# Assessing the Energy Generation Potential of Photovoltaic (PV) Solar Panels on the Rooftops of Places of Worship Within the Halifax Regional Municipality (HRM)

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# 1.0 Introduction

## 1.1 Motivation

Clean and renewable sources of energy have become a trending topic in today's society, as more pressure is put on industry and individuals alike to reduce their carbon footprint and use of fossil fuels. With energy demand predicted to increase globally until at least the year 2030 (Issac & Vuuren, 2008), there is much potential for renewable energy to play an increasing role in energy production. With an average annual growth rate of approximately 37% worldwide, from 1995-2005 (Denholm et al., 2007), photovoltaic (PV) solar energy has matured into a viable source of renewable energy moving forward (Wiginton et al., 2010). Currently, Nova Scotia relies on coal-fired power plants for approximately 60% of the province's electricity production (Nova Scotia Power, 2014), but has set a goal of reducing its greenhouse gas emissions by at least 10% below the 1990 levels, by the year 2020 (Government of Nova Scotia, 2014). As of 2012, Nova Scotia's emissions have been reduced by approximately 0.5-0.6% from 1990 levels (19.1 to 19.0 Mt $CO_2$ equivalent) (Environment Canada, 2014), meaning a divestment from coal power towards green energies, including solar power, could contribute to achieving this fast approaching deadline.

Small-scale solar projects catering to residential properties have begun to materialize across Nova Scotia and specifically in the Halifax Regional Municipality (HRM) for the past few years, with incentives like net metering, which will be defined in the next section. A prime candidate for this incentive could be the rooftops of places of worship within the HRM, as many religious buildings tend to have large roofs that are at ideal angles towards the sun (45°), meaning installation could be simple and solar collection could have a lot of potential. However a potential limitation with this scenario is that Nova Scotia Power will only allow a property to install a solar array large enough to generate the same amount of power as is typically used by the property in question on an annual basis (Nova Scotia Power, 2014). This is a potential issue because if a place of worship is not used for large periods of time throughout a seven day week, meaning the building's energy demand is low, a solar array being installed on the rooftop would only be large enough to supply this average energy demand, while the rest of the roof, and potential energy, could be left out of the picture. Subsequently, it is possible an important niche for solar energy production may be overlooked with regards to the rooftops of these religious buildings, whether they are used frequently or not, and it is because of this that I have proposed this study to examine the energy generating potential of these buildings to determine the extent to which they could be energy neutral, or even net energy producers. I will be examining the energy potential of installing photovoltaic (PV) solar panels on the rooftops of places of worship in the HRM.

## 1.2 Background

This study is focusing on photovoltaic (PV) solar panels. The panels convert light from the sun (photons) into electricity (voltage), a process known as the photovoltaic effect, by moving loose electrons across an electric field and through conducting wires to form a circuit (Renewable Energy World, 2014). Once this circuit has been completed the current of electrons can be sent to a battery where it is stored, or used as energy on the spot or transmitted through the electricity network to other electricity users immediately. A solar panel consists of many individual cells, typically made of silicon, each of which has a positive and negative layer that helps to catch photons, which free the electrons within the cell, starting the circuit (Renewable Energy World, 2014). When a group of solar panels are installed together in one location, such as a rooftop, it is referred to as a solar array (Shen, 2009). Solar PV technology has seen a steady increase in implementation and usage to the point that it has surpassed wind turbines as the fastest growing energy technology worldwide (Pinkse & van den Buuse, 2012). If the current growth of the industry continues, it is speculated that solar PV energy could become one of the most reliable energy sources, as an alternative to fossil fuels, on a global scale (Denholm et al., 2007).

For the purpose of this study, the term “place of worship” is defined as any building where religious groups congregate for religious ceremony and worship, such as churches, mosques, temples, synagogues and monasteries.

This study also examined the net metering system within Nova Scotia, a program established to encourage individuals to purchase small-scale renewable sources of energy (in this case PV solar panels) to install on their residence, with the aim of offsetting energy costs and when possible, selling energy back to the grid for a credit against future energy consumption (Nova Scotia Power, 2014). The annual electricity production of the PV solar panel must be not more than the amount of electricity being consumed by the building, and not exceed 1 megawatt (MW) of power production capability (Nova Scotia Power, 2014). Once the panels are operational, the energy generated is used to power the home or building, and any additional energy that is generated but not used can be sold back to the grid for others to use. At the end of the month Nova Scotia Power will assess your energy used and energy produced and any surplus in energy produced will result in a credit to the owner/ customer on their next bill. At the end of the year if more energy has been produced than consumed, then a cash payment is made to the owner at a price equal to the price of energy being provided from the grid (Nova Scotia Power, 2014).

