Opportunities for Mapping Rooftop Solar Energy using LiDAR

An Introduction for BC Local Governments

BRITISH COLUMBIA

March 2013

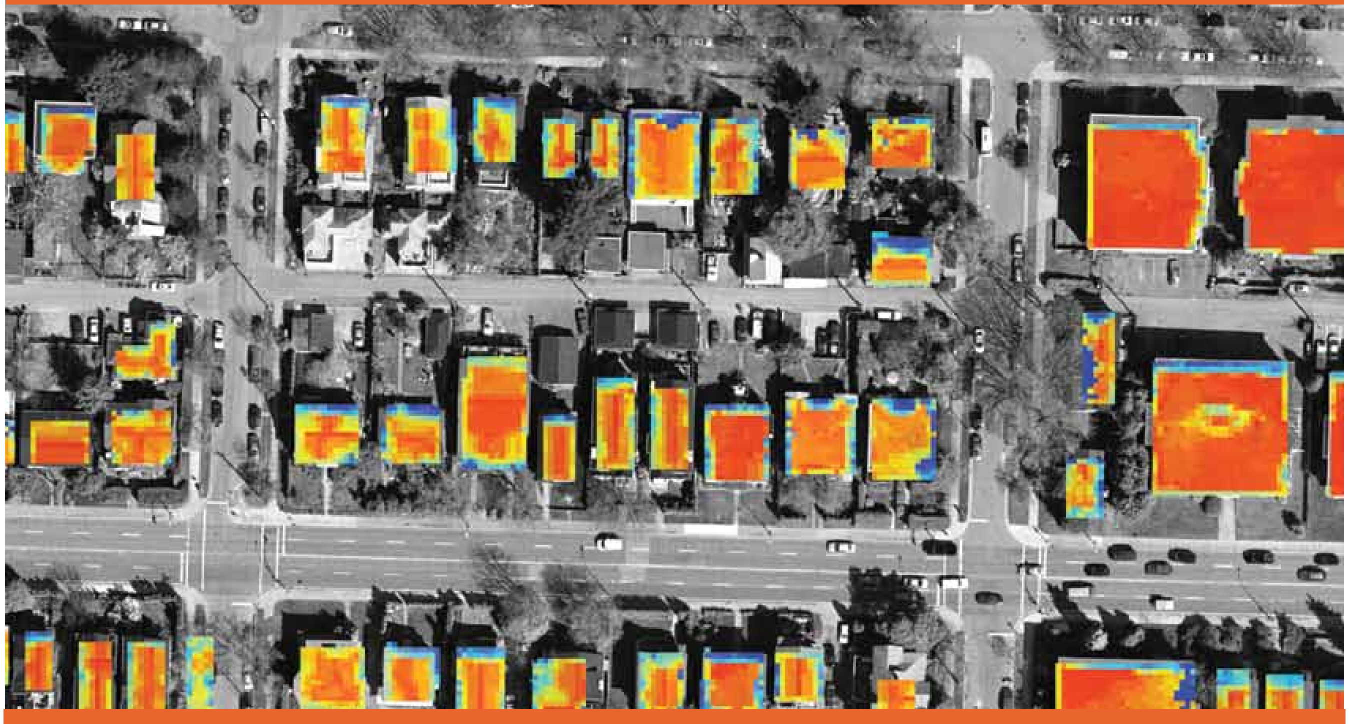
THOREAU RORY TOOKE

Opportunities for Mapping Rooftop Solar Energy using LiDAR

An Introduction for BC Local Governments

March 2013

THOREAU RORY TOOKE



Prepared for:

Ted Sheldon
Climate Action Secretariat
2nd Floor – 395 Waterfront Crescent
PO Box 9486 Stn. Prov. Govt
Victoria BC, V8W 9W6

by:

Thoreau Rory Tooke
Consultant
7 – 3885 Cambie St.
Vancouver BC, V5Z 2X6

Contents

Executive Summary

Light Detection and Ranging (LiDAR) is a powerful tool that local governments can use to improve management and planning tasks. Across British Columbia LiDAR datasets are becoming increasingly commonplace in municipal and regional data libraries and offer a much greater range of applications than traditional air photos. However, knowledge of the data and potential applications are not well understood across departments.

