Urban Solar Energy Modeling & Demonstration Technology

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Abstract

Solar energy potential in complex urban environments depends on the available solar irradiance, geographical location & local environment, technology efficiency, and social/economic factors. Many in the utility sectors, including customers, do not understand solar technologies nor do they understand the key issues such as building and roof orientation, shading, and other potential obstacles. The objective of this study is to develop an approach for assessing urban rooftop solar potentials and for the development of a web-based interface. A method was developed using geographic information systems (GIS) and energy modeling software tool in order to assess the urban solar potential of any given neighbourhood from high-resolution satellite imagery (orthophotos). The methodology is comprised of three main sections: (1) rooftop extraction from orthophotos under a GIS platform, (2) determination of suitable rooftop area for PV deployment based upon best published practices, and (3) estimation of peak kW capacity per building rooftop and determination of hourly solar PV electricity generation potential. An easy-to-use, integrated urban solar energy modeling and demonstration technology is currently under development. This web-based interface prototype allows for: (i) quick modeling and prediction of solar energy potentials of selected properties and solar technologies based on building characteristics and its immediate surroundings, and (ii) increasing the awareness and understanding of customers towards the potential benefits of adopting solar technologies. The method was tested on a study area in the City of Woodstock, Ontario. The solar potentials of the sample properties were modeled using the proposed method over a simulated year and the hourly solar estimates were validated using the historical electricity data obtained for existing solar PV installations for the month of June 2011. The accuracy of the modeling technique depends predominantly on the area determined from the orthophoto and the assessment of usable rooftop areas. For future work, additional 3D data will be considered in order to analyze the shadowing effects of surrounding buildings, and an improved automatic algorithm for rooftop extraction will be developed.

Keywords: photovoltaics, GIS, urban solar energy, electricity potential, rooftop extraction

1. Introduction

Solar photovoltaic (PV) energy offers a sustainable way of providing society with a renewable source of energy and reducing their reliance on electricity produced by fossil fuel consumption. Solar energy potential in complex urban environments depends on the available solar irradiance, geographical location & local environment, technology efficiency, and social/economic factors. Renewable energy development and integration into Ontario homes and businesses will have a significant impact on the way electric utilities conduct their businesses going forward. The Green Energy Act [1] sets out a vision, guidelines and expectations of local distribution companies in the Province of Ontario, Canada to support and encourage renewable distribution generation. Many in the utility sectors, including customers, do not understand solar technologies nor do they understand the key issues such as building and roof orientation, shading, and other potential obstacles. These knowledge gaps may lead to missed opportunities or failed installations that could otherwise be avoided with better public awareness. Geographical Information Systems (GIS) are powerful tools for analyzing and visualizing PV systems and have been extensively used in energy applications and infrastructures planning [2].

Recently, there have been many advances in the development of web-based solar estimation tools for quantifying solar PV potential and informing the public the benefits and costs associated with the usage of solar energy. A few examples include Solar Boston, In My Backyard, PVWatts and San Francisco Solar Maps. Web-based PV estimation tools can also be linked with GIS, and have been effectively used for on-site evaluations of PV installations [3,4]. GIS based solar radiation models can be very beneficial for researchers because of its ability to map and interpolate complex spatial information. It also has the ability to integrate environmental and socio-economic data to produce interesting complex scenarios [5,6].

Although there have been many advancements, there still remains a huge need for improved functionality, algorithms and calculation speed for GIS-based solar radiation models [7]. Further research is needed in order to create more complete and detailed 3-D solar radiation models in GIS that are capable of analyzing and considering the complex dynamics within an urban environment such as hourly insolation, vertical facades, inter-reflections between buildings, and HVACs.

The objective of this study is to develop an approach for assessing urban rooftop solar potentials and for the development of an interactive web-based interface prototype. This method will be using GIS and an energy modeling software tool to assess the urban solar potential of any given neighbourhood from high-resolution orthophotos. The developed web-based prototype allows for: (i) quick modeling and prediction of solar energy potentials of selected properties and solar technologies based on building characteristics and its immediate surroundings, and (ii) increasing the awareness and understanding of customers towards the potential benefits of adopting solar technologies. In this paper, the preliminary results are presented from the research project with our industry collaboration partner.

