5 kwh/m²/day
Canada	Canada Solar Radiation - Annual (Natural Resources Canada,/Canadian Atlas)	**Resolution:** Not available. Presents a broad categorization of Canadian solar regions. The map is based on a statistical model of data from 54 actual measurement stations which was combined with simulated data based on a numeric model an additional 93 locations. **Uncertainty:** Due to the broad categorization of regions within the map, little emphasis is put on accounting for cloud cover variations in micro regions. As such it can be expected that uncertainty greater than 20% can occur in some regions.	Public	Annual mean daily solar radiation for horizontal surface as well as for inclined surfaces of 90^o and 60^o facing south (the equator). Maps provide color coded regions categorized in zones ranging from 7 to 15 MJ/m². Maps are also available for average daily solar radiation for the months of April and October. Data used for the development of the map is from the 1956-1978 time period.
Canada	Annual Mean Daily Solar Radiation (CanSIA)	**Resolution:** Not available. Scanned black and white maps with broadly delineated regions of varying insolation rates. **Uncertainty:** Not available	Public	Monthly and annual mean daily solar radiation (megajoules per square meter) incident on a south-facing surface tilted at an angle equal to the latitude of the location.
Canada - Nova Scotia	Solar Resources of Nova Scotia (Green Power Labs)	**Resolution:** < 5 km **Uncertainty:** Not available	Public	Annual mean daily solar radiation (kWh/m^2/day). Shows color coded regional variation with a high degree of precision for the narrow range from 3.33 - 3.55 kWh/m^2/day. The map does not appear to have been validated by any government body.
Canada - British Columbia	Green Electricity Resources of British Columbia (BC Hydro/Canadian Cartographic)	**Resolution:** 1^o x 1^o **Uncertainty:** ~ 16%	Public	Annual average daily solar radiation (kWh/m^2/day). Also provides location of power generation and transmission infrastructure. Solar radiation recording stations are also indicated.
Canada – Quebec	Cartographie par satellite de la resource solaire au Quebec	**Resolution:** ~ 40 km **Uncertainty:** ~10%	Public	Average daily insolation for all months in kWh/m^2. Maps present an average of data from 1998-2000.

United States	United State Solar Atlas (NREL)	**Resolution:** 40 km **Uncertainty:** ~10 %	Public	Average annual solar insolation in kwh/m²/day; Ranging from less than 2 to greater than 9 kwh/m²/day. Some map websites have interactive features that allow the viewer to zoom in on a particular region and illustrate relevant regional geographic features such as power transmission infrastructure, cities, etc. Some of the interactive map websites also allow for determination of economic data for SWH, Solar venting and PV installations for a specific site.
United States	U.S. Solar Radiation Resource Maps (NREL)	**Resolution:** Not available. Statistical model based on data from 239 stations around the USA. Only presents broad regional categorization of daily insolation rates. **Uncertainty:** 16-20%	Public	Average daily insolation rates (kwh/m²/day) on an annual or monthly basis. Angle of orientation of the system can also be accounted for.
Western United States - Colorado, California, New Mexico, Arizona and Nevada etc.	Renewable Energy Atlas of the West (Land and Water Fund of the Rockies, Northwest Sustainable Energy for Economic Development (SEED), Green Info Network and Integral GIS)	**Resolution:** 40 km **Uncertainty:** 10%	Public	Illustrates potential in very specific locations within each state that are suitable for concentrating solar power generation based on daily average solar insolation rates (kWh/m^2/day). Also illustrates proximity to major power generation and distribution infrastructure.
Arizona, California, New Mexico, Colorado and Nevada	Concentrating Solar Power Resource Maps	**Resolution:** Not available **Uncertainty:** Not available	Public	Direct normal solar radiation maps—filtered by solar resource and land availability—to identify the most economically suitable lands available for the deployment of large-scale concentrating solar power plants. The actual solar resource is indicated in kWh/m2/day.
Mexico	Atlas of Solar Radiation for Mexico	**Resolution:** Not available **Uncertainty:** Not available (the discrepancy between maps and pyranometric measurements is in the range of 3-5%)		Contains 12 charts showing the global solar radiation isolines in MJ/m^2 and height about mean sea level, was prepared using data from the GOES satellite and the Tarpley statistical model.
Mexico	The Solar Atlas of the Mexican Republic	**Resolution:** Not available **Uncertainty:** Not available		Lists average actual exposure, average daily global solar irradiation in cal/cm^2·day, average daily direct solar irradiation in cal/cm^2·day, and average daily, monthly, seasonal and annual diffuse solar radiation in cal/cm^2·day.
Mexico	IIE	**Resolution:** Not available **Uncertainty:** Not available		Prepared maps of global, direct and diffuse solar radiation, measured monthly and annually in Wh/m^2·day, using the RADIAC model and information on sky cover observed at 2900 weather stations over a period of 10 years.

2.3.6.2 Public versus proprietary mapping initiative information

See above table.

2.3.7 Regional information gaps

2.3.7.1 Where is there missing information or lower quality/reliability information?

- The solar energy resource potential for Canada has been mapped entirely using a statistical model based on measured and synthetic data from just under 150 sites. This model establishes broadly categorized regions but does not accommodate for micro variations within these regions. Some efforts to use more advanced satellite data based models to developed more precise maps have been undertaken in some provinces such as British Columbia and Quebec, but these efforts and the maps that resulted from them have not been widely disseminated. The limited number of measured sites in Canada (54 actual measurement sites) used in the Canadian statistical mapping models makes them strongly dependent of interpolation. Micro regional effects are therefore poorly represented or accounted for.

- The US has mapped its solar energy resources to a high standard, using a physical model based on satellite data. The entire country has been mapped to the same standard.

- Mexico has extensively skilled human resources to map solar resources. Over the past two decades various domestic institutions have dedicated human and technical resources to this activity. For example, the Center for Atmospheric Sciences, the UNAM Institute of Geography and the UNAM Institute of Geophysics map global solar radiation with measurements obtained from the SMN's automatic weather stations. These maps may be of use in comparing the different solar modeling maps.

- According to some experts, the SMN weather stations are not adequately distributed for purposes of studying solar potential; for example, there are many stations in the area surrounding the Federal District but relatively few where solar radiation is measured, considering the WMO instrument maintenance recommendations.

- In addition, some state governments have expressed an interest in assessing solar power in their territories, for which purpose they have promoted solar assessment projects funded by so-called mixed funds and sector funds developed in conjunction with the National Science and Technology Council (Consejo Nacional de Ciencia y Tecnología—CONACYT). These projects are technically supported and executed by educational institutions.

2.3.7.2 Why? (remote location, funds, complex terrain, etc.)

- In Canada, the market for solar energy has been slow to emerge as a result of its high price compared to more traditional sources of energy. Consequently, there has been little incentive and pressure on national or provincial governments to undertake more thorough mapping initiative to increase the quality of existing solar resource maps.

2.3.8 Summary

2.3.8.1 What is missing?

- Higher resolution maps of Canada. Especially in high population density areas where grid integrated PV applications are expected to soon be economically competitive as a result of changes in net metering laws and feed in tariffs for solar.

- Access to long-term satellite weather data would allow Mexico to establish physical model based maps which allow higher resolution and accuracy and eliminate the dependence on broad distribution of properly calibrated measurement stations.

- The ability for real time solar resource mapping to allow for daily power planning and predicting generation capacity within unusual climate periods.

2.3.8.2 What should be done to improve capacity?

- The value produced by a power plant does not depends only on its energy yield, but also on its ability to provide added capacity to a local grid, a transmission and distribution system, or a utility customer. As a non-controllable, non-dispatchable resource, PV generation was, until recently, assigned a zero capacity credit by utility planners, particularly in region with moderate solar resource, such as the northeastern US.

- A more detailed look at the resource – its ability to match demand and shave peak demand – through the analysis of time/site specific solar resource data and coincident utility/regional loads often reveals that, in some cases the capacity credit of PV installations greatly exceeds their capacity factor (ratio of average output to rating). The benefits associated to this needs to be communicated and addressed as a motivation to improve solar resource mapping, especially in regions where the quality of existing data is inferior **[S8]**.

- Solar radiation models based on statistical modeling practices can be improved by increasing the number of sites for which measurements are being taken. This can allow for a better representation of the geographic distribution of solar radiation within a macro region and can potentially provide data to develop techniques to estimate solar radiation where there are no measurement stations. However, this would be a costly approach and would not yield as significant an improvement in output map quality and reliability as a revisiting of the resource maps using a physical model approach combined with daily satellite climate and atmospheric data sources **[S9]**.

- In Mexico, there are currently various versions of maps that generally describe the levels of solar radiation over national territory, although such maps need to be validated with land-based measurements. Greater sun measurement information is also required to enable a better understanding of changes in solar energy. For this purpose, the measuring equipment used should comply with internationally recommended specifications (ISO TR 9901 Solar Energy – Field pyranometers – Recommended practice for use). It is also necessary to implement calibration programs for existing measuring equipment, since its performance is altered over time. It is also advised that newly installed equipment be calibrated with reference to a single national pattern traceable to international patterns. The calibration schedules should consider such international standards as ISO 9847:1992, regarding the calibration of field pyranometers by comparison to a reference pyranometer.

2.4 Biomass

2.4.1 Overview of Findings

- Few biomass energy resource maps exist within the United States, Mexico and Canada as a result of the complicating factors that exist in quantifying this resource.
- The maps that do exist typically provide estimated total (lump-sum) quantities of energy that can be produced from a compiled variety of biomass sources available within a macro region, such as a county, municipality or even a province or state.
- A more practical approach to mapping biomass resources would be to map exact locations of concentrated biomass energy sources, such as forestry product manufacturing facilities, food processing plants, farms and landfills.
- Combining such information with location and capacity detail of power distribution infrastructure, municipal boundaries and other supporting infrastructure details could provide a much more useful tool to a potential project developer.

2.4.2 Biomass Resource Mapping -- why is it important?

- To minimize the economic risk and cost involved in planning a biomass energy generation project. In order to achieve this, maps must provide enough information to allow for at least a few preliminary locations with adequate volumes and type of biomass resources to be identified within a desired project boundary area. This in turn greatly reduces the time and cost of a screening process and minimizes the risk of pursuing projects in regions where they are not viable.
- It is also important in providing preliminary estimates of power and heat generation potential for a biomass project, as well as potential for expansion of the generation capacity in the future, and assessing potential rates of return for projects during the pre-feasibility assessment.
- There is presently no area basis or location specific measure for biomass potential in Canada or Mexico and there are a few area specific analyses for some locations in the U.S., but they are isolated, done by different agencies, and don't cover all feedstocks and therefore are of limited use for biomass energy generation project siting.

2.4.3 Industry mapping practices and methodologies

2.4.3.1 Characteristics of Biomass Energy

- Biomass is plant matter such as trees, grasses, agricultural crops, and other plant material. It can also include other agricultural sources, such as livestock manure, the organic fraction of municipal solid waste and food processing wastes.
- Biomass used for energy purposes can come from a broad range of sources. These include:
    - Leftover materials from the wood products industry

- Wood residues from municipalities and industry
- Forest debris and thinnings
- Agricultural residues
- Fast-growing trees and crops
- Animal manures
- A certain fraction of municipal solid waste
- Waste from food processing operations **[B1]**.

- For biomass to be a truly viable renewable energy resource it must be produced at a competitive cost, cause minimal environmental damage and be of a quality suitable for optimal energy conversion and end use.
- Biomass can be used in its solid form for heating applications or electricity generation, or it can be converted into liquid or gaseous fuels. Biomass fuels are converted to heat and electricity with technologies similar to those used when converting fossil fuels to heat and electricity.
- A key attribute of biomass is its availability on demand: much like fossil fuels, the energy is stored by nature in the biomass until it is needed, especially when the biomass is converted to a biofuel, such as bio-gas or bio-oil.
- Another key advantage of biomass based energy generation is that technologies have now been developed that can generate electricity from the energy in biomass fuels at scales small enough to be used on a farm or in remote villages, or large enough to provide power for a small town or city.
- It is difficult to quantify the energy content of biomass streams as it depends on the type of biomass, moisture content and its composition. The energy content of biomass is typically reported in either J/kg or J/L.
- The viability of using a particular resource for biomass energy generation is affected by several factors, such as:
  - Type of biomass resource
  - Competing demand for the resource (food supply, raw materials, soil nutrients etc.)
  - Reliability/sustainability of the resource
  - Distance the resource has to travel to be used for energy
  - Cost of using the resource for energy production
  - Type of energy conversion technology used
  - Seasonal growth or availability fluctuations

- Biomass production and harvesting requirements.

- These factors also affect the ease with which biomass resources can be quantified on a geographic unit basis.

- Certain forms of biomass are more plentiful in specific regions where climate conditions are more favorable for their growth.

- Generally, the most economical forms of biomass for generating electricity are residues. Residues are the organic by-products of food, fiber, and forest production such as sawdust, rice husks, wheat straw, corn stalks, and bagasse (the residue remaining after juice has been extracted from sugar cane) **[B1]**.

- Economic sources of biomass are also common near population and manufacturing centers **[B1]**.

2.4.3.2 Industry mapping practices and methodologies

- Few biomass energy resource maps exist within the United States and Canada as a result of the complicating factors that exist in quantifying this resource (listed above).

- The maps that do exist typically provide estimated total (lump-sum) quantities of energy that can be produced from a compiled variety of biomass sources available within a macro region, such as a county, municipality or even a province or state.

- Little modeling is involved in creating these maps as they depend primarily of statistical data available for macro-regions. Based on compiled statistical data, maps are created for a country or region by color coding within municipal or county boundaries according to an estimated biomass energy potential range. The units of such maps are typically provided in a generation potential unit of kW/region (e.g., kW/county). Figure 2.4.1 below provides an example of such a map.