This report is intended to familiarize local government staff and elected officials with the potential benefits of using LiDAR. The specific application of LiDAR to solar energy mapping is provided here, although this presents only one of many valuable products that can be generated from these datasets.

In this report, the reader is presented with a non-technical description of LiDAR technology and examples of existing solar mapping applications across the Province. The report concludes with a list of recommendations to support local governments interested in pursuing LiDAR data acquisition.

Acknowledgements

Thanks to the following people who have contributed to the production of this report:

Ted Sheldon – BC Ministry of Environment
Taylor Davis - Terra Remote Sensing
Azadeh Koohzare – McElhanney Consulting Services Ltd.
Matt Osler - City of Surrey
Tamsin Mills - City of Vancouver
Judith Cullington - City of Colwood
Julia Roberts – SolarBC
Jessica Webster – Natural Resources Canada
Nicholas Coops – University of British Columbia

Introduction

Objective of Report

The aim of this report is to familiarize local government staff and elected officials with LiDAR (Light Detection and Ranging) data and its application for community-wide solar energy mapping. LiDAR is becoming increasingly commonplace in municipal and regional government data libraries across British Columbia; however, staff are not often aware of the existence of these datasets, nor are the various planning and management relevant LiDAR applications well understood. The aim of this report is to help address these gaps by:

1. Providing a general description of LiDAR including basic technical considerations and costing, and
2. Showcasing LiDAR applications for solar energy mapping using existing examples across British Columbia.

Target Audience

This report is targeted to local government staff and elected officials. Although engineering or IT/GIS staff are typically responsible for procuring and managing LiDAR datasets, the value of the data extends across departments. By targeting a broad audience, this report aims to encourage internal discussion between local government departments as to the potential benefits and applications of LiDAR. Where LiDAR datasets are already available, this discussion can encourage new applications, and where a business case is being prepared it can help demonstrate the potential added value of a LiDAR acquisition.

Format of Report

To address the objectives listed above, this report is separated into three general sections.
The first section provides a background to LiDAR, including a discussion of applications, technical considerations and basic costing. The intention of this first section is to acquaint the reader with the fundamental information needed when considering the purchase and use of LiDAR. The second section showcases examples where LiDAR has been used to provide assessments of rooftop solar energy. This section draws on three regions in British Columbia, with each example providing a unique approach for implementing the LiDAR data. The third and final section contains a discussion of the future role of LiDAR for province-wide energy planning.

LiDAR Background

LiDAR Applications

Although the intention of this report is to showcase the application of LiDAR for rooftop solar mapping initiatives, there exists a wide range of urban planning and management applications well suited to LiDAR data inputs. Some of the more common applications include:

- Topography mapping
- 3D visualization
- Building detection
- Tree and vegetation classification
- Disaster planning
- Flood risk mapping
- Integrated storm water management
- Energy resource and demand mapping

It should be noted that while these applications have been undertaken using LiDAR data, there is no single software tool that allows complete processing from the raw data to all relevant planning or management products. As a result, engaging with engineering, IT or geomatics consulting firms and university research groups offer the most appropriate avenues for determining the best approach to process the LiDAR for a specific project.

LiDAR Technology

As noted above, LiDAR stands for *Light Detection and Ranging*, and in its essence is a technology used to measure the distance to objects. To calculate distances the LiDAR emits a laser pulse and records the time taken for that same pulse to return to a sensor. Using the time of the return and the speed of light, the technology is then able to accurately compute the distance to an object. Given that the location of the sensor is known, the LiDAR data can then be used to map the position and height of objects in its scanning range.

Much of the value of LiDAR is realized when the sensor is mounted to a moving object such as a vehicle or airplane. In these cases, large areas can be scanned to produce very accurate three-dimensional representations of an environment. Because the LiDAR emits and records individual laser pulses, three-dimensional surfaces and objects are collected and represented as a set of points, each typically containing geographic coordinates and a measurement of vertical height. The group of LiDAR points used to represent a three-dimensional surface is called a *point-cloud*. An example showing the point cloud representation of Vancouver City Hall is provided in Figure 1.

Another valuable aspect of LiDAR technology is the speed at which the data points are collected. Consider a traditional land surveying approach where a surveyor uses a set of instruments to determine the position of points on the Earth's surface and the distances and angles between them. To collect this information for one million points it would take the surveyor more than 15 years. In contrast, collecting one million points using LiDAR takes under 10 seconds.