2. Methodology

A methodology was developed using geographic information systems (GIS) and energy modeling software tool in order to assess the urban solar potential of any given neighbourhood from high-resolution satellite imagery (orthophotos). The methodology is comprised of three main sections: (1) extraction from orthophotos based on the GIS platform, (2) determination of suitable rooftop area for PV deployment based upon best published practices, and (3) estimation of peak kW capacity per building rooftop and hourly solar PV electricity generation potential. The following sections will discuss the details of each step of the workflow.

2.1 Overall workflow

The overall process for determining solar potential, depicted in Figure 1, involved three successive stages. ESRI ArcGIS was used on high-resolution orthophotos to extract building rooftops to determine gross surface area. Once the gross surface area of the building rooftops were identified, PV corrective factors were used established from best-published practices to determine usable area for PV installation based upon building typology: residential and industrial/commercial. Lastly, upon identification of usable area for PV deployment, total PV potential was determined using HOMER analysis software tool.

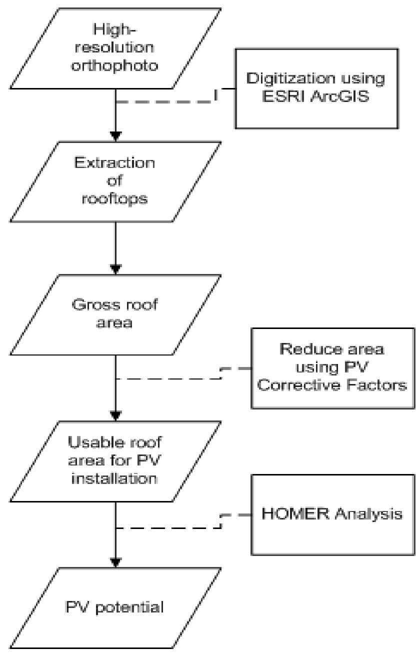

Figure 1. Workflow for assessing rooftop solar potential.

2.2 Gross roof area extraction

The roof extraction procedure was used to extract rooftop polygons from high-resolution digital orthophotos in this study. The size of a PV system installation is highly dependent on the total available rooftop area of each individual building. The total area can be determined using GIS, through a traditional remote sensing approach for identifying and extracting objects of interest in orthophotos. This process is the digitization process, which consists of a manual task of using image analysis and digitizing tools to extract the desired information of interest. The extracted data can be attributed and validated during this geospatial process [8]. General limitations to this traditional approach are that it is a very labour intensive process and time consuming. In progress is the automated extraction process for rooftop identification using the Feature Analyst software tool (extension to ArcGIS) for our web prototype, which will be discussed later in this paper.

2.3 Suitable area for PV deployment

In order to estimate adequate rooftop area suitable for PV installations, a method to eliminate occupied rooftop area was needed. This is because rooftops are occupied by structures such as chimneys, HVACs, and other sorts of equipment, which generally limit the space available for PV installation. Upon review of the literature, a method based upon best-published practices was selected. These best-published practices attempt to accurately estimate the amount of usable rooftop area through the usage of corrective factors or PV access factors to account for areas that are suitable for PV installations. These corrective adjustment factors identified in the literature are derived from professionals in the industry. However, it was found that there is a general lack of agreement between the authors on which PV corrective factors are best, which are highly dependent upon geographical location, climate, and building categories [9]. For example, in Canada, most residential homes have pitched roofs and PV installation is best suited on the south facing surfaces.

There are different PV access factors for different representative building type categories. The main categories identified in the literature were based upon the classification of building type, namely, residential and industrial/commercial [10,11,12]. The major solar access issues identified in these papers were: (1) Roof Type: There are two major types of roofs, flat and pitched. This changes the amount of space available for installation; (2) Structural soundness: This factor accounts for the structural soundness of the rooftop, since PV systems add weight to rooftops. Building code requirements (such as snow loading) and the structural adequacy of the roofs therefore need to be analyzed. It should be noted that this is not an issue for most buildings; (3) Material Compatibility: This refers to the material suitability and aesthetic appeal for PV installation. Again, this issue is hardly considered; (4) Orientation: The direction in which the surface of the rooftop is oriented. This is not an issue for flat rooftops; however, it has a significant impact upon pitched roofs; (5) Shading: This corrective factor accounts for the reduced solar irradiation that may be caused by trees, structural obstructions, such as HVACs and other local structures; and (6) Module Coverage: This factor accounts for the space needed between PV modules, inverters, wiring, access to modules and other maintenance requirements.