The total amount of energy that can be generated by a PV array is strongly based on the amount of solar radiation that will hit the panel(s). To optimize solar radiation, in Nova Scotia PV panels should be installed at approximately a 45° angle from the horizontal and be south facing, or within 45° of south (Calabro, 2013). When installing PV solar panels, shade must also be taken into consideration, as any time that the solar panel is in partial or complete shade, will reduce how much sunlight, and ultimately how much energy can be produced (Connect Green, 2011). The optimal time for solar collection will be through the summer months when the days are longer and the sun is higher up in the sky, however solar radiation is still emitted and captured through the winter months, allowing for 12 months of solar energy production with optimal conditions (Connect Green, 2011).

## 1.3 Summary of Literature

Currently there is very little literature pertaining specifically to the topic of PV panels installed on the rooftops of places of worship. Although this was not known at the inception of this project, it serves as motivation and reasoning for undertaking this study to help broaden the amount of knowledge and facts regarding solar energy potential. Currently, it does not appear that any similar study has been conducted in Nova Scotia or abroad, specifically pertaining to places of worship, however rooftop solar projects as a broad topic has become a source of increasing interest in past years as the industry has grown.

While studies and findings have been contributing to the growth of large-scale solar projects, smaller scale projects on a residential level still appear to have knowledge gaps regionally. In Ontario, Canada, where a similar renewable energy incentive program known as a feed-in tariff (FIT) is in place, Wiginton et al., 2010 identified the lack of a database regarding roof area in most regions as the main reason that PV potential is not known for rooftop projects. With technologies like geographic information systems (GIS) and improved satellite data, rooftop PV potential could prove to be a critical utility for city planning and accommodating grid capacity in growing cities within Ontario (Wiginton et al., 2010). In Europe, many studies done to assess rooftop PV potential on residential buildings have led to concrete findings regarding total energy potential for cities across Europe, helping the nations plan their energy options for the future (Bergamasco & Asinari (a), 2011; Ordonez et al., 2010).

## 1.4 Introduction to the Study

This study is focused on gathering data regarding the feasibility of generating energy from PV solar panels on rooftops in the HRM. My research question is: How much potential is there for generating electricity through solar photovoltaic panels on the rooftops of places of worship in the HRM?

The main objectives of this study are: (1) to acquire enough data regarding solar PV potential to be installed on the rooftops of places of worship in the HRM to extrapolate how much energy could potentially be produced within the region. By accumulating this data it is hoped that a preliminary database of solar energy potential can be produced, that clearly defines how much clean energy could be generated from solar energy from this building type, offsetting the use of fossil fuels and greenhouse gas emissions within the HRM.

A further objective within the study is: (2) to assess whether or not the energy demand compared to the potential energy generated by buildings of religious worship could justify having a larger solar array installed on the roof. This would address the issue that some large rooftops may be able to support an array with more energy generating potential than the building's energy demands. The guidelines of Nova Scotia's net metering agreement do not currently allow this, but these buildings could represent an exception to the rule. Because many places of worship have rooftops that are larger than most residential roofs, assessing the HRM's solar PV energy potential of the rooftops could identify a niche of clean, reliable energy, contributing to the divestment of fossil fuels within Nova Scotia.

I predict that: (1) data will suffice to clearly demonstrate that solar energy potential from places of worship in the HRM is viable and worth further examining, and (2) at least some, if not many, places of worship within the HRM can be net producers of electricity from solar power.

The scope of this study focused on the HRM from a spatial standpoint for the assessment of places of worship. The ability to use the data that was collected from this study to assess solar energy potential of all places of worship in Nova Scotia would be ideal, but is an undertaking beyond the capacity of this study. The data from the HRM will thus be used to assess the region's solar generation capabilities, generated from the places of worship, as well as a precursor to patterns and potential energy generation on a provincial scale. On a temporal scale, the majority of the data collection was done from January through March, when conditions were favourable to be outside and on site. However, the use of satellite technology and online aerial photography helped bridge the gap that arose from data collection being hampered due to bad weather conditions.