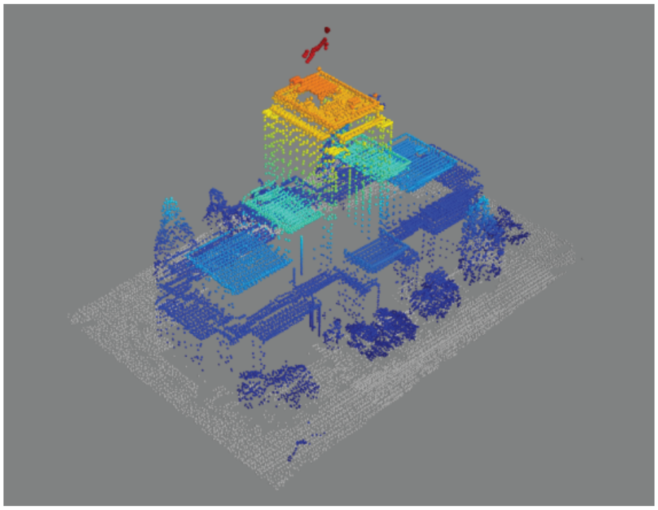


Figure 1. LiDAR point cloud representation of Vancouver City Hall.

The LiDAR datasets acquired across urban areas are typically collected using an airplane or helicopter. The advantage of data collection from the air is that it allows information to be gathered in areas otherwise inaccessible by person or by vehicle. Additionally, airborne LiDAR acquisition allows for the complete coverage of a city, with substantial cost savings compared to traditional surveying methods.

In this report the use of the term LiDAR will refer to airborne LiDAR unless otherwise stated. It is also important to acknowledge that terrestrial LiDAR, typically collected from a vehicle and acquired from the vantage point of city streets, is available from some LiDAR vendors, although applications and processing techniques are much less evolved than for airborne datasets.

Technical Considerations

To ensure that LiDAR datasets achieve their intended planning or management purpose, and to enable additional applications, it is critical that local government staff comprehend some basic technical considerations related to the acquisition of LiDAR. Feedback provided by LiDAR vendors suggests that project objectives and all potential applications be clearly stated in the procurement proposals for LiDAR data. In addition to the *important terms* listed at the end of the report, this section is designed to assist local governments in realizing the key considerations needed when planning for LiDAR acquisition.

The two most important technical considerations for a LiDAR acquisition are **point density** and **accuracy**. Point density refers to the number of laser pulses that reach an area on the ground, and are typically conveyed using the unit of *points per* m^2. Common urban LiDAR applications require point densities between 4 and 20 points per m^2, although choosing a point density at the higher end of this range generally enables more products to be derived from the LiDAR. It is also important to recognize that although the final product may not require such detailed information, the accuracy and quality of a generated product (for example, the delineation of buildings) is often greater with a higher point density.

In addition to point density, the accuracy of the LiDAR returns must also be considered. Accuracy is typically referenced for both the horizontal and vertical dimensions of the LiDAR point data. Like point density, the intended application of the LiDAR will determine the necessary accuracy. As an example, the Ministry of Forests, Lands & Natural Resource Operations - Coastal Flood Plain Mapping Guidelines and Specifications [1] requires a vertical and horizontal accuracy greater than 60% of the specified map accuracy for floodplain mapping applications.

The last key technical component of LiDAR acquisition to consider is flight planning. While the point density and accuracy are important initial metrics that the vendor can use to evaluate the success of a LiDAR acquisition, the ultimate success of the acquisition is determined by the quality of products that can be generated for the intended application. Designing a LiDAR flight configuration that meets the objective of a project requires careful consideration of the physical environment where the LiDAR is being flown. For example, variations in topography (and therefore flying height) or vegetation cover may influence the number of LiDAR returns that reach the ground surface. Flying height, flight-line overlap, and flight path direction therefore become important considerations for planning LiDAR acquisitions.

After the LiDAR is acquired, various techniques are available to classify the data. Most vendors provide a basic classification of ground and non-ground LiDAR returns, however, the points may be classified into a variety of features such as power line, building, vegetation, and water. Automated classification routines are available in some cases, but for best results the classification of LiDAR remains dependent on manual interpretation. LiDAR classification can also always be completed or improved at a later date.