Based upon the above factors, the roof space available identified for residential and commercial/industrial buildings for cool climates was 22% and 65% respectively, not taking into consideration the module coverage factor. This is because the module coverage factor was not provided as a percentage value, but was given instead as only a ratio value provided to reduce PV power output. The percentage values for the module coverage factor however, were found in other literature.

Two papers of particular significance were found which provided a percentage value for the module coverage factor. Wiese et al. [13] conducted research about PV access factors for rooftop space in Austin, Texas, based upon the research of Paidipati et al. [12]. A module coverage factor of 75% and 50% were found respectively for residential and commercial/industrial buildings. In another study conducted by Bergamasco and Asinari [14] based on pitched residential and industrial rooftops in Italy, a module coverage factor of 45% was found for both building types. Since both values are not affected by climate and geographical location, both factors were found to be applicable. An average of the two numbers was thus taken, and module coverage factors of 60% and 47.5% were decided upon for residential and commercial/industrial buildings respectively. Taking all these factors into consideration, the total amount of usable rooftop area for residential and commercial/industrial buildings are:

$$\textit{Residential} = \textit{grossArea} \times 22\% \times 60\% = 13.2\% \quad (1)$$

$$\textit{Commercial/Industrial} = \textit{grossArea} \times 65\% \times 47.5\% = 30.1\% \quad (2)$$

2.4 Estimating hourly solar PV output

With the identification of usable rooftop area, the peak kilowatt size capacity of each building needed to be identified. This was simply calculated by dividing the available surface area for installation, by the surface area of an individual panel. Solar panel and inverter specifications were selected based upon the client's desires. This data was then inputted into a solar analysis tool for hourly PV generation potential.

The software tool that was used to perform the solar analysis was the hybrid optimization model for electric renewables (HOMER). HOMER is an energy modeling software tool and was developed by the U.S. National Renewable Energy Laboratory (NREL). It is a very powerful analysis tool that contains optimization and sensitivity analysis algorithms, and is primarily used as an economic optimization model [15]. HOMER has a wide range of capabilities and technology options, and allows the user to model a power system's physical behaviours and its life-cycle costs [16]. It is capable of estimating hourly electricity output based on input parameters for solar PV applications as well as other renewable energy sources. HOMER simulates the PV system by making energy balance calculations for each of the 8760 hours within a year [17].

3. Application: Case study area

This project was done in collaboration with our industry partner, Woodstock Hydro Services, the utility company providing electricity to the City of Woodstock. The City of Woodstock is a city located in Southwestern Ontario, Canada, and covers approximately 43.79 km^2 of land. Woodstock Hydro Services would like to have the capability of modeling solar energy potentials on residential and industrial/commercial building rooftops for their customers. This is in effort to raise better public awareness, understanding and engagement of the current FIT programs. The methodology was to be tested on the buildings selected in consultation with Woodstock Hydro, and validation through the data obtained from the buildings with existing solar installations. Data for six sample properties with existing solar panel installations were provided for the study for the month of June in 2011.

3.1 Available data

A new aerial imagery project titled the South Western Ontario Ortho-photography Project (SWOOP) produced by the Ontario Ministry of Natural Resources was used in the study. The SWOOP project was acquired with 20 cm resolution panchromatic imagery and 40 cm multi spectral in the spring of 2010. The acquired imagery includes approximately 45,000 km^2 in an area covering Windsor to Tobermory, and down to the Niagara region. Imagery acquisition started on the 18th of March, 2010 and was completed on the 28th of April. The accuracy requirement for the ortho tiles was 50 cm horizontal. These digital orthophotos were acquired from the Ryerson University Library. Unfortunately, no 3D data is currently available for the case study area. An image of the case study area is depicted in Figure 2.

Figure 2. High-resolution orthophoto of the City of Woodstock.

3.1.1 Weather data

HOMER uses solar radiation data from the NASA Surface Solar Energy data set, which utilizes monthly averages of solar radiation. The data set used consists of twelve monthly values of the averaged insolation incident on a horizontal surface ($kWh/m^2/day$) and is based upon the latitude of the location. HOMER then creates synthesized values of the data sequence for the full hourly 8760 solar radiation values for the year using the Graham algorithm. The Graham algorithm creates realistic hour-to-hour and day-to-day variations to correlate for differences in weather, and takes into consideration the latitude of the location for calculation. Thus, analysis performed with this data will not necessarily perfectly reproduce the actual characteristics of the solar radiation for the location.