## 1.5 Summary of Approach

The research question was addressed by using online databases of photography and solar energy suitability, using programs like the HRM Solar Map and Google Earth/ Maps imaging to investigate rooftops. Furthermore, ground-truthing was performed to assess the sites first hand, in an effort to build upon the information that was gathered digitally. By understanding the dimensions of each property and the angles at play for each individual rooftop that was assessed, calculations were done to determine how many PV solar panels could be installed on each individual rooftop, how much it would potentially cost, and the total energy that can be generated once the panels are operational.

# 2.0 Literature Review

## 2.1 Introduction

Around the world there is currently a great deal of interest in finding alternative sources of energy to fossil fuels, with an emphasis on clean, renewable energy sources. With an average annual growth rate of approximately 37% worldwide from 1995-2005 (Denholm et al., 2007) and a growth rate of 15-20% in the past decade (Tester et al., 2012), PV solar energy is on a steady path to becoming a reliable and clean source of energy on a larger scale (Wiginton et al., 2010). In Canada the largest solar potential is found in Ontario, Quebec, and the Prairies (Canadian Centre for Energy Information, 2014), however the focus of this study is in the Halifax Regional Municipality (HRM), where solar energy potential is not far behind from the leading areas (Natural Resource Canada (a), 2013). With the implementation of government incentives, PV use on a smaller, single residential scale, has gained popularity, leading to more PV solar panels being installed on residential rooftops over the past two years (Halifax Regional Municipality, 2014). As Nova Scotia continues to try to achieve a goal of reducing greenhouse gas emissions by least 10% lower than 1990 levels by the year 2020, implementation of clean energy sources like PV solar energy around the HRM will play a growing role in achieving success (Government of Nova Scotia, 2014). Since the 1970's, PV systems have been the focus of many studies regarding efficiency and energy potential, leading to many improvements within the sector, with an emphasis on rooftop application of PV panels on buildings within cities (Tester et al., 2012). Although there are numerous studies of rooftop PV solar panels, the vast majority focuses on European and Asian cities, with the exception of studies by Natural Resources Canada (Luukkonen et al., 2013; Poissant & Vikis, 2013). There is a significant gap in knowledge and research regarding rooftop PV solar panels and the subsequent energy potential for the HRM and Canada as a whole.

## 2.2 Literature Search Approach

The search method of this literature review is topic based, focusing on the key components of the field, creating a well-rounded summary of the PV industry. The databases that were used for this search include Web of Science, Science Direct, and Google Scholar, as well as the use of books found in the Killam Library collection at Dalhousie University. To get the most well rounded accumulation of data and examples for PV rooftop projects, no limitations were placed on the searches with regards to geographic locations.

## 2.3 Solar Energy Potential in Canada

The geographic location of the HRM and the province of Nova Scotia allows for enough solar radiation throughout the year to make residential PV panel installation viable (Natural Resource Canada (a), 2013). Although the areas boasting the best potential for PV installation based on annual solar insolation (exposure to the sun's rays) are in parts of Ontario, Quebec, and the Prairies (Canadian Centre for Energy Information, 2014), Nova Scotia still receives enough solar radiation annually to be considered one of the better locations for PV solar panel installation (Natural Resource Canada (a), 2013). With an annual PV potential of just over 1000 kilowatt-hours per installed kilowatt of capacity (kWh/kW) for south facing PV panels with a tilt of ~45°, Halifax is not far off from the leader of major Canadian cities in PV potential, in Regina, Saskatchewan (~1300 kWh/kW) (Natural Resource Canada (a), 2013; Pelland et al., 2006). When comparing these statistics to other major cities on a global scale, Cairo, Egypt has the highest (1635 kWh/kW) while London, England has one of the lowest potentials with 728 kWh/kW, placing Nova Scotia and the HRM somewhere in the middle of the rankings (Natural Resource Canada (a), 2013; Pelland et al., 2006). This data helps to reinforce that Nova Scotia receives enough solar radiation for a resident in the area to consider solar energy as a viable option, and can become much more useful once coupled with other site-specific technologies like solar mapping.