Costing

The technical considerations discussed above provide an introduction to many of the factors that determine the cost of LiDAR. In addition to the extra flying time required for gathering greater point densities, costing will also depend on the size of the area being scanned, proximity to an airport, mobilization of the sensor and labour, calibration, scheduling, vendor workload and validation. The classification of various features in complex terrain, such as cities, may also add to the cost of the data. A general range of $2 to $10 per hectare can be expected, although there are a number of cost reduction or sharing opportunities that local governments should consider including:

- Combined remote sensing product acquisition, such as the simultaneous collection of aerial photography and LiDAR
- Internal collaboration between relevant municipal departments (e.g. Engineering, Planning, IT, Parks, Sustainability)

- Collaboration and partnership with neighbouring municipalities, utilities or relevant private sector industries (e.g. forestry, mining, construction, transportation)

Treating the LiDAR procurement like a construction contract, with a list of optional items is also recommended since it enables the breakdown of base cost plus the marginal cost associated with potential value added products or enhancements.

LiDAR-Based Rooftop Solar Mapping

Introduction

Solar energy generating technologies can be divided into two basic categories: those that produce electricity, and those that produce heat. The electricity generating technologies are photovoltaic (PV) cells that convert solar radiation into direct current electricity. Solar heating systems are comprised of solar thermal collectors that capture heat energy from the sun for use in a variety of heating applications. On a small-scale, solar heating systems are typically used in water heating for domestic purposes and in some cases for indoor space heating.

To assess the solar energy available on building rooftops, three fundamental processes must be considered. These are:

- Atmospheric effects
- Surface effects, and
- Sun geometry

When assessing building rooftop solar energy across an entire city, surface effects become the most important of these factors to consider. Surface effects include the influence of obstructions that might shade a rooftop, such as another building or a tree, and also include geometric parameters related to the roof itself, namely orientation and slope. Generating surface geometries is well suited to LiDAR since it provides a highly accurate three-dimensional representation of features on the ground. From the LiDAR data it is then relatively simple to produce rooftop slopes and orientations using available tools in *Geographic Information System* (GIS) software. Determining obstructions surrounding a rooftop is more complex, and various approaches have been used to model rooftop shading throughout the day and year.

The most common surface obstruction models used for assessing rooftop solar energy in a GIS evolved from hemispherical photograph interpretation. Hemispherical photography employs fisheye lenses to capture the entire sky hemisphere, which allows the interpretation of obstructing objects along the horizon. The adaptation of this technique to computer processing is referred to as *hemispherical viewshed modelling*. Obstruction angles generated from this approach are then compared to the location of the sun to determine surface shading. The solar position calculation is based on latitude, day and time.

Finally, atmospheric effects must be considered. The basic components of the atmosphere that influence solar radiation can be separated into clouds and aerosols. In the context of rooftop solar energy feasibility assessment, atmospheric conditions are critical to determining the total radiation available for energy production, although the variation of atmospheric conditions over a single city are relatively stable compared to surface effects.

Applications in British Columbia

Given the basic background to the important factors that are needed to assess rooftop solar energy mentioned above, the following section provides examples of existing cases in British Columbia where LiDAR has been applied to produce a variety of products used in the planning and management of local energy systems.

A common outlet for communicating rooftop solar energy has been to develop online mapping tools that the public can access to identify the solar potential of their own building. In recent years these maps have evolved to incorporate LiDAR, which provides a much more accurate estimate of the energy generating potential of individual buildings across a city. The table below (Table 1) lists online rooftop solar mapping examples for select North America cities and indicates whether they implement a LiDAR-based approach.

Table 1. List of online solar mapping tools for select North American cities.

City	**Use of LiDAR**	**Website Address**
San Francisco	No	http://sfenergymap.org/
Boston	No	http://gis.cityofboston.gov/solarboston/
Los Angeles	No	http://solarmap.lacounty.gov/
New York City	Yes	http://nycsolarmap.com/
Cambridge, MA	Yes	http://www.cambridgema.gov/solar/
District of North Vancouver	Yes	http://geoweb.dnv.org/applications/solarapp/

While the websites listed above tend to be prepared for educational purposes, the examples below help showcase a variety of planning objectives that use LiDAR-based solar mapping.