3.2 Web interface development & automated rooftop extraction

The development of a user-friendly solar radiation technology will promote the usage of renewable energy in Woodstock and other communities. This web-based solar potential estimation tool is an effort towards better serving the community, and enhancing the customers' understanding of the potential benefits of adopting solar technologies. Currently, a web-based prototype is in progress for the analysis of solar potential for all of the buildings in the City of Woodstock based upon the developed integrated workflow proposed in this study. Figure 3 provides a screenshot of the developed web-based prototype in progress.

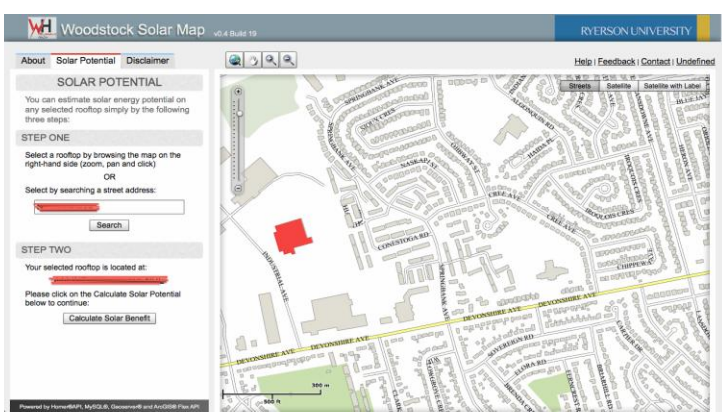

Figure 3. Screenshot of the web-based interface

This interface allows for the: (i) quick modeling and prediction of solar energy potentials of selected properties and solar technologies based on building characteristics and its immediate surroundings, and (ii) increasing the awareness and understanding of customers towards the potential benefits of adopting solar technologies. It will also inform the public about the savings they could potentially receive from the feed-in-tariff program. This web-based interface technology uses an automated rooftop extraction procedure, an expansion to the developed methodology of this paper.

3.2.1 Automated rooftop extraction

The automated rooftop extraction procedure used was the Feature Analyst (FA) image recognition program (an extension to ArcGIS). It recognizes spatial and spectral information and uses inductive learning algorithms and methods to model feature recognition [8]. FA uses a machine learner function to learn how to recognize certain images on an orthophoto and to extract those features based upon attributes such as color, texture, orientation, etc. [18]. Users of FA need to supply training sites for each feature of interest. The software then uses these sites to find areas in the image that are similar to the points of interest.

Currently, a training set of 100 rooftops with a variety of colors and types were digitized as a training set for FA. FA extracts features based on a number of input representations and algorithms, and the algorithm used in this study was the Manhattan pattern. All the rooftops in the case study area were extracted using this automated process. Figure 4 depicts the rooftop images extracted using FA.

Figure 4. Rooftops extracted using Feature Analyst.

A few difficulties have been encountered so far with the automated rooftop extraction procedure. First, there are spectral similarities between grey, flat rooftops on commercial and industrial buildings, parking lots, roads and pavement. Second, there is a large variation of roof types in various colors, materials and also shades of grey. These two issues make it difficult for the machine learner to differentiate between certain features, and thus manual hand digitization is required to override the errors made by the program. Further work is recommended in this area for the development of a better algorithm in order to increase detection accuracy of the program.

4. Preliminary results & discussions

4.1 Property estimates

The methodology was applied on the buildings selected in consultation with Woodstock Hydro, and the results were validated through the data obtained from buildings with existing installations. Data for six sample properties with existing solar panel installations were provided for the study for the month of June in 2011. This data included the number of PV panels installed, size of the PV array installation, inverter size, model numbers, and hourly PV read values for June 2011. In order to maintain confidentiality of the addresses and sensitive information used in this study, the properties will be labelled with a letter instead. Table 1 provides a brief summary of the information pertaining to the 6 sample properties, their estimated values, and their existing installations. The bar graph in Figure 5 illustrates the comparison between the read meter outputs for June 2011 and to the estimated solar PV output for the month of June.