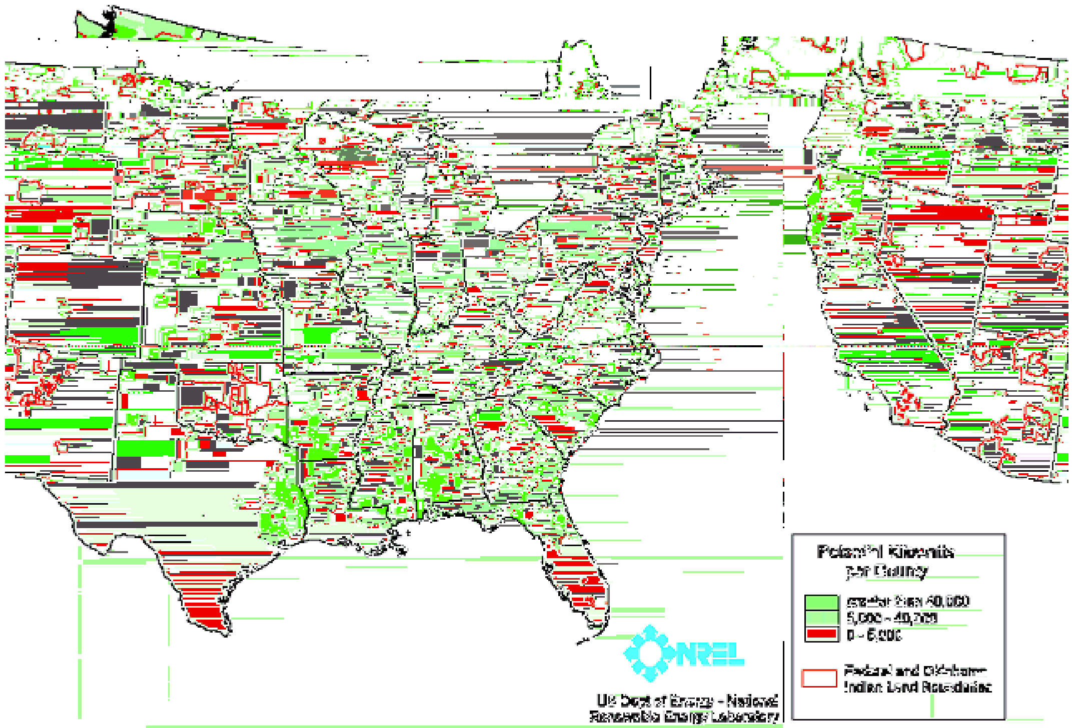

Figure 2.4.1: Biomass and Biofuels Resource Potential in the United States; Source: http://www.eia.doe.gov/cneaf/solar.renewables/ilands/fig14.html

- Some maps also exist in the US that illustrate county biomass resource by feedstock, an example of which is provided in Figure 2.4.2.

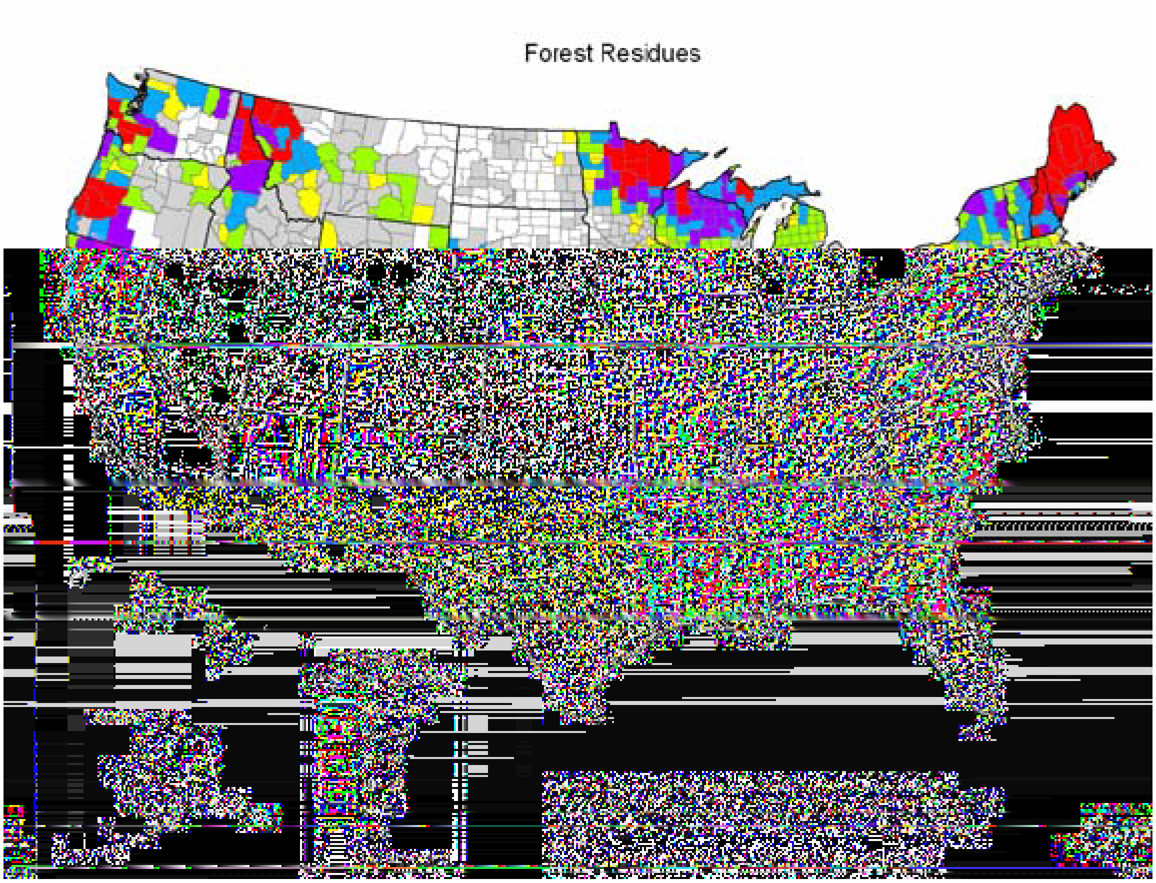

Figure 2.4.2: Forest Residue Resource Potential in the United States; Source: http://www.nrel.gov/docs/fy06osti/39181.pdf

- Biomass mapping is a new activity in Mexico. The IIE mapped national bioenergy potential at a municipal scale, based on the last farm census conducted by the National Institute of Statistics, Geography and Information (*Instituto Nacional de Estadística, Geografía e Informática*—INEGI), to estimate quantities of farm and stockbreeding waste produced in the country. To do so, it took account of general crop waste indices and manure production per head of cattle and principal species. To compute crops' energy content, their calorie content as reported in literature was taken, while cattle were used to estimate production of biogas from manure. To estimate the potential of timber waste, the accessible part of all vegetated areas was considered. That figure provided the volumes of standing species, and a factor was used to estimate energy content and equivalent energy. The potential of wood fuel obtained from energy crops was estimated using a classification of areas susceptible to be used to establish forestry plantations based on their suitability, providing the potential and equivalent energy of timber production. The energy potential of forestry and timber byproducts was determined with the volume of cut timber and waste with energy potential and the equivalent energy thereof. The volume of farming and agro-industrial byproducts was determined based on farm production and waste generation coefficients, which provided the byproducts' equivalent energy. The potential of livestock byproducts was determined as a function of number of heads of cattle, manure production, and thus the production of biogas and its equivalent energy. For energy crops, the production of ethanol and oil/biodiesel was considered as a function of the fuel production yield per type of crop. Lastly, the consideration of municipal byproducts included municipal trash production and its biogas yield.

2.4.4 Limitations to mapping biomass energy resources

2.4.4.1 Technical

- Quantification of biomass based energy resources within a given micro-area or on a unit area basis is complex and depends on several factors (as listed above), such as:
  - Type of biomass resource
  - Competing demand for the resource (food supply, raw materials, soil nutrients etc.)
  - Reliability/sustainability of the resource
  - Distance the resource has to travel to be used for energy
  - Cost of using the resource for energy production
  - Type of energy conversion technology used
  - Seasonal growth or availability fluctuations
  - Biomass production and harvesting requirements.
- For example, wood is the most commonly used biomass fuel for heat and power. The most economic sources of wood fuels are usually wood residues from manufacturers, discarded wood products diverted from landfills, and non-hazardous wood debris from construction and demolition activities. Quantifying these sources of wood in a reliable way on a micro-regional or unit area basis is a very challenging task, making mapping such a resource extremely difficult.
- There is no area basis or location specific measure for biomass potential unless dealing with a specific site or resource that can be appropriately qualified for use based on the factors listed above. High resolution mapping is therefore not possible or practical for biomass resources and maps are typically constrained to providing regional potential totals based on available biomass within a region.
- A more suitable approach might be to map precise locations where available and suitable resources exist.
- For example, a map illustrating the location and size of an untapped landfill resource may be of more use to a potential project prospector than a map showing total compiled biomass resources within a county.
- Similarly, a map could also show locations of wood processing plants that have residues available for practical conversion to energy and indicate the quantity of such residues on an estimated annual MJ or kWh basis. Food processing plants with suitable waste streams, livestock operations with manure streams and agricultural land with appropriate residues could also be precisely indicated on such a map along with quantities of biomass resource available at each.
- Combining such information with location and capacity detail of power distribution infrastructure, municipal boundaries and other supporting infrastructure details could provide a much more useful tool to a potential project developer.

- In Mexico, a major technical limitation to mapping is the lack of timely information on biomass production, since much of the available information is not up to date. There are various groups in Mexico working to assess the country's bioenergy potential, and they have recently endeavored to link existing capacities nationwide. Such is the case with the recent formation of the Mexican Bioenergy Network (*Red Mexicana de Bioenergía*—REMBIO), involving specialists in the study and use of bioenergy.

2.4.4.2 What is being done to overcome limitations?

- There does not presently appear to be any effort in place to develop maps that provide more precise and useful information for biomass energy project prospecting.
- Upon request, site specific biomass resource assessment can be produced by NREL. The GIS group at NREL has developed a methodology for better spatial representation of biomass resources showing the feedstock at its finer level – cropland and forest area, farms, landfills, wastewater treatment facilities, mill locations, urban areas, etc.

2.4.5 Typical data quality (resolution) and reliability

- A discussion of data quality is not pertinent here as resolution is not a factor in the context of existing biomass resource mapping practices.
- Reliability is entirely affected by the quality of statistical data used when compiling biomass energy generation potential within a macro-region (such as a county).
- Successful siting of a biomass energy generation facility is not directly affected by geographic location. It is mainly affected by the reliable availability of a sustainable biomass resource within a practical radius of such a facility. This is affected by several factors, discussed above, that cannot be practically represented geographically with today's methods of mapping. Therefore, today's biomass resource maps cannot be reliably used to accurately site a biomass project or even a feasibility study for such as project.
- Similarly in Mexico, information on biomass production sources is usually consistent and is for the most part in a reflection of actual production in a large region. However, more detailed analyses on the country's energy potential considering basic geostatistical areas (BGAs) are needed for a better understanding of the national distribution energy potential. The degree of aggregation of resources to support generation projects also needs to be determined.

2.4.6 Discussion of required data quality for practical energy project planning

- As previously stated, a successful biomass energy conversion project is strongly dependent on availability of a practical, reliable, cost-effective and sustainable source of biomass feedstock. Due to the broad range of factors that can affect this, it is not practical to plan an energy project based on the information provided in existing maps.
- As discussed above, a more practical approach to mapping biomass resources would be to map exact locations of concentrated biomass energy sources, such as forestry product manufacturing facilities, food processing plants, farms and landfills. Once a promising site

would be identified from this information, the only way to truly ensure the feasibility of a project would be to secure the supply of the biomass resource on a long term contract basis. Even then, there would be no defense against market or industry shifts.

- In Mexico, currently available information is insufficient and does not have the necessary quality to support the development of large, commercial power generation projects. To do so would require detailed field studies supported by the interpretation of remote sensor imaging and farm, forestry and stockbreeding census data.

2.4.7 Regional mapping initiatives and capacity (including an analysis of mapping capacity in remote areas)

2.4.7.1 What has been done? Where? What is the resolution/reliability of the information?

- The table below provides a summary of present mapping initiatives in North America.

Table 2.4.1: Regional Biomass Mapping Initiatives and Capacity

	Map Title (Source)	Resolution/Uncertainty	Public Access/ Proprietary	Available Information
Canada - British Columbia	Green Electricity Resources of British Columbia (BC Hydro and Canadian Cartographics)	**Resolution:** N/A **Uncertainty:** N/A	Public	Provides an estimate of available forest industry waste and landfill gas being used for and still available for electric generation in each forest sector of British Columbia.
United States	Biomass and Biofuels Resource Potential (DOE-NREL)	**Resolution:** N/A (county by county representation) **Uncertainty:** N/A	Public	Biomass electric generation potential per county. Color coded counties ranging from 0-5000, 5000-40000 and to greater than 40,000 kilowatts per county. Also indicates federal lands. One version of the map also shows power generation facilities using or not using biomass as a fuel.
United States	A Geographic Perspective on the Current Biomass Resource Availability in the United States (DOE-NREL)	**Resolution:** N/A (county by county representation) **Uncertainty:** N/A	Public	Provides several national maps broken down by county, each map presenting county totals for a different biomass resource type. The resource types presented include crop residues, methane from manure, forest residues, primary mill residues, secondary mill residues, urban wood waste, methane emissions from landfills, methane emissions from wastewater treatment waste and various dedicated energy crop potential projections.

Western States - (Washington, Nevada, Oregon, Montana, Idaho, Wyoming, Utah, Colorado, California, New Mexico and Arizona).	Renewable Energy Atlas of the West (Land and Water Fund of the Rockies, Northwest Sustainable Energy for Economic Development (SEED), Green Info Network and Integral GIS.)	**Resolution:** N/A (county by county representation) **Uncertainty:** N/A	Public	Total potential in mmbtu per county, color coded in a range from 50 to 11 200 000 mmbtu. The biomass resources per county were calculated by combining county totals of corn, barley and wheat residues from USDA agricultural crop estimates (2001–2002), animal waste from USDA county estimates (1996), forest and mill wood wastes from USDA Forest Service (1996), and potential and existing landfill gas recovery systems from the EPA landfill database (2001). Data source: US Department of Ariculture, 1996, 2002; Environmental Protection Agency 2001. Interactive mapping features allow illustration of power transmission infrastructure, roads, railroads etc.
Mexico	IIE	**Resolution:** N/A (county by county representation) **Uncertainty:** N/A	Not available	The IIE mapped national bioenergy potential at a municipal scale, based on the last farm census conducted by the National Institute of Statistics, Geography and Information (*Instituto Nacional de Estadística, Geografía e Informática*—INEGI), to estimate quantities of farm and stockbreeding waste produced in the country and various estimation techniques for forestry related biomass.

- There has been no effort to map biomass energy resources across Canada. Some maps of biomass coverage in Canada do exist for national inventory purposes, primarily for forestry resources, however, no provisions are made in these maps to indicate the parts of these resources that would be suitable for biomass energy generation or the quantity of energy that could be generated from such resources.

2.4.7.2 Public versus proprietary mapping initiative information

- See table above.

2.4.8 Regional information gaps

2.4.8.1 Where is there missing information or lower quality/reliability information?

- For the purpose of any realistic biomass energy planning, adequate mapping resources do not exist for any region in the United States Mexico or Canada.