Solar mapping technology allows for easy and accurate assessment of potential solar installation sites by looking at a site on a much smaller scale, mapping solar radiation that is being cast on each individual building (Gadsden et al., 2003). The technology predominantly used to create these assessments is Light Detection and

Ranging (LiDAR), a remote sensing method done from an airplane using a laser, scanner, and a GPS receiver, to perform an aerial assessment, which is then paired with site data relevant to the assessment being done, to produce an accurate and precise topographical map of an area based on the characteristics that are being studied. (National Oceanic and Atmospheric Administration, 2014). This technology is useful because the topography of the surface of a place being surveyed will affect how and if shadows will be cast throughout the day and year. By better understanding how hills, buildings, trees, and tall objects are situated with respect to the area being surveyed, a more accurate and representative assessment of solar generating potential can made. Once these maps are created, the public can make use of them to better understand how much sunlight is cast on an area annually. The residential sector plays an important role in cities' electricity consumption, and being able to assess an individual site, or larger areas through solar mapping, constitutes a valuable analytical tool to predict energy capabilities and production for an individual building or area (Santos et al., 2014). The use of this technology has been implemented to successfully determine the solar potential of entire regions and individual sites, helping city planners to better understand where solar energy has the most potential (Redweik et al., 2013). Furthermore, the ability to predict and realize the potential for solar energy contributes to understanding where energy will come from as cities and areas begin to expand and experience a rise in local population, leading to better planning of not only the layout of new developments, but improved structure to the energy grid (Rylatt et al., 2001). With this improved knowledge of solar potential through mapping, the capacity for solar PV energy has steadily grown in Canada over two decades leading to more efficient PV panels, at a more affordable price to the consumer (Luukkonen et al., 2013).

### 2.4 The Growth of the PV Market

The production of PV modules worldwide has seen a steady increase of about 15-20% per year over the past two decades, while the price of PV modules has consistently dropped over the same period (Tester et al., 2012). Where once the major arguments against PV technology were its high prices and low efficiency, the constant growth of the industry has done away with that notion, with analysts predicting the industry to be worth around $100 billion per year by 2020 -2030 (Hoffmann, 2006). A major contributor to the growth of the industry has been the falling price of installing PV panels, with 2002 installation prices close to $1,000 per $m^2$, falling to closer to $500 per $m^2$ by 2010 (Tester et al., 2012).  From a governmental standpoint, concerns about global climate change and energy security have led to increased pressure on leaders to diversify their countries' energy supply, which has helped to make PV technology a more attractive source of energy, and fueled the growth in the global PV market (Pinkse & van den Buuse, 2012). From a Canadian perspective, the PV market has seen an annual growth of about 25% per year from 1994 – 2008, while in 2010-2013 the market grew by 202%, 49%, and 50% respectively, due primarily to incentive programs (the introduction of a feed-in tariff in Ontario is the cause of such a huge growth in 2010) (Luukkonen et al., 2013). These major increases in the Canadian market have led to an average price drop of almost 30% per year, and on a global scale, the PV market is now one of the highest recipients of renewable technology investments (Poissant, & Vikis, 2013). All of these positives currently being experienced within the PV market have contributed to small-scale PV installations becoming much easier to accomplish, giving property owners access to photovoltaic solar panels that are more affordable and efficient.

While growth in the PV market has led to more interest from homeowners, the use of photovoltaic technologies in other energy sectors and industries is an indication of the reliability of solar power. A significant reduction in greenhouse gas could be seen by applying renewable energy based systems into industries, and among all the renewable energy sources, solar energy is emerging as having the most promise (Mekhilef, Saidur, & Safari, 2011). Within the energy sector, it is no secret that relying solely on non-renewable sources such as fossil fuels poses a major problem for long-term sustainability of a company, which was first realized during the oil crisis of the early 1970's (Pinkse & van den Buuse, 2012). British Petroleum (BP) is one of the biggest oil and gas companies in the world, but has the longest history of investing in the development and commercial usage of solar energy, dating back to the 1980's, as well as establishing the world's largest vertically integrated solar PV firm in 1999 (Pinkse & van den Buuse, 2012). While other large oil and gas companies like Shell have also made investments in the research and design of PV technology as part of a diversification strategy, their investments have exhibited "erratic patterns with sudden changes in perceived prospects of solar as a future growth market (Pinkse & van den Buuse, 2012). However a 2011 report from the Intergovernmental Panel of Climate Change (IPCC) stressed the importance of energy companies investing in renewable energies to not only reduce greenhouse gas emissions from fossil fuels, but also to make renewable energy sources more available, better developed, and ultimately, cheaper and more reliable

(Intergovernmental Panel on Climate Change, 2011). Tester et al., 2012, elaborate beyond this point, highlighting that PV technology is reliable and affordable enough to be implemented within the structure of buildings themselves, pointing out that external walls, windows and roof structures could all become solar collectors, a concept which has already gained momentum, with incentives and subsidies being offered by the government in the Unites States, parts of Europe, and Japan (Tester et al., 2012). As PV technology becomes more commonplace throughout society, there is a greater chance of developing a more dependable and comprehensive energy source.