Table 1. Building property parameters and estimates

Property	Building Type	RoofGross Area (m^2)	Estimated Usable Area (m^2)	Estimated # of panels	Estimated PV Array Size (kW)	Actual # of panels	Actual PV array size (kW)
A	Residential	202	26.67	15	2.85	14	2.66
B	Residential (multi)	1805.9	238.38	140	32.2	50	11.5
C	Residential (multi)	1164.09	153.66	90	20.7	50	11.5
D	Industrial	2262.12	680.90	400	94	25	5.875
E	Residential	184.39	24.34	14	3.43	18	4.41
F	Residential	178.32	23.53	13	2.47	14	2.66

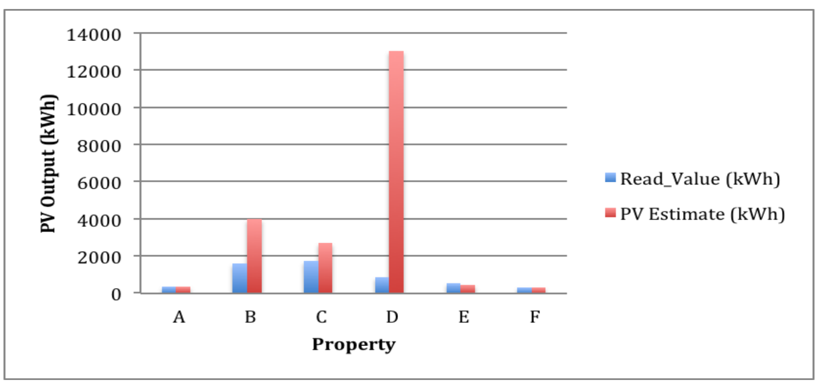

Figure 5. Read values from June 2011 vs. the estimated solar PV output for the month of June

The simulated PV output for the residential properties of Properties A, E and F matched with 93% accuracy for the month of June. Properties A, E, and F are single-family residential properties with surface area close to $200m^2$ with pitched rooftops. For preliminary results, this is a good sign that the PV corrective factors used to determine usable area for residential homes is of significant accuracy. Properties A and F estimated the number of panels within plus or minus one of the actual number of panels installed. Property E underestimated the number of solar panels by four. Reasons for this occurrence can be due to the fact that the PV corrective factors used to determine usable surface area are based upon the design of an average cold climate North American home, doesn't account for building anomalies, and takes into consideration for PV installations on only the south facing facades.

There are significant variations in the estimates for properties B, C, and D. Properties B, C and D are all larger than 1000m^2. Properties B and C were modeled as residential homes, but they do differ in characteristics from properties A, E, and F. Properties B and C are multi-residential homes, and occupy a large amount of space. The measured gross rooftop surface area of properties B and C was 1805m^2 and 1164m^2 respectively. These rooftops are comprised of some flat areas as well as some pitched areas. For both cases, the developed methodology overestimated the solar panel installation from the actual installed capacity. The reason for this is because the methodology was developed to account for the utilization of the full capacity of the rooftops, whereas, in real life, the full capacity of the rooftops may not be used due to various factors (such as cost of installation, aesthetic appeal, etc.). Also, the development of more refined PV corrective factors for larger residential home properties would be ideal for the future.

Property D was the only industrial/commercial rooftop building type in the given sample properties. This property only had 25 solar panels installed on its rooftop, even though its gross rooftop area was well over 2000m^2. Cleary, the surface area was not utilized to its full capacity when Property C, which is a property that is approximately half the size of Property D, has 50 existing solar panels installed on its rooftop. If Property C was to utilize its rooftop to its maximum potential, it could fit approximately 400 panels on its rooftop.

4.2 Weather variations

HOMER analysis was performed on all 6 properties to see what solar PV potential estimates would be generated from the methodology. The estimates were then compared to the actual solar panel read values for June 2011 for validation. Figure 6 provides a graphical example of the solar PV estimates generated for Property A, clearly illustrating the peaks in hourly generation potential and seasonal trend.