- In Mexico, Existing information for all of national territory is generic, only indicating resource availability for large areas. More detailed regional field studies are needed to identify specific production projects. The next step in the IIE's activity involves recalculating bioenergy potential at the BGA level, for a better understanding of the distribution of the potential. The governments of some states, such as Hidalgo and Veracruz, are considering studying biomass potential in their territories for purposes of proposing production processes to use such energy.

2.4.8.2 Why? (remote location, funds, complex terrain, etc.)

- The complexity in quantifying appropriate, sustainable and accessible biomass resources has a large impact on the ability to geographically represent these resources in a manner that is useful to an energy project prospector, i.e. on a micro regional basis.

2.4.9 Summary

2.4.9.1 What is missing?

- Few biomass energy resource maps exist within the United States, Mexico and Canada as a result of the complicating factors that exist in quantifying this type resource, especially on a unit area basis.

- The maps and data sets that do exist typically provide estimated total (lump-sum) quantities of energy that can be produced from a compiled variety of biomass sources available within a macro region, such as a county, municipality or even a province or state. However, information provided in this format does not allow a biomass energy project prospector to select a precise location to begin a feasibility analysis.

- In fact, such maps provide very little guidance to a prospector other than providing rough estimates of biomass resources potentially available within a large area, in most cases a county. This information does not give any indication of whether the biomass is concentrated at a specific location, whether it is economically accessible for energy generation, what type of biomass it is etc.

- In Mexico, the national assessment of biomass requires further studies to attain the level of detail required to propose specific projects. Census- and field study-based estimates also need to be updated.

2.4.9.2 What should be done to improve capacity?

- A more suitable approach might be to map precise locations where available and suitable resources exist.

- As stated above, a map illustrating the location and size of an untapped landfill resource may be of more use to a potential project prospector than a map showing total compiled biomass resources within a county.

- Similarly, a map could also show locations of wood processing plants that have residues available for practical conversion to energy and indicate the quantity of such residues on an estimated annual MJ or kWh basis. Food processing plants with suitable waste streams, livestock operations with manure streams and agricultural land with appropriate residues could also be precisely indicated on such a map along with quantities of biomass resource available at each.

- Combining such information with location and capacity detail of power distribution infrastructure, municipal boundaries and other supporting infrastructure details could provide a much more useful tool to a potential project developer.

2.5 Small Hydro

2.5.1 Overview of Findings

- Overall, small hydro is well documented in the US and Canada.
- Relatively speaking, areas that are either more remote or have low hydro potential are not as well covered as more promising populated areas.
- The maturity of small hydro mapping is representative of the maturity of the resource and its use.
- Data or equations that provide greater detail regarding flow duration would improve power generation estimates and allow for time-of-day and seasonal financial projections.
- Amounts of "available" power specified in small hydro resource maps are gross numbers that would be greatly reduced by feasibility assessments accounting for other viability factors.

2.5.1.1 Canada

- Canada has an extensive data base of potential sites, however, the associated map provides less detail than the US Small Hydro Virtual Prospector.
- The Provinces relying significantly on small hydro, namely British Columbia and Ontario, are the ones with the best map resources. BC has had a very thorough resource mapping undertaken, comparable to that of the US efforts. The Ontario resource map is based on the same database used for the Canadian national resource map, but has been recently updated to provide higher resolution and more corresponding detail, for example details pertaining to proximity to power lines.
- An interactive small hydro resource map tool with full relevant geographic information representation similar to the Small Hydro Prospector in the US would be useful for all of Canada.

2.5.1.2 United States

- The US has an excellent tool available publicly, while Canada also has an extensive data base of potential sites. Visually, the US system is more user friendly, through the use of Geographic Information System (GIS) mapping resources.
- The large population base in the US has allowed it to fund a superior GIS based survey of small hydro sites.
- Overall, mapping coverage is extensive, and the most advanced amongst the three countries.
- Small improvements may be made through improved use of observed data.

2.5.1.3 Mexico

- Mexico has sufficient technical capabilities to assess mini- and micro-hydro resources, as several institutions have studied these resources over more than 30 years. However, it should be noted that much of the work has lacked field studies to locally corroborate measurements made using indirect methods. In addition, it is necessary to have advanced tools to estimate small hydro potential to identify possible areas of interest where more precise analysis may be carried out.

- An interactive GIS small hydro resource map for the entire country would be a useful tool for small hydro project planners in Mexico.

2.5.2 Small Hydro Resource Mapping – why is it important?

- As with the other renewable energy resource types covered by this assessment, detailed and reliable small hydro resource maps can greatly reduce the effort and cost required by a potential project developer during site identification. It can also minimizes the risk of cost over-runs during the pre-feasibility assessment of a site and actual the feasibility analysis phase of the project.

2.5.3 Industry mapping practices and methodologies

2.5.3.1 Characteristics of Hydropower

- Hydropower is generated as water flows through a set of blades (turbine) turning a generator to produce electricity. The force of the water flow is equivalent to the height (or head) that it travels from before hitting the turbine.

- Hydropower stations are divided into two basic designs, ones with a dam providing a large reservoir of water for controlled usage in the turbines. The other form is 'run of the river' meaning there is little or no reservoir associated with the station, and the flow of a river is only diverted temporarily into the turbines through a separate channel. Once the water has passed through the turbine it is returned to the river.

- Key factors contributing to the amount of electricity produced are the volume of water and the force with which it passes through the turbines. The turbines and generators are generally sized to match the amount of water estimated to be available and the head at the site.

2.5.3.2 Industry mapping practices and methodologies

- Three dominant mapping efforts are considered below:
  - The US 'Virtual Prospector' which is a high resolution small hydro map and data base.
  - Canada's national small hydro data base managed by Natural Resources Canada through the International Energy Agency.

- BC Hydro's Green Power program small hydro mapping effort.
- Ontario's Ministry of Natural Resources hydro power inventory.

- Mapping of small hydro resources can comprise either very basic information regarding for example the existence of a river, to very sophisticated Geographic Information System (GIS) based evaluation of multiple factors before identifying a source on a map.

- The current state of publicly available small hydro resource in Canada and the US is such that a prospective developer could avoid significant pre-feasibility costs by availing him/her self of these resources.

- The mapping efforts in the US, British Columbia and Ontario that offer a higher resolution of detail will help reduce costs even further for a developer **[H1]**.

- The inventory of sites can be based on sizing each project to the mean annual flow and assuming operating on a run-of-river basis. However, this may not be the optimal configuration for some of these projects **[H2]**.

- An inventory can be developed from map and regional hydrology studies. In the case of a BC Hydro run-of-the-river mapping exercise, 1:50,000 scale topographical maps were reviewed to find stream basins that seemed to have development potential. Stream basin areas were determined and the steepest section of creek that was over 10%(±) slope was selected as the best location for an intake, penstock and powerhouse. No consideration of reservoir area was included due to the run-of-river emphasis **[H2]**.

- The proximity of a site to an existing transmission line is important to note. For example, in the case of the BC Hydro map, the available maps show only 69kV lines and higher. Distances to 25kV lines were based on local knowledge and reasonable assumptions about probable areas of service. Typically, a higher kV line is more valuable to a developer **[H2]**.

- Areas off limits to development – a mapping or resource data base can choose to exclude projects that would be located in areas that are likely to be off limits to development – such as in parks **[H2]**.

- Many small hydro mapping efforts are a culmination of historic data and observations from field research, blended with more modern mapping (i.e. GIS) techniques. This is the case with BC Hydro's small hydro mapping exercise, and the NRCan/IEA small hydro inventory of Canadian sites.

- Maps or data bases which contain an estimate of the power available from a stream flow in kilowatts (kW) produce the conclusions as a function of the design flow (how much water would enter channel to the turbine) and the available gross head at an assumed 80% efficiency for a generator (which includes head loss) **[H2]**.

- In the case of the maps done for BC Hydro, the design flow is related to regional runoff patterns and is set as the mean annual flow, which provides a reasonable estimate of an economic plant size. The choice of mean annual flow is only an indicator, because other considerations apply, including: - a relatively high electricity value, which will encourage a larger project and higher design flow; - peak runoff in a run-of-river situation, which will result in smaller design flows being optimal; - amount and timing of fish flow releases; - site specific considerations, such as project layout; penstock and turbine availability; storage or flow regulation; values of electricity by time of day and seasonally; and operational and lending costs **[H2]**.

- In order to determine or estimate stream flow, hydrological surveys are often relied upon to estimate the amount of water that will be available throughout a year for power generation.

- Measuring the head from a contour map can be done, only as an estimate however. In some mapping examples, waterfalls will be listed without information about the topography.

- In the case of the US 'Virtual Hydropower Prospector' mapping tool, state-of-the-art digital elevation models and GIS tools were relied upon to assess the power potential of a mathematical analog of every stream segment within each region. Only water energy resources associated with natural water courses were assessed (e.g., effluent streams, tides, wave power, and ocean currents were not included). Summing the estimated power potential of all the stream segments in the region provided an estimate of the total power potential in the region. Stream segments that had power potentials less than 1 MW and hydraulic heads less than 30 ft and power potentials less than 100 kW (micro hydro) were segregated and summed to provide an estimate of total low head/low power potential in the region. Having power potential estimates in such small increments allowed the low head/low power potential to be further divided to determine the amounts of potential corresponding to the operating envelopes of three classes of low head/low power hydropower technologies: conventional turbines, unconventional systems, and micro hydro **[H3]**.

- The approach taken in the US study offers a higher resolution than the mapping done in Canada. The calculation of the stream flow rate, hydraulic head, and subsequently, power potential utilized a three-dimensional representation of the hydrography and related drainage basin information. The three-dimensional hydrography provides the extent of stream networks and the elevation differences required to calculate hydraulic heads. Related drainage basin information provides essential data for the calculation of stream flow rates. While the national hydrography dataset provides the best two-dimensional depiction of the United States hydrography, it does not provide the required elevation information or related drainage basin information. In order to obtain the required hydrography parameters, the Elevation Derivatives for National applications (EDNA) dataset was used. This dataset provided the needed three-dimensional hydrography in the form of analytically derived stream networks with associated elevation values and the drainage area associated with each stream reach that could be summed to produce the drainage basin supplying runoff to points of interest along a stream **[H3]**.

- The importance of the above cross referencing is that key to understanding the value of a water resource for electricity generation is the volume of the water, and the distance/angle of it's drop in altitude (head height).

- Similar to the Canadian NRCan small hydro data base, the US mapping effort incorporates equations based on gauged stream flows within the regions spanning many years. The drainage area used is the sum of the upstream catchment areas. The other two variables, mean annual precipitation and mean annual temperature, were derived from the 'Parameter-elevation Regressions on Independent Slopes Model (PRISM)' dataset. Both temperature and precipitation data contained in the PRISM dataset are in grid format. The cells of the grids are much larger than the grid cells on which the EDNA dataset is based (30 ´ 30 m); therefore, an averaging function was used to calculate the mean annual precipitation and mean annual temperature for each catchment in the EDNA data. The catchment temperature and precipitation values were used to produce an area-weighted value for each drainage basin. Precipitation and temperature values for each drainage basin along with the drainage basin area were used to calculate the estimates of the annual mean flow rate at the upstream and downstream ends of each reach **[H3]**.

- In order to calculate the power potential of each stream segment contained in the Virtual Prospector, the hydrography in the region was derived using the U.S. Geological Survey's Elevation Derivatives for National Applications (EDNA) dataset. In addition to the hydrography, the dataset provided the elevations of the upstream and downstream ends of each stream segment, which were used to calculate hydraulic head. The dataset also allowed the calculation of the drainage area providing runoff to each stream segment. Use of the EDNA data in conjunction with climatic data provided the variables needed to calculate the annual mean flow rate for each stream segment using a regression equation or equations developed specifically for each region in the study area.

- Combining stream flow rate with hydraulic head provided the power potential of the stream segment. Because the hydrography used was "synthetic," stream segments were compared to streams in the U.S. Geological Survey's National Hydrography Dataset. Unconfirmed stream segments were eliminated from the datasets that were used to estimate total power potentials. A GIS layer containing streams and areas that are excluded from development by federal statutes and policies was used to segregate excluded and non-excluded stream segments. The amount of power potential that has already been developed in the region was derived from average annual electricity generation data provided by the Federal Energy Regulatory Commission's Hydroelectric Power Resources Assessment (HPRA) Database. Developed power potential was subtracted from the total, non-excluded, power potential in each power class to produce estimates of "available" power potentials. No feasibility assessments were made; therefore, the results are gross numbers that do not include the elimination of "available" sites that probably would not be developed at this time. Also, "available" power potential only refers to amounts of potential that have not been developed and are not excluded from development by federal statute or policy. No assessment of actual availability for hydropower development was performed **[H3]**.

- The graph below is an example from the BC Hydro Small Hydro resource assessment, of how the information obtained through a resource assessment or mapping exercise can be combined to provide an indication of the electricity generation potential in a particular river.

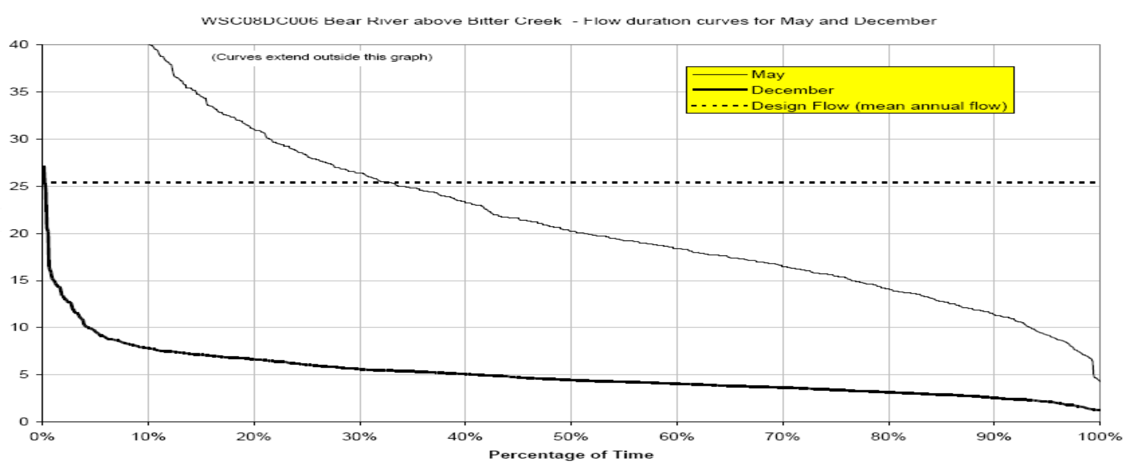

Figure 2.5.1: BC Hydro Small Hydro resource assessment: Monthly Capacity Factor estimate
Source: BC Hydro Green Power Study, 2002

- The identification of sites with resource development potential requires detailed description of a combination of the factors listed below. The greater the detail, the greater the value to a developer.