## 2.5 Comparing Different PV Models

As PV technology has improved over the years, addressing different site conditions and buyer needs has led to the development of different types of PV panel models to accommodate varying conditions. Currently there is a large variety of materials used to create PV solar panels, however the three most common types of PV panels are all silica-based (Si): single crystalline silicon (s-Si), polycrystalline silicon (p-Si), and amorphous crystalline silicon (a-Si) (Carr & Pryor, 2004). As of 2009, two-thirds of all PV installations used s-Si or p-Si, with the main trade off being efficiency versus manufacturing cost (Tester et al., 2012). The s-Si silicon panels have the highest efficiency, with each cell made of one piece of crystalline silicon, however this also makes them the most expensive panel to produce (Pinkse & van den Buuse, 2012; Tester et al., 2012). The p-Si panels are on average 2-3% less efficient than s-Si panels, however because they are made from multiple crystals of silicon, it is much cheaper to produce them. Therefore, most commercial installations use p-Si because of the larger array being installed, while s-Si is used where square footage is at a minimum, to maximize energy efficiency (Tester et al., 2012). Finally, a-Si panels were developed as an alternative to crystalline panels in an attempt to bring down manufacturing costs, which has led to a much slimmer solar panel made of a thin coating of amorphous silicon on an inexpensive support material, making for the most inexpensive choice of the three, however the trade off is also that a-Si panels are the least efficient of the three choices (Gottschalg et al., 2004; Tester et al., 2012). The major benefit to using a-Si panels is that they are less affected by shading and the thin profile allows for flexibility, which is ideal when trying to integrate PV technology into buildings, as previously mentioned (Carr & Pryor, 2004). All three types of PV cells, in addition to panels made of other materials, are constantly being re-assessed to improve efficiency levels and other characteristics through research and design, as a varied selection of PV models is an asset to a purchaser interested in installing an array on their property.

## 2.6 Optimum Tilt, Angles, and Conditions for PV Solar Panels

The proper configuration and installation of solar panels is pivotal in maximizing energy generation potential. The performance of a PV system is a function of the amount of solar radiation received. At the latitude of Nova Scotia, the optimal angle for a PV panel to receive the most solar radiation throughout the year is around 45°, and facing due South (Kemery et al., 2012; Li & Lam, 2007). The weather and obstructions, such as trees, tall buildings, or any type of object that could cause shading, will directly affect the overall amount of solar radiation that a PV panel can capture (Xiao, Ozog, & Dunford, 2007). The seasons also play an important role in how much solar radiation is available to be collected, as there are less hours of sunlight, in addition to the sun being lower in the sky, throughout the winter months (Calabro, 2013). Additionally, the winter poses a problem with the potential buildup of snow on rooftops and solar panels, which also must be taken into account when planning the installation of a PV solar panel, however this is something that can be controlled for the most part as the snow can be removed if the panel is accessible (Gottschalg et al., 2004; Kemery et al., 2012). To optimize the potential for energy generation from a PV panel or array installed on a rooftop, each individual site must be assessed to understand if the building is properly geographically situated, as well as the best rooftop orientation of the panels.

## 2.7 Rooftop installations: Assessments in Other Regions

Rooftop PV panel studies and installations in urban areas of many cities around the world have seen a high degree of successful results. A common trend among most rooftop projects is the use of aerial technology to first assess their solar potential in urban settings (Bergamasco & Asinari (a), 2011; Brito et al., 2012; Redweik et al., 2010). A 2000 study by (Alsema & Nieuwlaar) identified the energy payback time (EPBT), the amount of time it takes to produce enough energy to offset the initial cost of installation, as one of the driving factors in approving a PV installation (rooftop or ground mounted) in urban settings. The study also concluded that of the two types of PV installations, rooftop installations were the shorter of the two payback periods as they tended to be smaller arrays (thus a smaller initial investment) and more removed from obstructions like trees & houses. With the help of technological advancements and further studies, the EPBT of rooftop PV installations has continued to make it a viable energy project, with