Prince George

In 2012, Natural Resources Canada in partnership with the City of Prince George developed a model to evaluate the energy, greenhouse gas emissions and cost implications of energy use and supply actions in the residential sector [2]. The model was designed to support the City's Official

Community Plan (OCP), with LiDAR being used to identify candidate buildings suitable for installing solar energy technologies.

The basic criteria to determine whether a building was a suitable candidate for solar technologies were as follows:

1. A building has a minimum 8 m^2 of south-facing roof space with constant plane to install a typical 2-panel solar hot water system.
2. A building has a minimum 25 m^2 of south-facing roof space for the installation of a photovoltaic array.
3. South-facing roof includes the aspects between 135 and 225 degrees, and must receive minimal shadowing from nearby objects.

The LiDAR was used to determine each of the above, and a map was generated showing where the candidate buildings were located within the study area (Figure 2). To assess the potential energy of these residential buildings, solar energy estimates were generated from the RETScreen Analysis Tool [3], and costing identified using quotes from local equipment suppliers.

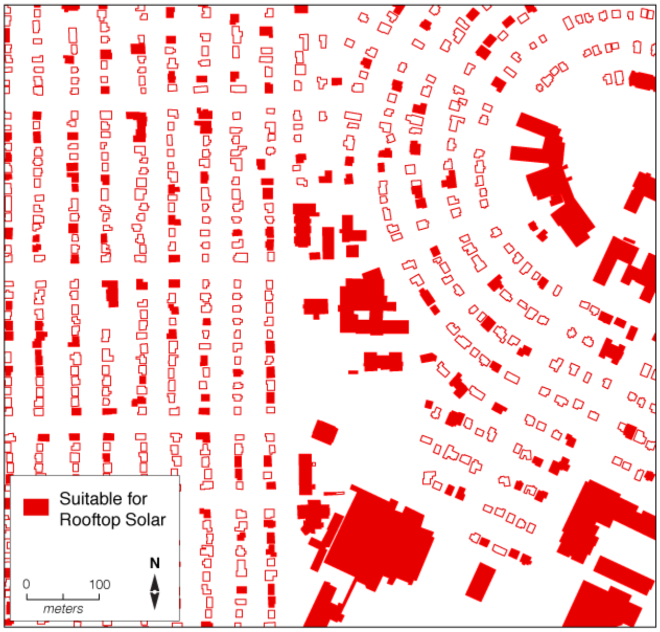


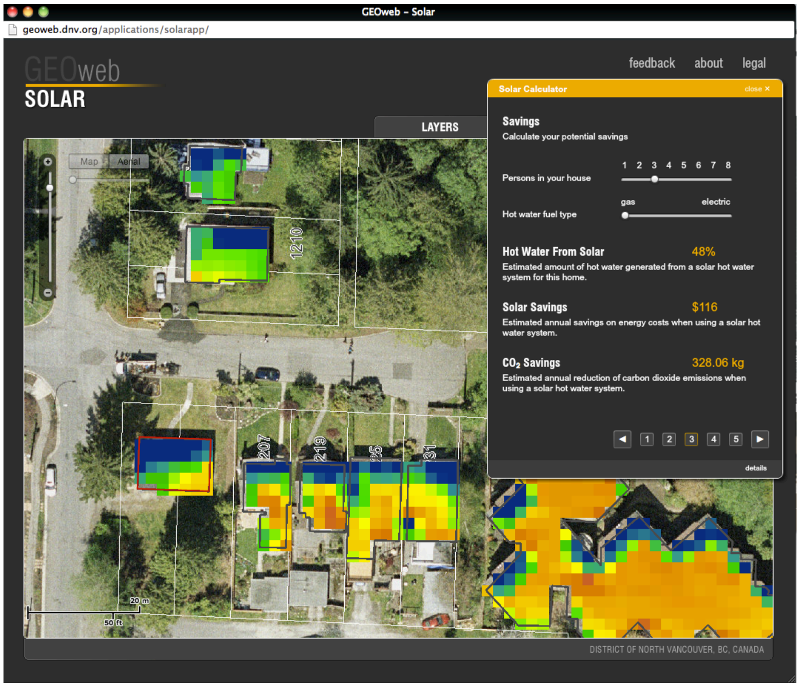
Figure 2. Example of buildings in the City of Prince George that have been identified as suitable candidates for rooftop solar energy systems.