- Basic information on a map, or in a database can include:

  - Site names
  - River names
  - Site region
  - Development status
  - Proximity to electricity transmission or distribution infrastructure (power lines, transformer stations)
  - Location latitude/longitude (in the case of a data base)
  - Catchment area (can be represented visually, or in terms of measured area for a data base)
  - Design flow at the site in cubic metres second
  - Head at the site
  - Total estimated capacity (based on water volume, flow, and head)
    - Water volume estimates are often derived from historic rainfall records, temperature averages, soil type analysis
    - Mean annual flow, low and high bands for flow
  - Site applicability for the common technology options
  - Site characteristics in terms of run of the river, vs. small reservoir
    - In the case of either, but most particularly run of the river – detailed hydrological information would increase the value of the mapping exercise to developers
    - Environmental considerations (ie. Is the river fish bearing?)
    - Silting concerns

- Below is an example taken from the US based Virtual Hydropower Prospector which illustrates the identification of streams, and different catchment areas using colours to separate them.

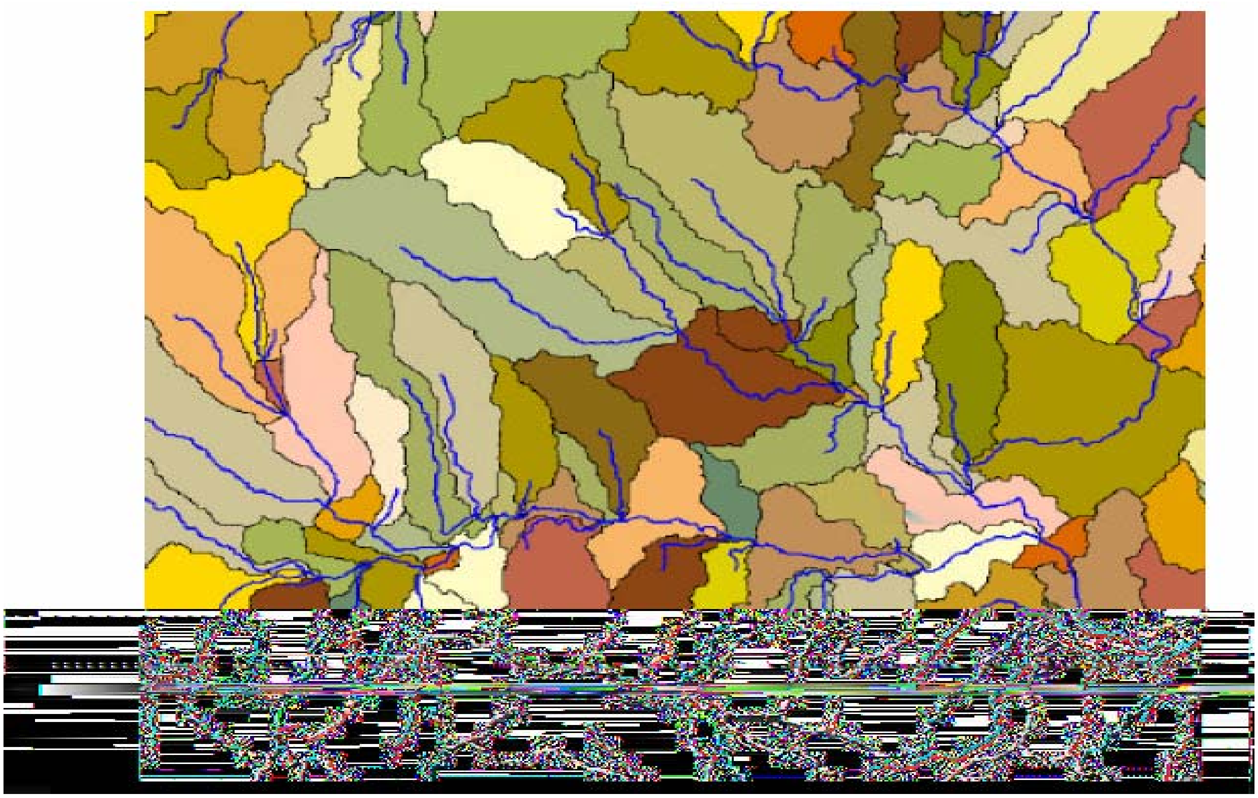

Figure 2.5.2: Sample Map from US Virtual Hydropower Prospector; Source: The Virtual Prospector, 2004

- Small hydro is different from Large Reservoir Hydro mapping for the following reasons: Since there is no water storage, a thorough assessment of the stream flow including the various hydrological factors that contribute to it is particularly important to small hydro assessments.

- Mexico has in effect a water conservation standard, establishing the specifications and method for determining the mean annual availability of national waters. Exhibit A of the standard provides the methods for determining the mean annual volume of natural runoff, namely the direct and indirect methods. The direct methods uses hydrometric records to obtain the basin's annual volume of natural runoff using the gauged downstream runoff, the concessioned volume of surface water, the annual volume of gauged upstream runoff, the annual volume of exports, the annual volume of imports and the annual volume of returns. The indirect method, called precipitation-runoff, uses the annual volume of natural runoff based on annual precipitation in the basin, the basin area and the runoff coefficient **[H4]**.

2.5.4 Limitations to mapping small hydro power resources

2.5.4.1 Technical

- In the case of the US based virtual prospector, the accuracy of the power potential estimates is dependent on the accuracy of the individual stream reach power potentials that were summed to produce total values of interest. The calculated reach flow rates had standard errors ranging from 9% to 96%. These errors reflect sampling and measurement errors, but do not address annual flow variability (i.e., the difference between predicted annual mean flow rate and the actual mean annual rate in a specific year). As such, a project developer would still likely be required by investors to conduct direct in-stream water flow measurements for some predetermined time span in order to build the business case for a project.

- A further limitation on power potential estimates is explained in the Virtual Prospector guidance document: "Power potential estimates provided in this report have large uncertainties for some hydrologic regions, because of the uncertainty in the flow rate estimation equations used to produce them. Use of flow rate prediction equations developed for smaller areas than entire hydrologic regions would probably offer increased flow rate prediction accuracy and thus increased power potential accuracy. In addition to increased accuracy in predicting annual mean flow rates, data or equations that allow flow duration to be factored into estimates of available and developable power potential are needed. Research should be conducted to locate such equations and data, and the study results and any subsequent feasibility assessment should be upgraded using them." **[H3]**

- The amounts of "available" power potential are gross numbers that would be greatly reduced by a feasibility assessment accounting for the viability of resources based on such parameters as site accessibility, proximity to load centers and infrastructure, and constraints on development that have not been addressed in this study **[H3]**.

- To assess minihydraulics, hydrometric records must be obtained from duly calibrated equipment for a period of at least 20 years. When the studied basin has insufficient or scarce information from hydrometric records, the mean annual volume of runoff should be estimated with indirect methods, using at least 20 years' recorded rainfall. To assess the drainage network, it is advised to use survey information at a scale of 1:50000 or greater.

- A challenge for measuring run of the river flow is the intermittent nature of the flow and its sensitivity to rainfall and temperature variations.

- Mexico has the CLICOM database containing information from 5,000 manual weather stations, measuring variables including precipitation. The stations' measurements are taken once each day, thereby obtaining accumulated rainfall every 24 hours. While in some cases there are database gaps or the measuring equipment is worn, it could be said that there is enough precipitation information to assess minihydraulic potential.

- Also in Mexico, advanced computation hydraulic models are not often used, this is a serious drawback given the time currently spent on such studies. Also, because it comes from different sources, the available topographical and river way information shows discrepancies.

- As noted above, there may be cases in Mexico of low-quality information obtained from weather stations, considering the high number of gaps found in available databases, although in most cases measurements could be considered reliable. Notwithstanding the above, for the installation of micro and small stations, a good amount of field work is still needed to identify possible sites to take advantage of small hydro resources.

2.5.4.2 Geographic

- Most hydro mapping or resource assessment efforts seek to exclude areas that may not be appropriate for development due to designations of a park, urban settings or otherwise. While these ‘gaps’ are important to note, there may still be the potential for development in those areas, however it would require more field work and background work with the appropriate public officials, or private owners of an area.

- Most small hydro mapping or resource assessments will have a ‘cut off point’ in terms of the size of installation they are showing as being possible. As such, many small installation opportunities may be missed.

2.5.4.3 Budgetary

- Cost is an important factor – jurisdictions where economies of scale (US) or interest in developing small hydro (BC and Ontario) is significant, sophisticated resource assessments get developed and are made available to the public.

- Small hydro, by its definition, implies that the site will be of minimal size, thus requiring any mapping effort to take into account a myriad of possible site-specific information, which are difficult to find. This fundamental nature of the resource implies that mapping efforts will be more costly than for other technologies.

- Soil conditions are relevant to understanding small generation potential since differing types affect how much water that falls as precipitation will flow into a river vs. being absorbed into the ground. Understanding local soil conditions requires significant field work, resulting in higher costs, or lower quality data if site specific soil data is not collected.

2.5.4.4 What is being done to overcome limitations?

- Typical data quality (resolution) and reliability issues can be resolved by delving more deeply into the key ingredients in a mapping effort, such as climatic information.

- Required data quality for practical energy project planning: the factors listed in section 2.5.3 above covers the key data sets that assist a small hydro project developer. Beyond those factors the critical resource specific information that will be required is actual observed stream flow data. It is this information, combined with access/permits to the land that will allow a project developer to seek private financing for a project.

2.5.5 Regional mapping initiatives and capacity

Table 2.4.1: Regional Small Hydro Mapping Initiatives and Capacity

Coverage	Map Title/Origins	Detail
United States	Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources, 2004 Idaho National Engineering and Environmental Laboratory	**Coverage** The entire country, equally. **Background** The Idaho National Engineering and Environmental Laboratory in conjunction with the U.S. Geological Survey recently completed assessments of all 20 hydrologic regions in the United States, which in combination provide assessment results for this entire area of the United States. Parsing of the regional assessment results using geographic information system (GIS) pools produced assessment results for each of the 50 states. The assessments provided not only estimates of the amount of low head/low power potential, but also estimates of power potential in several power classes defined by power level and hydraulic head, and an estimate of the total power potential of water energy resources in individual states and hydrologic regions and in the nation
United States	U.S. Hydropower Resource Assessment 1998	**Background** To provide a more accurate assessment of the domestic undeveloped hydropower capacity, the U.S. Department of Energy's Hydropower Program developed a computer model, Hydropower Evaluation Software (HES). HES allows the personal computer user to assign environmental attributes to potential hydropower sites, calculate development suitability factors for each site based on the environmental, legal, and institutional attributes present, and generate reports based on these suitability factors.
United States	Hydropower Resource Assessment Database	**Background** This database is maintained by FERC and contains the best available national inventory of undeveloped hydropower capacity. It contains information about all sites that have been subject to any FERC hydropower licensing action and information on project sites that have been identified by FERC, or other agencies, as having development capacity even if no licensing action has taken place. This database lists project sites and corresponding basic site data. Approximately 5,700 sites with undeveloped hydropower capacity are listed in the HPRA database.
United States	The Nationwide Rivers Inventory National Park Service	**Background** Initially completed in 1982 by the National Park Service and has been periodically updated since that time. Park Service regional offices systematically collected information on rivers and identified those with outstanding resources. Uniform procedures for identifying rivers for the Nationwide Rivers inventory, including field and map verification of each river's values, were applied throughout the country. Specific outstanding resources were identified for those river reaches selected for inclusion in the Nationwide Rivers Inventory. Reaches were identified if outstanding fisheries, wildlife,

		geologic features, historical resources, cultural resources, recreation resources, scenic values, or other resources were present. The Nationwide Rivers Inventory also indicates the presence of threatened and endangered species (classified as fish or terrestrial wildlife) and whether the reach is part of, or considered for, inclusion in a state or federal wild and scenic rivers program.
Canada	Small Hydro Data Base Natural Resources Canada and the International Energy Agency	**Coverage** The entire country, however it relies partially on field reports, implying that northerly or remote areas would likely have received less attention than others. **Background** A recently completed inventory of Canadian small hydro sites identified over 5500 sites with a technically feasible potential of about 11,000 MW but only about 15 per cent of this total would be economically feasible under current socio-economic conditions and at the current state-of-the-art. If capital cost can be reduced by 10 to 15 per cent, which should be achievable though further technological improvements, a further 2000 MW of economically exploitable small hydro capacity will be available. A good number of these will be small hydro projects The International Small Hydro Atlas, which covers Canada, including all provinces and territories. The atlas was developed by the Small-Scale Hydro Annex of the International Energy Agency's Implementing Agreement for Hydropower Technologies and Programs Environment Canada's water survey – provides data on surface water, however it is not tailored to providing the input required for energy production analysis, much less for small hydro specifically.
British Columbia	Green Energy Study for BC Phase 1: Vancouver Island 2001 BC Hydro	**Coverage** Extensive coverage (beyond the NRCan effort) for Vancouver Island. **Background** Potential projects range in size from 500 kW to about 18 MW and they are located throughout VI. Due to differing terrain, capacities and hydrology, the projects also have a range of unit energy costs. Approximately 60% of the project sites are developable at less than 7 ¢/kWh (which comprises about 80% of the total developable energy).
British Columbia	Green Energy Study for BC Phase 2: Mainland 2002 BC Hydro	**Coverage** Extensive coverage (beyond the NRCan effort) for BC. **Background** The inventory of 756 sites is based on sizing each project to the mean annual flow and assumes operating on a run-of-river basis
Ontario	Ministry of Natural Resources	**Coverage** All of Ontario with a high level of detail including placement of power transmission infrastructure and other relevant supporting

		infrastructure for small hydro project development. **Background** Waterpower opportunities are being released to help the Ontario government achieve its commitment to add 5% or 1350 megawatts of new renewable generating capacity by 2007 and an additional 5% for a total of 10% or 2700 megawatts by 2010. These opportunities will also help the Ontario government achieve its commitment to eliminate coal-fired electricity generation by 2009.
Mexico	Conae and the CFE	**Background** Conae and the CFE have conducted some studies at different areas throughout the country to identify potential minihydraulic sites, basically for small-scale power generation.
Mexico - Baja California, Jalisco, Oaxaca and Veracruz.	IIE	**Background** As part of the second SIGER stage, the IIE conducted preliminary studies of minihydraulic potential of rivers in the states of Baja California, Jalisco, Oaxaca and Veracruz. Part of the IIE's scheduled activities in the SIGER project is the estimation of the potential of minihydraulics in various parts of the country, using the water drainage network, using INEGI's digital survey information at a 1:50000 scale and rainwater information found in the CLICOM database. This work will enable a general determination of potential areas for using minihydraulics for a more detailed further analysis.
Mexico	CLICOM database	**Background** Mexico has the CLICOM database containing information from 5,000 manual weather stations, measuring variables including precipitation. The stations' measurements are taken once each day, thereby obtaining accumulated rainfall every 24 hours.