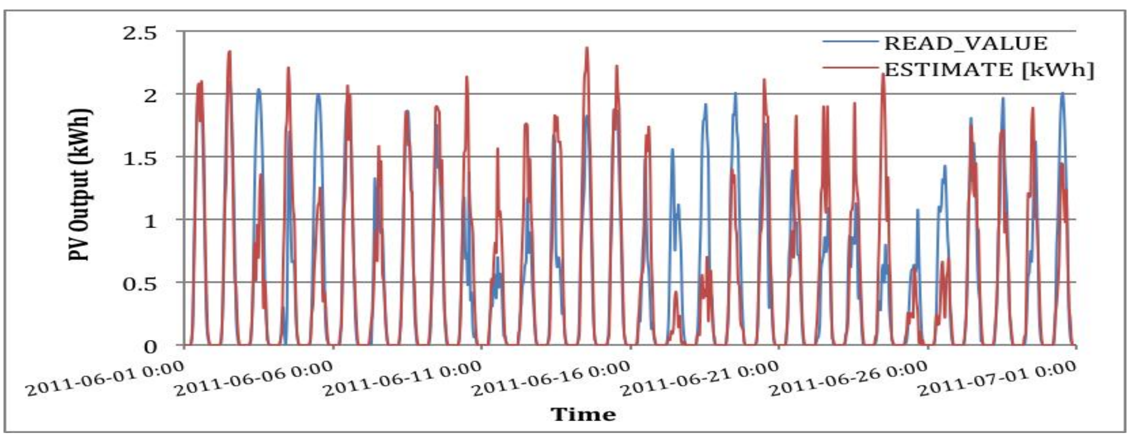

Figure 6. Estimated hourly solar generation potential for Property A and actual read meter read value for June 2011.

Upon closer inspection of Figure 6, it is clear that there are some differences in peak solar generation between the actual read meter values and the simulated values from HOMER. This trend is also evident in the graphs of the 5 other properties. The reason for this is because HOMER uses simulation weather data that is derived from long-term weather averages, which represents average weather conditions, and will therefore not be able to account for anomalies. Also, the simulation program automatically introduces variations into their estimates to account for cloud cover and other weather patterns. Ideally, in order to perform a more accurate analysis, weather data from June 2011 should be used instead for analysis. It would potentially explain the difference in daily peak values. This argument also illustrates the importance of accurate weather data for solar simulations. Various weather stations were contacted for solar irradiation data for the City of Woodstock in 2011, however, that data is currently unavailable due to a time delay in production.

5. Conclusions & future work

This study presented an approach for the assessment of urban rooftop solar energy potentials and for the development of an interactive web-based interface. The methodology was based on three main phases. In the first phase, ESRI ArcGIS was used on high-resolution orthophotos to extract building measurements in order to determine gross rooftop area. Once the gross rooftop surface area of the building was identified, the suitable area available for PV deployment based upon best-published practices was employed. This process also required the categorization of buildings by type, namely, residential and industrial/commercial. Lastly, upon identification of the usable surface area, the estimation of the peak kW capacity per building rooftop and hourly solar PV electricity generation potential was determined using HOMER.

This project was done in collaboration with our industry partner, Woodstock Hydro Services, the utility company providing electricity to the City of Woodstock, Ontario. The method was tested on 6 sample properties selected in consultation with Woodstock Hydro, and validated using historical electricity data obtained from existing solar panel installations. It was found that for single-family residential properties, the solar output matched with an accuracy of 93% for the month of June 2011. For multi-residential and industrial/commercial, the developed methodology over-predicted the actual solar installations of the buildings. This is due to the fact that our estimates do not consider the potential irregularity of the geometric shape of the rooftop usable area. We may also think about the possibility of the current installations not fully utilizing the usable areas, something which we didn’t check for on those properties. The assessment of usable roof space is based upon the maximum utilization of the space available, and these assessment factors are based on the average north American building codes.

An interactive web-based interface prototype has been developed for technology demonstration. The web-based prototype uses an automated rooftop extraction procedure based upon image recognition and machine learning. The development of this user-friendly solar radiation technology will hopefully promote the usage of renewable energy in Woodstock and other communities. Its ultimate goal is to inform customers and the public about the savings they could potentially receive from the FIT program in Ontario.

This study has presented a methodology for the assessment of urban rooftop solar potential, and the development of a prototype web-based interface. Limitations in this study can be mainly attributed to weather data, gross area determined from the orthophotos, and the assessment of usable rooftop areas from PV corrective factors. A larger sample size would be ideal for future testing as well, since data was only obtainable for 6 sample properties. Access to more data would increase the validity of this study greatly. It is recommended for future work that access to a 3D model of the case study area would improve the accuracy of the study and help with analyzing the shadowing effects of surrounding buildings and local obstructions. Also, an improved FA algorithm for the automated extraction of rooftops is recommended, as well as more studies on PV corrective factors, especially for multi-residential buildings.