Results of the LiDAR-based analysis indicated that 24% of the existing residential buildings had rooftops suitable for solar hot water installations and 35% could accommodate solar photovoltaics for electricity generation. The results also have important implications for local energy planning and policy, specifically related to building design, since complex roof shapes often associated with new buildings severely restrict the potential for installing rooftop solar systems.

District of North Vancouver

In 2008, the GIS Department at the District of North Vancouver partnered with the Integrated Remote Sensing Studio (IRSS) at the University of British Columbia in order to map rooftop solar energy. As a SolarBC Solar Community, the District of North Vancouver has committed to developing the market for Solar Hot Water, and the map is intended to raise public awareness about the availability of solar energy on every roof in the District. The project used LiDAR data, originally acquired to assess landslide hazards, in order to provide an accurate representation of three-dimensional roof surfaces that was then used to generate a solar map.

The resulting map is freely available online (geoweb.dnv.org/ applications/solarapp), and allows the user to enter an address to obtain a report of the potential for installing a solar hot water system for that location. In addition to a map showing how much solar energy is received at different locations on the roof, the tool also provides an indication of the annual variation of solar energy and allows the user to enter the number of people occupying the house and the type of water heater being used to calculate how much energy and CO_2 emissions can be reduced by installing a rooftop solar hot water system. An example of the Solar Calculator tool is shown in Figure 3.



Solar Calculator close ×

Savings
Calculate your potential savings

Persons in your house: 1 2 3 4 5 6 7 8 (3)

Hot water fuel type: gas electric (gas)

Hot Water From Solar 48%
Estimated amount of hot water generated from a solar hot water system for this home.

Solar Savings $116
Estimated annual savings on energy costs when using a solar hot water system.

CO_2 Savings 328.06 kg
Estimated annual reduction of carbon dioxide emissions when using a solar hot water system.

◀ 1 2 3 4 5 ▶

details

Figure 3. Screenshot of the District of North Vancouver *Solar Calculator* tool showing a selected building, the location of solar energy on the roof (notice tree shading), and an estimate of energy and emissions savings associated with a solar hot water installation.

Metro Vancouver

As part of the Illustrated Guide to Community Energy, prepared by the Collaborative for Advanced Landscape Planning (CALP) at the University of British Columbia, sustainable energy resources were assessed across the entire Metro Vancouver region. Part of this regional assessment included the potential for rooftop solar energy. Since LiDAR was available for only select areas, an approach was used to associate rooftop solar energy potential with land use classes and then applied to the entire region.

The first step in this approach was to find built land-use classes that had LiDAR coverage. In areas where the LiDAR covered multiple polygons of the same class, the polygon with the most representative built structure was used. In each case a solar radiation model [4] was run based on the LiDAR, which accounted for roof shade, orientation and slope in addition to ground-measured atmospheric effects. To apply the results to the entire region, the rooftop solar energy assessment was calculated as the total south facing (or flat) rooftop solar energy per unit land area. The table below (Table 2) shows the modelled south facing roof solar energy (insolation), the percentage of the land covered by south facing (or flat) roof, and the resulting density of south facing roof insolation.

Table 2. South facing rooftop insolation values for Metro Vancouver land use classes.

Land Use Class	**Mean South Facing Insolation ($Wh/m^2/day$)**	**South (and Flat) Roof Area Fraction**	**Rooftop Insolation Density ($Wh/m^2/day$)**
Single Family Dwellings	3371	0.036	121.36
Rural	3375	0.006	20.25
Lowrise	3183	0.178	566.57
Highrise	3080	0.129	397.32
Mixed Use	2719	0.191	519.33
Commercial	3111	0.185	575.54
Industrial	3313	0.248	821.62

From the table above, the mean south facing insolation column shows some variation in the solar energy received on building roofs, which can be attributed to shading and the roof geometry. Even more drastic however, is the variation in the fraction of south facing roof space by land use class. A map of the rooftop solar energy density across Metro Vancouver can be seen in Figure 4. From this information, strategies could be envisioned that might be implemented based on the density of rooftop solar energy. For example, industrial areas tend to have a high density of rooftop space available for solar installations, which may be suited to commercial solar leasing opportunities, while single family areas are perhaps better suited to individual homeowner investments.