2.5.6 Regional information gaps

2.5.6.1 Where is there missing information or lower quality/reliability information?

- Relatively speaking, areas that are either more remote or have low hydro potential are not as well covered as more promising or populated areas.

- In comparison to the US GIS based mapping effort that has been undertaken, Canada's resource assessment effort is less detailed and could thus be referred to as an 'information gap' relative to the US situation.

- The Canadian province of British Columbia has had a very thorough resource mapping undertaken, comparable in detail to that of the US effort, without the reliance on the GIS approach. It is more advanced than the pan-Canadian information available through the Small Hydro database, but has lower 'resolution' than the US information.

- In the case of both the Canadian and US small hydro resource assessments, the amounts of "available" power potential are gross numbers that would be greatly reduced by feasibility assessments accounting for the viability of resources based on such parameters as site accessibility, proximity to load centers and infrastructure, and constraints on development.

- Notwithstanding Mexico's high number of weather estimates, there are also a high number of database gaps due to the long operating downtimes of the measuring equipment.

- INEGI has sufficient information on Mexico's permanent river ways throughout all regions in national territory, although there is insufficient field work to corroborate the estimations made in desk studies.

2.5.6.2 Why? (remote location, funds, complex terrain, etc.)

- The differences in quality of resource potential can directly be related to the population base the resource might support, and the amount of small hydro available in a jurisdiction. For example:

  - The large population base in the US, as compared to Canada, has allowed it to fund the superior GIS based survey of small hydro sites.

  - In Canada, the provinces relying significantly on small hydro are t he ones with the best mapping resources, BC and Ontario.

  - Quebec, which also has significant small hydro resources, has taken the strategic direction to concentrate on large hydro, thus obviating the need for detailed small hydro site information.

2.5.7 Summary

- The maturity of small hydro mapping is representative of the maturity of the resource. Mapping resources are extensive wherever the resource is plentiful.

2.5.7.1 What is missing?

- In the US example, a high resolution tool has been developed. The only apparent gap is wider access to observed data on the stream low for the various sites identified.

- In Canada, the national small hydro data base, while very thorough, could technically be improved by adding a GIS based map such as the one developed in the US.

- Canadian provinces and territories besides BC and Ontario have not conducted detailed assessments of their small hydro sites that are made available to the general public.

- Mexico has sufficient technical capabilities to assess small hydro, several institutions have studied these resources over more than 30 years. However, it should be noted that much of the work has lacked field studies to locally corroborate measurements made using indirect methods.

- In addition, it is necessary to have advanced tools to estimate small potential to identify possible areas of interest where more precise analyses may be carried out.

2.6 Ocean Energy

2.6.1 Overview of Findings

- Resource assessments and mapping initiatives are as critical to the development of ocean energy projects as they are to other forms of renewable energies.
- There are technical and geographic limitations to ocean energy mapping in North America.
- Funding has been very limited for ocean energy research in parallel with the development of the wave and tidal current technologies. As these technologies progress, demad for improved information regarding the best location for ocean energy installations will increase. This trend is already underway.
- Estimates of wave ocean energy have been completed at a general level for all US coasts, and in Canada for the BC coast and Nova Scotia. Some site specific tidal resource quantification efforts have been undertaken at several promising sites in the US and Canada.
- Canadian and American efforts to map the ocean energy resources for all three coasts are underway but are in the very early stages. Detailed, multi attribute (energy, bathymetry, environmental, socio-economic) site specific data are important gaps remaining for a better understanding of good ocean energy sites.
- Wave and tidal energy may be used at some points within Mexico. However, there are presently no estimates of its energy potential. Some research institutions are currently interested in conducting joint studies to assess resource potential.

2.6.2 Ocean Energy Resource Mapping -- why is it important?

- Wave and tidal energy represent a significant potential renewable energy resource in North America.
- New wave and tidal technologies are emerging and it is important to be in a position to successfully deploy them. Key geographic/site-specific information is presently generally lacking to do this.

2.6.3 Industry mapping practices and methodologies

2.6.3.1 Characteristics of Ocean Energy

- Ocean energy, for the purposes of this assessment, covers wave and tidal current technologies.
- For the two types of ocean energy there are different mapping or resource assessment approaches for each.
- Wave energy refers to the capturing of the energy density of wave action.

- The power or energy flux in a wave is proportional to the square of the wave height (or amplitude) and the wave period (waver length). Wave energy potential is generally represented in kW/m.

- Technology to convert wave energy to electrical energy is in its starting phase; over 1000 related technology patents have been filed to date, while 2 MW of wave energy generation capacity have been installed worldwide.

- The total power of waves breaking on the world's coastlines is estimated at 2 to 3 million megawatts, however, only a fraction of this can be practically harnessed. In favorable locations, wave energy density can average more than 50 megawatts per mile of coastline.

- Several approaches to capturing wave energy exist and include:

    - Floats or Pitching Devices (Attenuators) - These devices generate electricity from the bobbing or pitching action of a floating object. The object can be mounted to a floating raft or to a device fixed on the ocean floor.

    - Oscillating Water Columns (OWC) - These devices generate electricity from the wave-driven rise and fall of water in a cylindrical shaft. The rising and falling water column drives air into and out of the top of the shaft, powering an air-driven turbine.

    - Wave Surge or Focusing Devices - These shoreline devices, also called "tapered channel" or "tapchan" systems, rely on a shore-mounted structure to channel and concentrate the waves, driving them into an elevated reservoir. Water flow out of this reservoir is used to generate electricity, using standard hydropower technologies.

    - Overtopping Terminator: These devices capture wave water coming over a ledge and funnel it through a turbine under the force of gravity and return it to the source waters.

    - Point Absorbers: These devices use a submerged piston like, closed cylindrical structure with a bobbing air filled reservoir that moves magnets relative to a stator coil. The bobbing motion of the air filled reservoir is driven by the oscillating force of waves passing overhead **[O1]**.

- In the case of this emerging field, it is important to understand the technologies, to help guide the resource assessment process in its collection of relevant information.

- In stream tidal current energy refers to capturing the energy contained in the tidal current flows. Good sites often occur at narrow passes on the shoreline where there is a concentration of the flow so as to increase the energy density contained therein.

- Tidal current technology typically involves one of two options:

    - The erection of a dam across the opening of a tidal basin, functioning much like a hydro reservoir does. Once the basin is filled by the incoming tide, the water is held back and the channeled through a generating station. This practice is not preferred due to its severe environmental impact.

- The use of a water column or blade system that captures the energy in the current passing through, which then turns a turbine.

- Tidal current energy is unique in the field of low impact renewable energy as it holds the promise of providing 'capacity' electricity, although quantity of this electricity may be difficult to ascertain due to the variable behavior of the resource. Capacity refers to electricity that can be relied upon, as opposed to intermittent sources such as wind or run of the river hydro, which only generate when the resource is producing. This gives tidal current a distinct advantage for achieving market success with utilities. As a result, it is important for the mapping exercise to provide a project developer not only an estimate of the potential electricity generation, but also an estimate of a reliability and predictability of the ongoing supply.

2.6.3.2 Industry mapping practices and methodologies

- The BC Hydro wave energy map utilizes information from the Wind and Wave Climate Atlas, produced by Transport Canada in 1993 **[O2]**.

- EPRI produced a report "Guidelines for Preliminary Estimation of Power Production by Offshore Wave Energy Conversion Devices" in 2004 which helps guide the resource assessment process. It produced a similar report for tidal energy in 2005 **[O3]**.

- Wave energy readings are taken from reference stations that typically comprise long term offshore weather stations situated along the coast lines of both the US and Canada. However, these sites are not necessarily where a wave power plant would be built, as such their data is only used to extrapolate or interpolate an approximate estimate. In addition wave data needs to be overlaid with site specific information related to proximity to power lines, ocean floor information, and other environmental impact related data.

- In the US, the largest inventories of long term measured wave data are maintained by the National Data Buoy Center (NDBC) of the National Oceanic and Atmospheric Administration and by the Coastal Data Information Program (CDIP) of Scripps Institution of Oceanography.

- Tidal current – shown as kW/m^2 values. Power conversion factors are generated by taking the volume of water intercepted by a device, the current speed, and the density of the water.

- Generally speaking, tidal ranges are well understood, mapped and documented in Canada and the US. Tracking of tides has historically been done for the sake of the shipping industry. Much of this information can be used as a basis for tidal energy mapping.

- Tidal current energy is derived from the flow of coastal ocean waters in response to the tides. Large tidal currents do not necessarily require a large tidal range. Two important factors that influence the magnitude of tidal currents are the phasing of the tides (location and timing of high and low tides) and the presence of narrow passages (concentration of tidal flow) **[O4]**.

- The Electric Power Research Institute (EPRI) in the United States uses the following selection criteria when assessing a potential tidal current energy site:

- Tidal current energy resource attributes (annual average energy flux per unit aperture area of 'TISEC' device, and in –stream power density at ebb and flood peak flows)
- Candidate site bathymetry and seafloor geology suitable for TISEC devide foundation or anchoring system and submarine cable routing to shore (bottom composition, potential for sediment mobility under severe conditions and bottom changes over time)
- Coastal utility grid and substation loads and capacities, and availability of a suitable onshore grid interconnection point with a capability of handling the 500kW pilot plant supply and with potential for growth to a 10MW commercial plant.
- Nearby regional shipyard labor and infrastructure for device fabrication and assembly, with sufficient local maritime infrastructure and harbor service vessels for system deployment, retrieval and offshore servicing or in-harbor repair.
- Minimal conflict with competing uses of sea space (navigation channel clearance and maintenance dredging activities, commercial and sport fishing, protected marine areas) and likelihood of public acceptance.
- Unique opportunities to minimize project costs and/or attract supplemental funding, such as:
    - Existing utility easement which can be used to route power cable and shore crossing
    - High local demand and growth forecast, where installation of local generation source could eliminate need for distribution or transmission line upgrade
    - Local public advocacy for project and highly-visible public education opportunity.

- Figure 2.6.1 below is an early map of the wave energy estimates for the BC coast. The coasts of mainland British Columbia and Vancouver Island have the potential to supply a major portion of the ocean energy resource. This preliminary assessment of wave energy on the west coast of Vancouver Island indicated an average near-shore power level of 33 kW/meter of wave front, and a total incident wave power of ~8.25 GW.

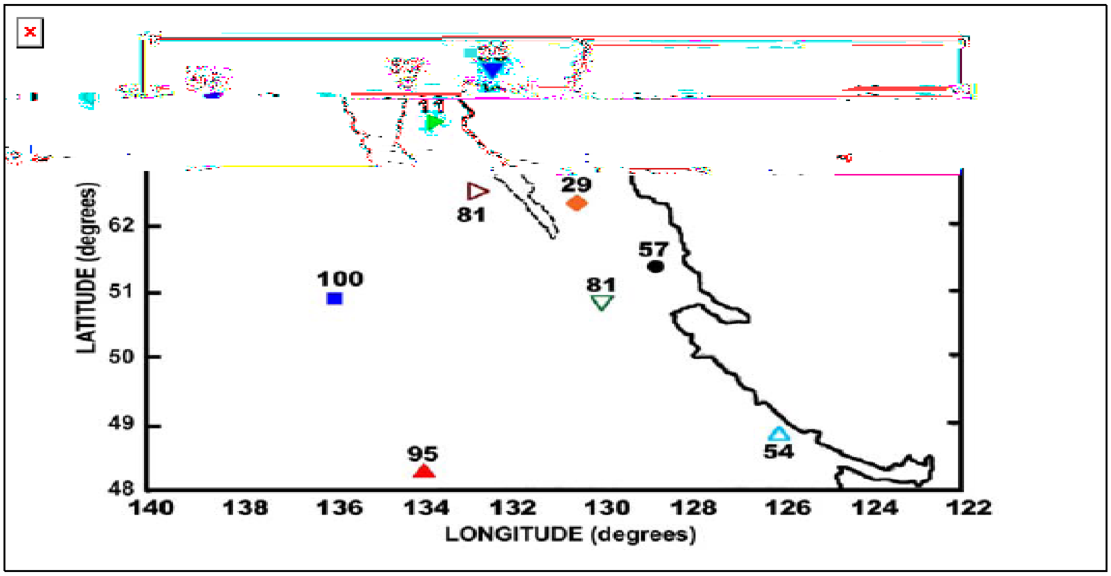

Figure 2.6.1: Ocean energy illustration; Source: BC Hydro Green Energy Study, 2001

- In Mexico, there are analytical tools available for mapping tides and waves along the country's coastlines created for oceanographic purposes, port engineering and other similar applications. Measurements have been taken over several years at various points on the Mexican coast, principally by the CFE, the Ensenada Center for Scientific Research and Higher Education (Centro de Investigaciones Científicas y de Educación Superior de Ensenada) and the Secretariat of the Navy (Secretaría de Marina). The CFE has conducted studies at coastal sites using pressure sensors to determine wave heights. The effects of wind on the sea surface and wave production have also been widely studied for scientific purposes.

2.6.4 Limitations to mapping ocean energy power resources

2.6.4.1 Technical

- Due to ocean energy technologies being at an earlier stage of development than other low impact renewables, mapping appropriate sites becomes more difficult. For example, the energy production and cost estimate data are limited and have a high degree of uncertainty compared with those for the other resources.

- Since tidal currents ebb and flow in strength and duration, a range of velocities need to be considered for sites. Mapping needs to consider the flow in both directions, while many of the technologies may not convert energy at the same rate of efficiency in both directions.

- Wave activity and project siting preferences have an inverse relationship: wave energy is reduced as they move towards shore, and projects become more expensive the further from shore they are located.

- There are presently no standardized approval processes for wave and tidal technology projects, meaning that certain key issues associated to project siting may not be addressed in present mapping efforts.

- In Mexico, there are no technical limitations on the mapping of wave and tide energy, as for several years research institutions have been dedicated to the study of these phenomena. However, little or nothing has been done to use wave energy to produce electricity.

2.6.4.2 Geographic

- In the case of wave energy, the best sites for the resource are further out into the ocean away from land, making mapping, resource assessment and actual project construction more difficult than for a site closer to shore.

- The best tidal current sites are by definition in areas with a strong current, making data collection more complex, and project siting a challenge as well.

- Considering the early stage of technology development for wave and tidal current, it would be difficult to justify studying remote sites since they will be more costly to both analyze and develop. With so few projects underway, resource assessment will likely concentrate on areas which offer multiple benefits for project siting.