6. References

[1] Ministry of Energy and Infrastructure, "Green energy and green economy act", 2009, Retrieved June 2, 2012, from http://www.ontla.on.ca/web/bills/bills_detail.do?locale=en&BillID=2145&detailPage=bills_detail_the_b

[2] Ramirez-Rosado I.J., Fernandez-Jimenez L.A., Monteiro C., Garcia-Garrido E., Zorzano-Santamaria P., "Spatial long-term forecasting of small power photovoltaic systems expansion", *Renewable Energy*, Vol.36, 2011, pp.3499-3506

[3] Hofierka J., Kaňuk, J., "Assessment of photovoltaic potential in urban areas using open-source solar radiation tools", *Renewable Energy*, Vol. 34, Iss. 10, 2009, pp.2206-2214

[4] Suri M., Huld T.A., Dunlop E.D., "PV-GIS: a web-based solar radiation database for the calculation of PV potential in Europe", *International Journal of Sustainable Energy*, Vol. 24, Iss. 2, 2005, pp.55-67

[5] Suri M., Hofierka J., "A new GIS-based solar radiation model and its application to photovoltaic assessments", *Transactions in GIS,* Vol. 8, Iss. 2, 2004, pp.175-190

[6] Nguyen H. T., Pearce J. M., "Estimating potential photovoltaic yield with r.sun and the open source geographical resources analysis support system", *Solar Energy,* Vol*. 84*, Iss. 5, 2010, pp.831-843

[7] Fu P., Rich P., "Design and implementation of the solar analyst: An ArcView extension for modeling solar radiation at landscape scales", Proceedings of the Nineteenth Annual ESRI User Conference*,* 1999

[8] Blundell J. S., Opitz D.W., "Object recognition and feature extraction from imagery: The Feature Analyst® approach", *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* 2006

[9] Vardimon R., "Assessment of the potential for distributed photovoltaic electricity production in Israel", *Renewable Energy*, Vol. 36, 2011, pp.591-594

[10] Chaudhari M., Frantzis L., Hoff T. E., "PV grid connected market potential under a cost breakthrough scenario*",* Navigant Consulting, Inc., 2004, Retrieved October 13, 2012, from http://www.ef.org/documents/EF-Final-Final2.pdf

[11] Frantzis, L, Graham S., Paidipati J., "California rooftop photovoltaic (PV) resource assessment and growth potential by county No. CEC-500-2007-048). San Franciso, CA, USA: Navigant Consulting Inc., 2007

[12] Paidipati J., Frantzis L., Sawyer H., Kurrasch A., "Rooftop photovoltaics market penetration scenarios" No. NREL/SR-581-42306). Burlington, Massachusetts, USA: Navigant Consulting Inc., 2008

[13] Wiese S., Long E., Libby L., Ryan B., "A solar rooftop assessment for Austin", SOLAR 2010 Conference Proceedings, Phoenix, USA, 2010.

[14] Bergamasco L., Asinari P., "Scalable methodology for the photovoltaic solar energy potential assessment based on available roof surface area: Application to Piedmont region (Italy)", *Solar Energy,* Vol. *85*, Iss. 5, 2011, pp.1041-1055

[15] Brown S. J., Rowlands I. H., "Nodal pricing in Ontario, Canada: Implications for solar PV electricity", *Renewable Energy,* Vol. 34, Iss. 1, 2009, pp.170-178

[16] Lambert T., Gilman P., Lilienthal P., "Micropower system modeling with HOMER", In F. Farret, & M. Simões (Eds.), *Integration of alternative sources of energy*, John Wiley & Sons, Inc., 2006, pp.379-418

[17] National Renewable Energy Laboratory (NREL). "Getting started guide for HOMER version 2.1.", 2005, Retrieved August 15,2012, from http://homerenergy.com/pdf/HOMERGettingStarted210.pdf

[18] Wiginton L. K., Nguyen H. T., Pearce, J. M., "Quantifying rooftop solar photovoltaic potential for regional renewable energy policy", *Computers, Environment and Urban Systems,* Vol. 34, Iss. 4, 2010, pp.345-357

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