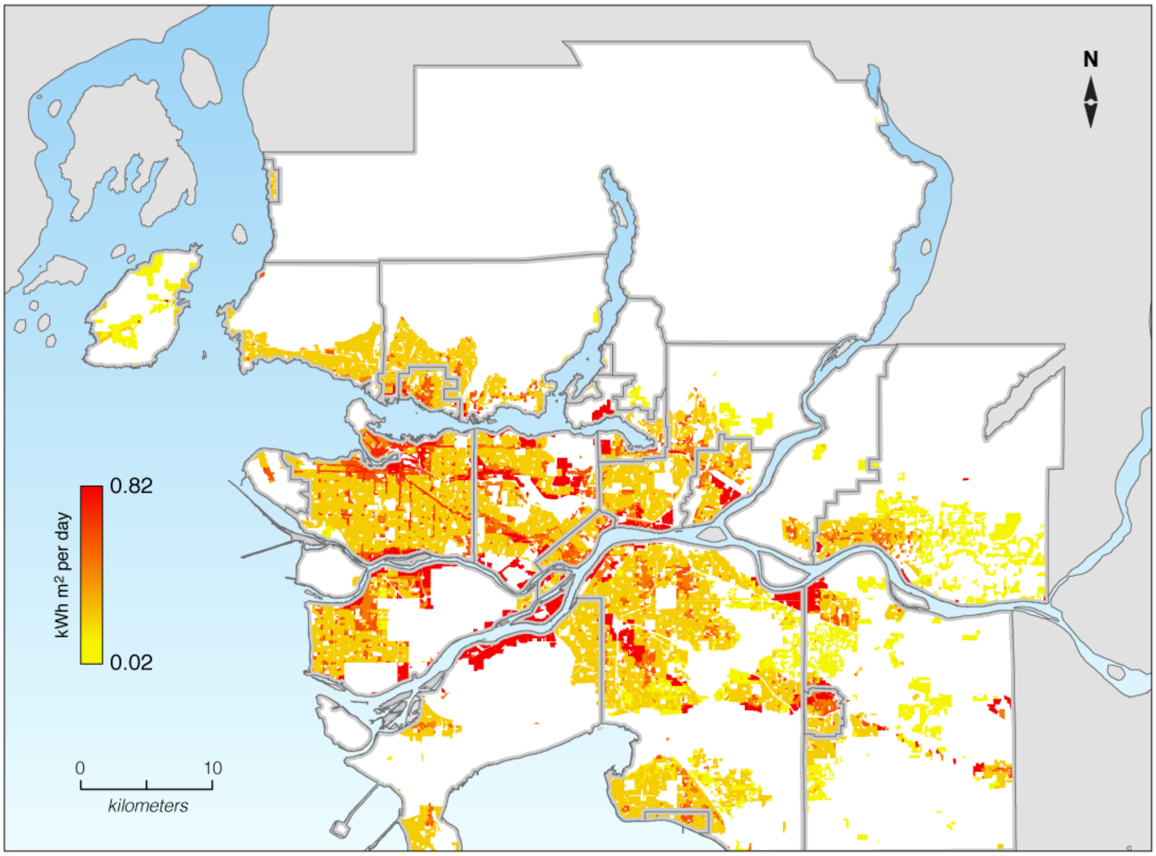


Figure 4. Map of Metro Vancouver showing the south facing rooftop solar energy.

Province-Wide Energy Mapping

Although the cost and data storage requirements of LiDAR may limit its acquisition across the entire province, there is nonetheless a wide range of options for using LiDAR to map and assess various energy resources. At a local level, the following energy resources have been identified as being particularly well suited to assessment using LiDAR [5]:

- Solar
- Wind
- Biomass (forest)
- Hydro

Initiatives designed to share data across levels of government and with utilities can help build the capacity for producing detailed maps of energy resources across British Columbia. Statistical analyses designed to inform broader level analysis from select LiDAR datasets might also help reduce some of the assumptions used in energy resource models and maps. The Metro

Vancouver solar case presented above provides a simple example of how LiDAR-derived information can be scaled to an entire region. In addition, many energy resource assessments prepared in the private sector currently use LiDAR in some capacity, including pre-feasibility studies and site planning. Partnerships with these industries may allow simultaneous data acquisition or data sharing opportunities.