2.6.5 Discussion of required data quality for practical energy project planning

- Project developers will benefit from both general resource assessments, as well as site specific information that includes both ocean energy estimates, as well as information relevant to the other aspects of a project, including: proximity to electricity infrastructure, sea bed characteristics, environmental considerations, other uses for project area (eg. fishing, oil and gas).

- Mexico does not have sufficient experience in exploiting the potential of waves or tides. Some isolated efforts have been made to use these resources, but thus far no progress has been made.

2.6.6 Regional mapping initiatives and capacity

Coverage	Map Title/Origins/ Technology/ Public Access	Detail
US - Wave	EPRI – 2004 Study available publicly – data only available to financers.	**Coverage** All coasts with specific sites highlighted. Total annual US Wave energy estimate: 2100TWh/yr (EPRI) extractable energy is less, but still significant. Detailed information was mapped for the following states: Maine, Massachusetts, California, Oregon, Washington and Hawaii. http://www.epri.com/oceanenergy/attachments/ocean/briefing/IEABriefingRB111705.pdf

		Background EPRI's work covers all coasts in the US, with specific readings per state divided by time of year. The assessment includes Alaska's remote coastline, as well as Hawaii. They surveyed, and characterized potential North American Wave Farm sites. EPRI/DOE/NREL are conducting a phased offshore wave energy project. It began in 2004 with a technology assessment, and important to this review, a site assessment. The project will involve the construction of an actual wave plant.
US – Tidal	EPRI 2005-2006	**Coverage** All coasts with specific sites highlighted. **Background** Coverage of all coasts, with some detailed analysis of good candidate tidal flow areas. EPRI/DOE/NREL are conducting a phased in-stream energy conversion project. It began in 2004 with a technology assessment, and important to this review, a site assessment. The project will involve the construction of actual tidal plants.
Canada	OREG/Hydraulics Research Centre -- NRCan	**Coverage** A Canadian study is underway. Key gaps are the East and Arctic coasts. **Background** OREG/Hydraulics Research Centre -- NRCan have created a working group of industry and government to do a resource assessment for tidal current and wave. A multi-year federal government-funded project, called "The Canadian Ocean Energy Atlas Project", has been initiated. The project is led by the Canadian Hydraulics Centre of the National Research Council Canada in collaboration with Environment Canada, Fisheries & Oceans Canada, OREG, Triton Consultants and Powertech Labs. Natural Resources Canada (NRCan) is providing the majority of the funding for the phase one of the program. At the end of year one, the study will deliver a preliminary first-order inventory and assessment of Canada's wave and tidal current energy resources. In subsequent years, the project will work to improve the accuracy and spatial coverage of the preliminary assessment, and deliver the Ocean Energy Atlas. The Atlas will be a geo-referenced database containing ocean current data, wave climate data, offshore wind data and meta-data for all Canadian waters, integrated with an interactive viewer/mapper and wrapped in a user-friendly interface. The digital Atlas will be equipped with a toolbox of statistical, temporal and spatial analysis tools for analyzing and interpreting the data. Like

		the Canadian Wind Energy Atlas, the Ocean Energy Atlas will be web-enabled so that it is accessible to all **[O5].** http://www.iea-oceans.org/newsletters/news5.pdf http://www.oreg.ca/news/roundtablereport/view?searchterm=resource%20assessment
Nova Scotia	EPRI/DOE/Nova Scotia Power **Tidal** Publicly available	**Coverage** Covers Nova Scotia tidal current resource. **Background** Analysis of tidal current strengths, as well as other key factors including sea bed make-up, proximity to transmission lines, on shore infrastructure, environmental considerations, socio-economic factors amongst many.
British Columbia	*Assessment of Wave Energy Resources for the West Coast of Canada,* by Bhuyan, G. and Allievi, A Powertech Report, 1994	**Coverage** Coverage of the BC coast, with several key sites highlighted. **Background** In 1995, Powertech Labs Inc. carried out a wave energy resource assessment for the coast of British Columbia based on the wave records obtained by Marine Environmental Data Services of Canada. Most promising resources are estimated for Queen Charlotte Sound and the west coast of Moresby and Graham Island.
	BC Hydro Green Energy Study of BC 2002 **Wave** Publicly available	**Coverage** Updated coverage of the BC coast, with greater detail than the 1995 study. **Background** The report shows average wave power of 33 kW/m along the west coast of Vancouver Island. Total incident wave power for the west coast of VI is estimated to be 8.25 GW. The map show the variation in wave energy density off the West Coast of BC and the two potential wave energy sites discussed in detail in the green energy study done by BC Hydro. The two sites have a combined potential of 990GWh. The map shows an estimated average wave energy density zone, for water depths greater or less than 50m, with no offshore shoals. The reason for this delineation is the significant reduction in wave energy density near shore. The study and map provide seasonal variation figures for wave power density for the two sites.

British Columbia	BC Hydro Green Energy Study of BC **Tidal** Publicly available	**Coverage** BC coast, with specific sites highlighted. **Background** This study is the first assessment of its kind done for tidal current energy in B.C. This study involved preliminary assessment of the resource and identification of potential sites. Case studies of two sites were done to produce a projection of what the resource may cost to develop. The identified tidal current projects have an energy potential of about 1500 MW (2700 GWh per year) with a capacity factor of about 20%. The production costs range between 11 and 25 cents per kWh. The resource assessment identified 55 sites with current speeds over 2 metres per second (m/s), which would yield a gross annual energy potential in the order of 20 000 GWh. Selection of sites that are more feasible for development yielded 12 sites with a total energy production of 2700 GWh per year. It is expected that the number and capacity of potential tidal current sites could increase as the application of the technology to the resource is advanced In British Columbia, some of the highest-velocity tidal current flows occur through the passages between the Strait of Georgia and Johnstone Strait. The tidal range is moderate (five metres), but the tides from the Pacific through Johnstone Strait are roughly 180 degrees out of phase with the tides entering the Strait of Georgia from the southern end of Vancouver Island. This phase difference may mean that tidal currents in B.C. could provide a more consistent source of electricity than typically provided by single-phase tidal projects. \http://www.bcinnovationcouncil.com/database/img_4179287628312.pdf
[redacted]		
Mexico		**Background** Some Mexican institutions have simulators to estimate wave and tide heights, as well as the capacity to do so at various points along the national coastlines. The extent to which such capacities could be used to assess the tidal energy potential is unknown. The IIE and the Mexican Institute of Water Technology (Instituto Mexicano de Tecnología del Agua) are in talks to launch a project to estimate the energy potential of waves and tides at points of interest on the Mexican coast.

2.6.7 Regional information gaps

2.6.7.1 Where is there missing information or lower quality/reliability information?

- For the US, while there are two projects underway by a consortium of interests, led by EPRI, for both wave and tidal current, there remains significant opportunity for improved information. EPRI has taken readings from existing weather stations or buoys, and made extrapolations along each coastline. They have also identified a number of specific sites for further data collection. With this in mind, areas for further information gathering could be the following:

- Greater level of detail for full coastline mapping for tidal resources
- More individual sites identified and analysed for detailed information for tidal.
- Enhanced higher resolution modeling for waver resources.

- For Canada, a project is underway that will help fill the current gaps in information. The resolution and specificity contained in that resource assessment will likely leave some gaps for further information gathering.
- Mexico has wave monitoring sites and prediction tools. However, these tools have not been put to use for energy purposes. Current simulators are thought to enable estimations of wave and tide heights at several points, which seem to be appropriate for studying their energy potential. However, there is not yet any hard information on such potential.

2.6.7.2 Why? (remote location, funds, complex terrain, etc.)

- As per the discussion of the limitations to mapping above, there are technical and geographic reasons for the gaps in information regarding ocean energy in Canada and the US.
- Funding has been very limited for ocean energy research in parallel with the development of the wave and tidal current technologies. As the technologies progress along the commercialization continuum, demand for improved information regarding the best location for ocean energy installations will increase. This trend is already underway.

2.6.8 Summary

- Resource assessments and mapping initiatives are as critical to the development of ocean energy projects as they are to other forms of renewable energies. Developing a thorough understanding of the renewable energy resources is key to building a business case for a project, along with several other viability factors, since the resource is the fuel for the energy production.
- Wave and tidal energy may be used at some points within Mexico. However, there are presently no estimates of its energy potential. Some research institutions are currently interested in conducting joint studies to assess resource potential.

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Appendix: Renewable Energy Resource Mapping Links

North American Wind Resource Maps and Information Sources

	Author/Source	Regional Coverage	Document	Resolution/Uncertainty	Information	Web Site
Global	NASA's and Earth Science Enterprise program (RETScreen International-NRC)	World	NASA Surface Meteorology and Solar Energy Data Set	Resolution 1° by 1° (longitude by latitude) grid system average condition within a grid element are provided. Uncertainty associated to this data is in the range of 20-25%.	Average, maximum and minimum wind speeds, wind speed distribution information (% of time at each level) and wind direction at 50 m and wind speed at 10 m.	http://eosweb.larc.nasa.gov/sse/documents/SSE_Methodology.pdf; http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?na+s01+s05#s01
North America	Standford University - Nasa	North American Map	Assessment of global wind power in North America	Data from 7753 surface stations and 446 sounding stations. Results of extrapolations are color categorized by range of average wind speed and are represented as color dots at the locations of the particular measurement point.	Wind speeds calculated at 80 m height	http://www.stanford.edu/group/efmh/winds/global_winds.html
Canada	Environment Canada, Projet Eole	Country	Canadian Wind Energy Atlas	5 km²	30, 50, 80m	http://www.windatlas.ca/en/maps.php?field=E1&height=50
	HELIMAX	Quebec	Report on the wind energy potential for each region of the province	1 km²; 1:250 000	80m	http://www.helimax.com/Regie/Regie_files/Dossier_R35262004.pdf
	HELIMAX, Ressources Naturelles et Faunes Québec	Quebec	Inventory of Quebec's Exploitable Wind Power Resources (Inventaire du Potentiel Éolien Exploitable du Québec)	200m² ; 1:250 000	30, 50, 80m	http://www.mrnf.gouv.qc.ca/publications/energie/eolien/vent_inventaire_inventaire_2005.pdf
	Ressources naturelles et Faune Qc	Quebec	Wind potential maps of Quebec (speed & density)	200m² and 3 km²	65, 80,100m	http://www.mrnf.gouv.qc.ca/energie/energie/energie-sources-vent-inventaire.jsp
	Ministère des Ressources naturelles	Quebec	Wind Potential Measurement Program	41 measurement towers measuring were installed at 33 different sites.	40m	http://www.mrnf.gouv.qc.ca/english/energy/sources/sources-wind.jsp
	Université du Québec à Rimouski, WECTEC	Quebec	Carte des vents du Québec	Data from 35 sites in the province	levels from 10 to 60 m (seems to have been taken at 30 m judging from the map -- CB	http://www3.uqar.uquebec.ca/ailinca/Recherche/RenewableEnergyV28_1881-1897.pdf

	Ressources Naturelles et Faunes Qc	Quebec	L'énergie au Québec	Data from 35 sites in the province	30m	http://www.mrnf.gouv.qc.ca/publications/energie/energie/energie-au-quebec-2004.pdf
	Ministry of Natural Resources/Helimax/AWS Truewind	Ontario	Ontario Wind Atlas	1 km	10 m, 30 m, 50 m, 80 m, and 100 m	http://ontariowindatlas.ca/en/
	BC Hydro	BC	British Columbia Predicted Wind Speed Map	1 km²	65m	http://www.bchydro.com/rx_files/environment/environment1839.pdf
	BC Hydro	BC	Wind data & Wind Speed Map	Data from 18 sites in the province	From 10 to 60 m	http://www.bchydro.com/environment/greenpower/greenpower1764.html
	PEI provincial government/PEI Energy Corporatrion/Universite de Moncton	PEI	Prince Edward Island Wind Atlas	Resolution: 200 m Uncertainty: ~5-7%	Average wind speed at 30m, 50m and 80 m, power lines, power generation infrastructure, topography, surface roughness, protected nature areas etc.	http://www.gov.pe.ca/envengfor/windatlas/
	Universite de Moncton	New Brunswick	Atlas eolien du Nouveau Brunswick	Resolution: 1 km Uncertainty: ~5-7%	Average wind speed at 10 and 50 m and streams and power lines.	http://www.umoncton.ca/cge/atlas_eolien/
	HELIMAX/Manitoba Hydro	Manitoba	Wind energy potential in Manitoba	Data from 7 sites in the province	50m	http://helimax.com/projets/fiche_en.asp?nopr=104
United States						
	NREL (National Renewable Energy Laboratory) - National Wind Technology Center	Country map	Wind Resource: US Wind Resource Maps	1km²	10& 50 (wind speed and wind power density)	www.nrel.gov/wind/wind_map.html
	NREL	Country map	United State Wind Map Resources Potential (Atlas of the USA)	1km²(CB - Resolution does not look nearly that high. I would put it closer to 100 km2)	10 & 50m	http://mapserve1.nrel.gov/website/wind_resource1/viewer.htm
	NREL - Renewable Resource Data Center	Info by state	Wind Energy Resource Atlas of the United State	1km²(CB - Resolution does not look nearly that high. I would put it closer to 100 km2)	10 & 50m	http://rredc.nrel.gov/wind/pubs/atlas/maps.html
	Standford University - Nasa	Country map (data by point)	The Spatial and Temporal Distributions of U.S. Wind and Windpower	Data from 1587 surface stations & 97 soundings	80m (CB - extrapolated from measured data to 80 m)	http://www.stanford.edu/group/efmh/winds/us_winds.html
	U.S. Department of Energy	Info by state	State Energy Information: Wind Resources	1km²	10 & 50m	http://www.eere.energy.gov/state_energy/states.cfm?state=
	U.S. Department of Energy - Energy Efficiency & Renewable Energy (EERE)	Info by state	Wind & Hydopower Technologies Program - State Wind Resource Maps	200m to 1000m	50m	http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp

U.S. Department of Energy - Energy Efficiency & Renewable Energy (EERE)	Info by state	Wind & Hydopower Technologies Program - State Wind Resource Maps	-	-	http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp
U.S. Department of Energy - Energy Efficiency & Renewable Energy (EERE)	Info by state	Wind & Hydopower Technologies Program - State Wind Resource Maps	Depends of the States	50m	http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp; http://www.nrel.gov/gis/index_of_gis.html
Northwest Sustainable Energy for Economic Development (NWSEED)	Western States (California, Nevada, Washington, Idaho, Oregon, Wyoming and Utah)	Wind Power Maps	400 m	Wind power and wind speed at 50 m height.	http://www.nwseed.org/communityenergy/resources/mapping/default.asp
Land and Water Fund of the Rockies, Northwest Sustainable Energy for Economic Development (SEED), Green Info Network and Integral GIS.	Maps of 11 Western States (including: Arizona, California, Nevada, Montana, New Mexico, Washington, Wyoming, Idaho Oregon and Utah)	Renewable Energy Atlas of the West	Resolution: appears to be better than 1 km	50m	http://mapserve1.nrel.gov/website/atlas/viewer.htm; Document d'explication: http://www.energyatlas.org/downloads/ID_booklet.pdf
VERA Wind Energy Consulting	Vermont (County by County)	Wind Resource Mapping of Vermont Counties	Better than 1km	Wind speed at 30 m height	http://www.northeastwind.com/resources/maps.html
AWS Truewind LLC	Ohio, New Jerser and New York	Wind Resource Explorer	Better than 1km	Average wind speed and wind power density at 30, 50, 70 and 100 m, elevation and surface roughness.	http://www.windexplorer.com/iisstart.htm
Renewable Energy Trust	New England	New England Wind Energy Resource Maps	200 m	Average wind speed at 30m, 50m and 70 m and 100 m as we as average wind power density at 50 m	http://www.mtpc.org/renewableenergy/Community_Wind/wind_maps.htm
Hawaii Wind Working Group	Hawaii	Hawaii's Windiest Locations	Better than 1km	Average wind speed at 30m, 50m and 70 m and 100 m as we as average wind power density at 50 m	http://www.state.hi.us/dbedt/ert/wwg/windy.html

Mexico	Renewables for Sustainable Village Power	Oaxaca, Baja California Norte Border Region, Western Chihuahua Border Region, Northwestern Mexico Border Areas, Eastern Sonora Border Region, Western Sonora Border Region, the Quintana Roo Region, the Yucatan Region and the Campeche Region.	Wind Resource Maps	Better than 1km	50 m	http://www.rsvp.nrel.gov/wind_resources.html
	Mexico Renewable Energy Program	Some States	Mapas de Recurso (Wind map resource)	1 km²	30m	http://www.re.sandia.gov/en/ac/ac-fs.htm (selectTechnical info., and than Resource maps).
	Electrical Research Institute	Some sites	Wind data	Every 10 minutes (11 sites)	10, 16, 20 & 40m	http://planeolico.iie.org.mx/iiepnud.htm
	Electrical Research Institute	Some areas	Wind resource maps	0.5 x 0.5 km²	10m	http://genc.iie.org.mx/genc/index2.html
	NREL: National Renewable Energy Laboratory	Oaxaca	Wind Energy Resource Atlas of Oaxaca	1 km²	50 & 80m	http://www.nrel.gov/docs/fy03osti/34519.pdf
	Comision National Para el Ahorro de Energia	Oaxaca	Mapas Éolocos Preliminares del Estado de Oaxaca	1 km²	50m	http://www.conae.gob.mx/wb/distribuidor.jsp?seccion=2085

North American Geothermal Resource Maps and Information Sources

	Author/Source	Regional Coverage	Document	Resolution	Information	Web Site
North America	World Energy Council	Countries information	Survey on Energy Resource 2004	-	-	http://www.worldenergy.org/wec-geis/publications/default/launches/ser04/ser04.asp
	Southern Methodist University (SMU) Geothermal Lab Research	Countries map	2004 Geothermal Map of North America	Created from four data bases , with a total of more than 24 000 points for the three North American countries. Resolution:~0.1° Longitude by Latitude	1: 6 500 000; Wells with depths deeper than 25 meters Heat flow in mW/m2	http://www.smu.edu/geothermal/2004NAMap/2004NAmap.htm
Canada	BC Hydro and Canadian Cartographics Ltd	British Columbia	Green Electricity Resources of British Columbia	N/A	Color categorization into three ranges of geothermal potential: Low (not significant), Moderate (gradient heat with temperatures up to 200 °C) and High (presence of hot fluids often in excess of 200°C), location of temperature readings are provided, as is the potential for development in GWh/year.	http://www.canmap.com/geo.htm
	International Geothermal Association	*Information*	World-wide direct uses of geothermal energy 2000	*N/A*	Merely provides country by country estimates of use/potential for various applications	http://iga.igg.cnr.it/geoworld/pdf/Lund_Freeston_Geothermics.pdf
	International Geothermal Association: Proceedings World Geothermal Congress	*Information*	The current status of geothermal explration and development in Canada	-	Provides an summary of the present status of geothermal exploration in Canada.	http://iga.igg.cnr.it/pdf/WGC/2000/R0878.PDF
	GeothermEX, Inc.	BC	Geothermal assessment of British Columbia geothermal data	-	Describes a geothermal generation project in BC	See: http://www.geothermal.org/articles/canada.pdf (International Geothermal Development Potential, July 2004, pages 164-165)
USA	Land and Water Fund of the Rockies, Northwest Sustainable Energy for Economic Development (SEED), Green Info Network and Integral GIS.	Maps of 11 Western States	Renewable Energy Atlas of the West	1km²	Heat flow gradient greater than 150 mW/m2 at the deepest interval sampled. Also based on SMU map.	Map: http://mapserve1.nrel.gov/website/atlas/viewer.htm / Research: http://www.energyatlas.org/contents/default.asp
	U.S. Department of Energy	Info by state	US Geothermal Resource Map	Heat flow contours are patterned in intervals of 20 milliwatts per square meter (mW/m²)	Broad regional divisions based on estimated subterranean temperatures at a depth of 6 kilometers presented in a ranges from 0 to > 200 °C.	http://www.eere.energy.gov/geothermal/geomap.html
	NREL (National Renewable Energy Laboratory) - EIA	Country map	Geothermal Resource Potential	5km²	Geo-referenced data of heat flow in units of mW/m^2. Contours were then interpolated for intervals of 10 milliwatts/m^2.	http://www.eia.doe.gov/cneaf/solar.renewables/ilands/fig15.html
	Oregon Institute of Technology's: Geo-Heat Center's	Country map	Map of the U.S. Geothermal Resource Areas	Data provide on over 8,977 thermal springs and wells	Temperature above & below 100 °C	http://geoheat.oit.edu/images/usmap1.gif
	Oregon Institute of Technology's: Geo-Heat Center's	States map	Where are Geothermal Resources Located?	Map show cities & towns that are located within 5 miles of a known geothermal resource that has a temperature greater than 50°C	Temperature & Depth (M) information	http://geoheat.oit.edu/colres.htm
	Southern Methodist University (SMU) Geothermal Lab Research	Country map	Heat flow	Resolution:~0.1° Longitude by Latitude	mW/m²	http://www.smu.edu/geothermal/heatflow/heatflow.htm

	Idaho National Laboratory	Info by state for Western United States (Alaska, Arizona, California, Colorada, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming)	Geothermal Energy	Same as other SMU maps	These maps were produced by the INL Geothermal Technologies Program with data from the Southern Methodist University Geothermal Laboratory.	http://geothermal.id.doe.gov/maps-software.shtml; http://geothermal.inl.gov/maps/index.shtml
	Geothermal Energy Association	Country map	Geothermal Potential: Estimated Earth Temperatures (ºC) at 6 km Depth	-	Grading from 0 to 250 ºC; 6km of depth	http://www.geo-energy.org/USGeoProv.pdf
	USGS Science for a changing world	Country information	Ground-Water Data for the United States	-	-	http://waterdata.usgs.gov/nwis/gw
	Great Basin Center for Geothermal Energy, University of Nevada	Great Basin area	Regional Assessment of exploration potential for geothermal systems in the Great Basin using a geographic information system (GIS).	-	-	http://www.unr.edu/geothermal/pdffiles/CoolbaughGIS2.pdf
	GeothermEX, Inc.	Country assessment	Publications and Recent projects	-	Nothing of use	http://www.geothermex.com/frame_e.html
Mexico	World Energy Council		Survey on Energy Resource 2004	-	-	http://www.worldenergy.org/wec-geis/publications/default/launches/ser04/ser04.asp
	Secretaria de Energia	Country info	Prospectiva del sector eléctrico 2004-2013	-	-	http://www.energia.gob.mx/work/resources/LocalContent/2183/21/prospec_elec_04_13.pdf
	Secretaria de Energia	Country info	Energías Renovables para el desarrollo sustentable en Mexico	-	-	http://www.energia.gob.mx/work/resources/LocalContent/1835/1/e_renovables_mexico.pdf
	Comisión Federal de Electricidad (CFE)	Country info	Programa de Obras e Inversiones del sector Electrico (2004-2013)	-	-	http://www.cfe.gob.mx/NR/rdonlyres/445BC7FF-A7E8-4487-A7CB-666861684A08/0/POISEINTEGRADO.pdf; http://www.cfe.gob.mx/www2/QueEsCFE/conocimiento/PublicacionesCFE/
	International Geothermal Association	Country info	World-wide direct uses of geothermal energy 2000	-	-	http://iga.igg.cnr.it/geoworld/pdf/Lund_Freeston_Geothermics.pdf ; http://iga.igg.cnr.it/geoworld/geoworld.php?sub=map&country=mexico
	International Geothermal Association: Proceedings World Geothermal Congress	Country info + map	Geothermal Production and development plans in Mexico	The map indicate only geothermal fields and zones in Mexico	-	http://iga.igg.cnr.it/pdf/WGC/2000/R0293.PDF ; http://iga.igg.cnr.it/geoworld/geoworld.php?sub=map&region=northamerica&country=mexico
	Instituto de Investigaciones Legislativas del Senado de la Republica	Country map	Nueva Energieas Renovables: Una Alternativa Energitica Sustentable para Mexico: Location of the Geothermal Developement	41 sites	3 or 4 km	http://xml.cie.unam.mx/xml/se/pe/NUEVAS_ENERG_RENOV.pdf
	US Department of Energy	Country map	An Energy Overview of Mexico	Megawatts (Mwe)	-	http://www.fe.doe.gov/international/Western%20Hemisphere/mexiover.html
	GoethermEX, Inc.	Country info	Publications and Recent projects	-	-	http://www.geothermex.com/frame_e.html

North American Solar Resource
Maps and Information Sources

	Author/Source	Regional Coverage	Document	Resolution	Information	Web Site
North America	World Energy Council	Countries information	Survey on Energy Resource 2004	N/A	N/A	http://www.worldenergy.org/wec-geis/publications/default/launches/ser04/ser04.asp
	NASA's and Earth Science Enterprise program (RETScreen International-NRC)	Global Coverage. Allows manual input or point and select latitude/longitude information anywhere in the world.	NASA Surface meteorology and Solar Energy Data Set	1° by 1° (Longitude by latitude) grid system, select information by latitude and longitude , Uncertainty: ~16%	Provides parameters for solar cookers, Sizing and Pointing of Solar Panels and for Solar Thermal Applications, Solar Geometry, Parameters for Tilted Solar Panels, Parameters for Sizing Battery or other Energy-storage Systems, Parameters for Sizing Surplus-product Storage Systems, Meteorology (Temperature), Diurnal Cloud Information. Specific parameters within each of these categories are listed at: http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?cboivin@delphi.ca+s07#s07	http://eosweb.larc.nasa.gov/sse/documents/SSE_Methodology.pdf; http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?na+s01+s05#s01
	World Energy Council, Environment Canada & Nasa Center	Countries map	Solar Energy - Measuring Solar Insolation	> 40 km	Average monthly solar insolation for the months of January and April based on Earth Observatory data from NASA for the years 1984-1993. The data in presented as color coded ranges 0 to 8.5 kwh/m²/day	http://www.worldenergy.org/wec-geis/publications/reports/ser/solar/solar.asp
Canada	Natural Resources Canada, Canadian Atlas	National Coverage	Canada Solar Radiation - Annual	Low resolution. Broad categorization of canadian regions. Basedd on 54 actual measurement stations Stations & numeric model was used simulated and additional 93 other locations. Map: 1: 12 500 000 (data from 1956-1978)	Annual mean daily solar radiation for horizontal surface as well as for inclined surfaces of 90o and 60o facing south (the equator). Maps provide color coded regions categorized in zones ranging from 7 to 15 MJ/m². Maps are also available for average daily solar radiation for the months of April and October	http://atlas.gc.ca/site/francais/maps/archives/5thedition/environment/climate/mcr4076; http://atlas.gc.ca/site/english/maps/archives/5thedition/environment/climate/mcr4078?w=4&h=4&l=3&r=0&c=0
	CanSIA	Canada	Annual Mean Daily Solar Radiation	Low, just a back and white map with broadly delineated regions of varying insolation.	Daily Insolation (MJ/m2/day)	http://cansia.ca/solarmap.asp
	Green Power Labs	Nova Scotia	kWh/m^2	~ 1km2.	Annual mean daily solar radiation (kWh/m2/day). Shows color coded regional variation with a high degree of precision for a vary narrow range from 3.33 - 3.55 kWh/m2/day.	http://greenpowerlabs.com/pics/solar.jpg
	BC Hydro and Canadian Cartographics Ltd	British Columbia	Green Electricity Resources of British Columbia	~ 1o x 1o (based on RETScreen Data which in turn is based on NASA's and Earth Science Enterprise program Uncertainty: 16%.	Annual average daily solar radiation (kWh/m2/day). Also provides location of power generation and transmission infrastructure. Solar radiation recording stations are also indicated. The map is based on Environment Canada solar radiation data compiled in RETScreen international.	http://www.canmap.com/green.htm
	Resources Naturelles & Faune Québec (Maps from UQAC)	Québec	Cartographie par satellite de la resource solaire au Quebec.	Resolution is ~40 km. Use satellite imaging and a physical model. Uncertainty: ~ 10%	Average daily insolation rate for all months based on data from 1998-2000.	http://www.mrn.gouv.qc.ca/energie/energie/energie-portrait-non-conventionnelles-cartes.jsp
USA	NREL (National Renewable Energy Laboratory) for the U.S. Department of Defense	Country map	Solar Resource for the Department of Defense	Resolution: 40km Uncertainty: 10%	kwh/m²/day; Ranging from less than 2 to greater than 9	http://mapserve1.nrel.gov/website/L48MarineCorp/viewer.htm
	NREL	Country map	United State Solar Atlas	Resolution: 40km Uncertainty: 10%	kWhrs/m²/day	http://mapserve1.nrel.gov/website/L48NEWPVWATTS/viewer.htm
	EIA (website) & National Renewable Energy Laboratory for the U.S. Department of Energy	Country map	Federal & Indian lands with solar resource potential	Resolution: 40 km Uncertainty: 10%	kwh/m²/day; Ranging from 2-3 to 8-9	http://www.eia.doe.gov/cneaf/solar.renewables/ilands/fig11.html