Conclusion and Recommendations

LiDAR provides a valuable dataset that can be used for a variety of applications suited to the planning and management needs of local governments. Although costs may initially appear to be a constraint on LiDAR acquisition, understanding the technology and its various applications is a critical step in preparing a successful business case. This report showcases the specific example of using LiDAR for solar energy mapping. Nevertheless, applications abound and local governments across British Columbia are beginning to acquire LiDAR in addition to more traditional aerial photographs. The following list of recommendations was prepared in consultation with LiDAR vendors and local government staff who have recently purchased LiDAR and is intended to provide important considerations for pre and post LiDAR acquisition:

- Research the range of LiDAR applications to ensure all potential products are understood.
- List LiDAR technical specifications in relation to project objectives to allow the vendor to design an effective acquisition program.
- Combine acquisition of airborne data products (e.g. air photos and LiDAR) to save costs.
- Prepare LiDAR Request for Proposals with a base requirement and additional optional items to allow the vendor to provide a range of potential services.
- Encourage communication between various provincial and municipal departments and contractors in the preparation of a LiDAR acquisition.
- Consult with independent contractors and university research groups to prepare the necessary additional products, since in-house abilities for LiDAR processing may be limited.

References

[1] Ministry of Forests, Lands & Natural Resource Operations - Coastal Flood Plain Mapping Guidelines and Specifications. Ministry of Forests, Lands & Natural Resource Operations - Coastal Flood Plain Mapping Guidelines and Specifications. Final Report, June 2011.

[2] Webster, J., Korteling, B., Boulter, R., Cooper, K., Mohareb, A., Saikali, L., Tooke, T.R. (2012). Evaluating residential energy, emissions and cost scenarios for Prince George's official community plan: ICEM approach, methods, and SCEC3 model results. Natural Resources Canada: Housing, Buildings, Communities & Simulation Group, 108 pages.

[3] http://www.retscreen.net/

[4] Tooke, T.R., Coops, N.C., Christen, A., Gurtuna, O., Prevot, A. (2012). Integrated irradiance modeling in the urban environment based on remotely sensed data. Solar Energy 86, 2923-2934.

[5] Tooke, T.R., Coops, N.C. A review of remote sensing for urban energy system management and planning. Joint Urban Remote Sensing Event (JURSE). Sao Paolo, Brazil, April 21-23, 2013.

Important Terms

Classification	Automated or manual techniques used to assign a label to points in the LiDAR data.
GPS Base Station	A *Global Positioning System* (GPS) receiver located at a known fixed location and used to correct nearby GPS receivers. During a LiDAR flight, base stations are used to improve the accuracy of LiDAR measurements.
Hemispherical Viewshed Modelling	A computer processing technique used to determine the location and angle of obstructions for a location on the Earth.
Insolation	The power of solar radiation energy per unit area and unit time (e.g. kWh/m^2).
Irradiance	The power of radiation energy per unit area incident on a surface (W/m^2).
LAS	A public binary file format for the interchange of three-dimensional point cloud data between users.
LiDAR	Light Detection and Ranging, a technology used to measure the distance to objects.
LiDAR Return	The laser energy returned to the sensor for which coordinates are recorded.
Payload	The part of a vehicle's (e.g. aircraft) load from which revenue is derived.
Photovoltaic	A technology used to generate direct current electricity from solar energy.
Point Cloud	A set of vertices in a three-dimensional coordinate system. Collected LiDAR data is represented as a point cloud with each point containing x, y and z values.
Point Density	The number of LiDAR returns per unit area of ground.
Pulse Rate	The number of laser pulses emitted per unit time, usually measured as kHz (kilohertz).
RMSE	Root Mean Square Error, is an indicator of how much a LiDAR measurement varies from the actual coordinates of an object.
Solar Domestic Hot Water	A technology used to generate hot water for domestic purposes from solar energy.
Sortie	A single deployment in which the aircraft carrying the LiDAR sensor is in flight. A sortie typically lasts about 3 hours, and is dependent on the payload, data storage and processing, distance to airport and aircraft type.