	Renewable Resources Data Center	Country map	U.S. Solar Radiation Resource Maps	Data from 239 stations around the USA. Low resolution as data is from interpolation of the measurements from these sites. Based on a statistical model.	kwh/m²/day (can get data for individual month or annual. Angle of orientation of the system can also be accounted for.	http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/
	US. Department of Energy	Info by state	The solar resource	Low resolution, broad categorization of various regions. Based on above statistical model.	Ranging from 1000 to 7500 Whr/m²/day	http://www.eere.energy.gov/state_energy/states.cfm?state=__
	US. Department of Energy: Energy Efficiency & Renewable Energy: State Energy Alternatives	Country map	The solar resource	Low resolution, broad categorization of various regions. Based on above statistical model.	Ranging from 0 to 9+ kwh/m²/day	http://www.eere.energy.gov/state_energy/states.cfm?state=__
	NREL	Southwestern States: Arizona, California, Nevada, New Mexico and Colorado.	Concentrating Solar Power Resource Maps	Resolution: 40 km Uncertainty: 10%	Illustrates potential in very specific locations within each state that are suitable for concentrating solar power generation based on daily average solar insolation rates (kWh/m2/day). Also illustrates proximity to major power generation and distribution infrastructure.	http://www.nrel.gov/csp/maps.html
	Land and Water Fund of the Rockies, Northwest Sustainable Energy for Economic Development (SEED), Green Info Network and Integral GIS.	Maps of 11 Western States	Renewable Energy Atlas of the West	Resolution: 40 km Uncertainty: 10%	kwh/m²/day (Annual solar potential from 3.5 to 7kwh/m²/day - Solar radiation from 1 to 7)	http://mapserve1.nrel.gov/website/atlas/viewer.htm; Document d'explication: http://www.energyatlas.org/downloads/ID_booklet.pdf
Mexico	World Energy Council		Survey on Energy Resource 2004	-	-	http://www.worldenergy.org/wec-geis/publications/default/launches/ser04/ser04.asp
	Secretaria de Energia	Country info	Prospectiva del sector eléctrico 2004-2013	-	-	http://www.energia.gob.mx/work/resources/LocalContent/2183/21/prospec_elec_04_13.pdf
	Secretaria de Energia	Country info	Energías Renovables para el desarrollo sustentable en Mexico	-	-	http://www.energia.gob.mx/work/resources/LocalContent/1835/1/e_renovables_mexico.pdf
	Comisión Federal de Electricidad (CFE)	Country info	Programa de Obras e Inversiones del sector Electrico (2004-2013)	-	-	http://www.cfe.gob.mx/NR/rdonlyres/445BC7FF-A7E8-4487-A7CB-666861684A08/0/POISEINTEGRADO.pdf; http://www.cfe.gob.mx/www2/QueEsCFE/conocimiento/PublicacionesCFE/
	NREL & Sandia	Country map	Annual Average Global Horizontal Solar Radiation for Mexico	Grid resolution is 40km & 2km²	kwH/m²/day; ranging from less than 1 to greater than 9	http://www.re.sandia.gov/en/ac/ac-fs.htm I51
	Universidad Nacional Autónómica de Mexico (UNAM)	Country map	México - Atlas de radiación solar	-	-	http://serpiente.dgsca.unam.mx/pue/publi.html
	Instituto De Investigaciones Legislativas Del Senado de la Republica	Country map	Nuevas Energias Renovables: Una alternativa Energetica sustnetable para Mexico	5kWh/m²	kwH/m²/day; ranging from 0 to 12	http://xml.cie.unam.mx/xml/se/pe/NUEVAS_ENERG_RENOV.pdf

North American Biomass Resource
Maps and Information Sources

	Author/Source	Regional Coverage	Document	Resolution	Information	Web Site
North America	World Energy Council	Countries information	Survey on Energy Resource 2004	-	-	http://www.worldenergy.org/wec-geis/publications/default/launches/ser04/ser04.asp
Canada	IEA Bioenergy: Media Centre	Country map	Bioenergy in Canada	-	-	http://www.ieabioenergy.com/media.php?read=47
	BIOCAP Canada Foundation,	Canada	Biological resources – in particular, agriculture and forestry	-	`	http://www.biocap.ca/images/pdfs/BIOCAP_Biomass_Inventory.pdf
	Government of Manitoba	Manitoba	Manitoba's Homegrown Energy: Al-Corn Fuel Production	-	-	http://www.gov.mb.ca/est/energy/ethanol/eth_energy.pdf
	BC Hydro	BC	Biomass Potential	-	-	http://www.bchydro.com/environment/greenpower/greenpower1735.html
	Ressources Naturelles et Faunes Qc	Québec	L'énergie au Québec	Assessment of residual biomass	Data assessed in billion of TEP	http://www.mrnf.gouv.qc.ca/publications/energie/energie/energie-au-quebec-2004.pdf
	BC Hydro and Canadian Cartographics.	British Columbia	Green Electricity Resources of British Columbia	N/A	Provides an estimate of available forest industry was and landfill gas for electric generation in each forest sector of BC.	http://www.canmap.com/bio.htm
USA	National Renewable Energy Laboratory (NREL)	Country maps	A Geographic Perspective on the Current Biomass Resource Availability in the United States	County by county spacial presentation.	Provides several national maps broken down by county, each map presenting county totals for a different biomass resource type. The resource types presented include crop residues, methane from manure, forest residues, primary mill residues, secondary mill residues, urban wood waste, methane emissions from landfills, methane emissions from wastewater treatment waste and various dedicated energy crop potential projections.	http://www.nrel.gov/docs/fy06osti/39181.pdf
	EIA	Country map	Federal lands with biomass resource potential		% of biomass resource potential. Ratings are in units of potential kilowatts per county. Indiactes lands tha have a 5000 kW per county rating. Also indicate federal lands and location of power generation facilities and biomass using facilities.	http://www.eia.doe.gov/cneaf/solar.renewables/page/biomass/biomass.gif
	EIA	Country map	Biomass and Biofuels Resource Potential	Information per county	Ranging from 0-5000, 5000-40000 and to greater than 40,000 kilowatts per county. Also indicated federal lands.	http://www.eia.doe.gov/cneaf/solar.renewables/ilands/fig14.html
	US. Department of Energy	Info by state	Renewable Potential Maps: State energy information	-	Fuelwood Harvested (3+ million cubic ft/yr)	http://www.eere.energy.gov/state_energy/states.cfm?state=
	US. Department of Energy	Info by state	State energy information: Bioenergy resources	-	Dry Tons: Ranging from 0 to 6000 thousand tons per county	http://www.eere.energy.gov/state_energy/states.cfm?state=
	Oak Ridge National Laboratory (ORNL)	Info by state	Biomass Feedstock Availability in the United States	-	$/dry ton delivered	http://bioenergy.ornl.gov/resourcedata/index.html
	Land and Water Fund of the Rockies, Northwest Sustainable Energy for Economic Development (SEED), Green Info Network and Integral GIS.	Maps of 11 Western States (Washington, Nevada, Oregon, Montana, Idaho, Wyoming, Utah, Colorado, California, New Mexico, Arizona).	Renewable Energy Atlas of the West	Scale of data: 1:100,000 & 1:5,000,000	Total potential in kWh/BTUs per county from 50 to 11 200 000. Biomass resources were calculated by combining county totals of corn, barley and wheat residues from USDA agricultural crop estimates (2001–2002), animal waste from USDA county estimates (1996), forest and mill wood wastes from USDA Forest Service (1996), and potential and existing landfill gas recovery systems from the EPA landfill database (2001). Data source: US Department of Ariculture, 1996, 2002; Environmental Protection Agency 2001	http://mapserve1.nrel.gov/website/atlas/viewer.htm; Document d'explication: http://www.energyatlas.org/downloads/ID_booklet.pdf
	General Bioenergy	Southern East & Florida	Assessment of Biodiesel Potential in the Southeast and in Florida	-	-	http://www.bioenergyupdate.com/

Mexico	World Energy Council		Survey on Energy Resource 2004	-	-	http://www.worldenergy.org/wec-geis/publications/default/launches/ser04/ser04.asp
	Instituto de Investigaciones Legislativas del Senado de la Republica	Country information	Nueva Energieas Renovables: Una Alternativa Energética Sustentable para Mexico: Location of the Geothermal Developement	-	-	http://xml.cie.unam.mx/xml/se/pe/NUEVAS_ENERG_RENOV.pdf
	Electrical Research Institute	Country maps	Bioenergy maps (from livestock and agriculture wastes)	Municipality	Petajoules (PJ)	http://genc.iie.org.mx/genc/index2.html
	ANES: Red Mexicana de Bioenergica	Country data & tables	Potencial de la Bioenergía en México y Principales Acciones de Fomento del Sector Energía, SENER (presentación powerpoint)	-	-	http://www.anes.org/bioenergia/beventos.html
	ANES: Red Mexicana de Bioenergica	Country data	Mapas Tecnológicos para el Desarrollo de las Energías Renovables en México, IIE, Jorge M. Huacuz Villamar (presentación powerpoint)	-	-	http://www.anes.org/bioenergia/beventos.html
	Food and Agriculture Organization of the United Nations (FAO)	Country data	Wood fuels Integrated Supply/Demand Overview Mapping (WISDOM): A methodological approach for assessing wood fuel sustainability and supporting wood energy planning.	2 435 counties	Assess different variables (see the document); scale is 1:250 000	http://www.fao.org/documents/show_cdr.asp?url_file=//DOCREP/005/y4719e/y4719e07.htm
	LAMNET: Latin America Thematic Network on Bioenergy	Country information	Project Scope: Assessment of Resources	In process	In process	http://www.bioenergy-lamnet.org/
	Nasa	Southern Mexico	In progress: Evaluation of the rainforest capacity	-	-	

North American Small Hydro Resource Maps and Information Sources

	Author/Source	Regional Coverage	Document	Resolution	Information	Web Site
North America	International Small Hydro Atlas	North America	Database and Web GIS of small hydro potential sites	1:1 000,000 (digital chart of the world as base maps)	-	Canada: http://www.small-hydro.com/index.cfm?fuseaction=countries.sites&country_ID=13; USA: http://www.small-hydro.com/index.cfm?Fuseaction=countries.country&Country_ID=82; Mexico: http://www.small-hydro.com/index.cfm?Fuseaction=countries.country&Country_ID=53
Canada	Environment Canada: Canadian Atlas	Country map	Water Survey (Steamflow)	2 838 stations	1:7 500 000; River flow: Ranging from 85 to 12 500 meter³/sec	http://www.wsc.ec.gc.ca/hydrology/main_f.cfm?cname=streamflow_f.cfm; http://atlas.gc.ca/site/english/maps/archives/5thedition/environment/water/mcr4178?w=2&h=2&l=2&r=0&c=0
	Hydro-Québec	Québec	Le potentiel hydraulique du Québec - Hydro Potentiel in Québec (1995)	589 sites		
	Hydro Québec	Québec	Hydro energy in Quebec: potential & current development	-	watt/hour (Wh)	http://www.mrnf.gouv.qc.ca/publications/energie/energie/energie-au-quebec-2004.pdf
	Ontario Minstry of Natural Resources	Ontario	Inventory of potential waterpower opportunities on crown land (extranet website)	1:750,000 (southern Ontario) 1:1,000,000 (northern Ontario)	891 potential sites	https://www.extranet.mnr.gov.on.ca/waterpower/hardcopymap.html
	BC Hydro - Sigma Engineering Ltd.	BC	Green Energy Study for British Columbia: Phase 2 : Mainland - Small Hydro	Assessment of stations (see table 2 but approximately 12 000 sites)	Scale 1:50 000; Power (kW), Energy (GWh)	http://www.bchydro.com/rx_files/environment/environment3931.pdf
	BC Hydro	BC	Inventory of undeveloped opportunities at potential micro hydro sites in British Columbia	Assessment of steams basin areas	River flow (m³/s), Power (kW), Energy (GWh), Green energy (GWh), Cost ($/kWh).	http://www.bchydro.com/rx_files/environment/environment1837.pdf
United States	Idaho National Engineering and Environmental Laboratory	Info by State	Virtual Hydropower Prospector: Region Selector	Different data sources: http://hydropower.inel.gov/prospector/data_sources.shtml	Depend of the option selected	http://hydropower.inel.gov/prospector/r_selector.shtml
	Idaho National Engineering and Environmental Laboratory	49 States	Estimation of Average Annual Streamflows and Power Potentials for 49 States	See Abstract to this document: http://hydropower.inel.gov/resourceassessment/pdfs/03-11111.pdf	-	http://hydropower.inel.gov/resourceassessment/states.shtml
	National Renewable Energy Laboratory	US	Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants		Provides true hydropower potential using a damless small hydro development model and associated development criteria	http://hydropower.inl.gov/resourceassessment/
	Idaho National Engineering and Environmental Laboratory	Alaska & Hawaii	Estimation of Average Annual Streamflows and Power Potentials for Alaska and Hawaii	See Abstract to this document: http://hydropower.inel.gov/resourceassessment/pdfs/03-11111.pdf	-	http://hydropower.inel.gov/resourceassessment/states.shtml
Mexico	Instituto De Investigaciones Legislativas Del Senado de la Republica	Country map	Nuevas Energias Renovables: Una alternativa Energetica sustnetable para Mexico	-	Potential evaluate in MW & TWh/yr	http://xml.cie.unam.mx/xml/se/pe/NUEVAS_ENERG_RENOV.pdf
	US Department of Energy	Country map	An Energy Overview of Mexico	-	Megawatts (Mwe)	http://www.fe.doe.gov/international/Western%20Hemisphere/mexiover.html

North American Wave and Tidal Resource Maps and Information Sources

	Author/Source	Regional Coverage	Document	Resolution	Information	Web Site
Canada	BC Hydro	British Columbia	Wave Energy Potential: Wave Monitoring Data Available	-	-	http://www.bchydro.com/environment/greenpower/greenpower6791.html
	Canadian Hydrolics Centre - National Research Council Canada	Canada's Atlantic and Pacific Coasts	Inventory of Canada's Offshore Wave Energy Resources	Broadly (macro) categorize wave resource regions	Rough estimates of wave power off the Atlantic and Pacific Coasts of Canada. Data is based on interpollation/extrapollation of actual measured sea data.	
United States	Electric Power Resource Institute	Information in few US States including: Oregon, California, Maine, Washington, and Hawaii. Have also done tidal assessments in Nova Scotia, Canada	Wave energy report 2003-2005	The study is based on reference stations from 6 US States (Maine, Massachusetts, California, Oregon, Washington, and Hawaii)	Annual wave height and peak wave period at each selected sites, data in kWh per meter per year	http://www.epri.com/targetWhitePaperContent.asp?program=267825&value=04T084.0&objid=297213