EPBTs ranging from 5-10 years (with ideal conditions), with a lifespan of about 20-30 years for the solar panels (Lu & Yang, 2010). Across Europe, growing populations have contributed to the residential sector's growing portion of overall energy demand (Ordóñez et al., 2010), which has led to many city and urban planning strategies to implement rooftop PV installations as a counter measure (Bergamasco & Asinari (a), 2011; Bergamasco & Asinari (b), 2011; Brito et al., 2012). Under ideal conditions, it was predicted that an urban region in Portugal, with 538 buildings deemed to be appropriate for PV installation, could generate 48% of the region's yearly electricity demand (Brito et al., 2012). The region of Andalusia, Spain, which has the highest solar energy potential in Europe, based on geographic conditions and weather patterns, was assessed and it was determined that rooftop PV panels installed on all residential buildings that could accommodate PV panels, could generate just under 80% of the yearly electricity demand for the area (Ordóñez et al., 2010). It is worth noting that these assessments are looking at rather large, wide spread PV installations, which would certainly be a major undertaking, however the results solidify that PV solar panel installation on rooftops has great potential, and is worth pursuing. European nations may be undertaking these large assessments based on the EU directive 2010/31/EU which states that all new buildings from 2020 onwards must be "nearly zero energy buildings" meaning the local energy production has to cover the local energy demand (Redweik, Catita, & Brito, 2013). With this goal in mind, the large scope of these assessments is better understood. A similar study was conducted in the southeastern region of Ontario, Canada, extending east to Ottawa, north to Algonquin Provincial Park, south to Lake Ontario, and west to Peterborough, stopping before the Greater Toronto Area. It was estimated that with the installation of high-end solar PV cells on all residential properties in the area, just over 30% of Ontario's yearly energy demand could be met (Wiginton et al., 2010). Once again, though these statistics are very encouraging, it is important to conceptualize how large the area of study is (48,000 $km^2$), and realize that this study, and the European examples, serve more as evidence that long term investment in renewable energy sources like PV solar panels can contribute a substantial amount of energy to the total energy demand of an area. It is important to consider the results and implications of studies undertaken in urban areas around the world as a motivating factor to explore the potential energy capacity in the HRM, and incentives like net metering that make installing a PV panel on residential rooftops more appealing.

## 2.8 Net Metering & Feed-in Tariffs

The structure and details regarding a jurisdiction's incentives for renewable power play a major role in the feasibility of small-scale solar panel installation. In Nova Scotia, a homeowner can install PV panels on their property, sized to meet their average annual energy consumption, and not capable of producing more than 1 MW (1000 kW) of electricity (Nova Scotia Power, 2014). Upon installing the net-metered array, a new electric meter is installed on the building that can record energy flow in both directions (into the property from the utility, out of the property to the utility) (Poullikkas, 2013). On each power bill after installation, Nova Scotia Power will compare the energy consumed against the energy generated, and any surplus of energy generated will be put on the customer's bill in the form of a credit equal to the rate that energy is being sold from the grid (Nova Scotia Power, 2014). As net metering programs become more popular, and PV arrays become more affordable, power utilities in some jurisdictions have the ability to restructure the payment scale if too many residential properties are producing excess energy, which in turn protects them from paying too much money back to the consumer, and possibly raising their energy rate (Poullikkas, 2013). This does pose a small issue to the property owner, as there is no contract signed between the two parties, so changes to the rate could occur (Darghouth, Barbose, & Wiser, 2011). At this time however, this is not an option within Nova Scotia's program, but it is worthwhile to be aware of, should the net metering program receive changes to this matter.

The second incentive option is a feed-in tariff (FIT), which offers the solar PV project owner an established price per kilowatt hour (kWh) for projects producing electricity from qualifying renewable resources. In Nova Scotia, there is a FIT in a unique form called a Community-Based Feed-In Tariff (COMFIT), which is only available to community organizations, non-profit groups, universities, municipalities and Mi'kmaq bands (Nova Scotia Department of Energy, 2011). Much like net metering, the energy produced is sold back to the grid, however the price is set by government policy and the whole amount generated is sold at that price, rather than the net amount generated. This incentive is directly aimed at small-scale local renewable energy projects, able to supply to their community (Nova Scotia Department of Energy, 2011). The eligible technologies are: wind (50 kW and under, and over 50 kW), small scale tidal, biomass, and small-scale hydro electricity (Natural Resource Canada (a), 2013). It is unfortunate that solar energy is not included as an acceptable technology, as solar energy would be an accessible technology for many more people and community groups. While this incentive does not apply to solar PV in Nova Scotia, nevertheless it is important to identify all incentive programs available in Nova Scotia to understand the context in which solar PV is developing alongside other renewable energy technologies in the province.

### 2.9 Knowledge Gaps

The current literature available creates a solid foundation for understanding how the solar energy sector operates, as well as its current and predicted future state. Furthermore, there is a breadth of information regarding PV solar panels and the potential they possess for energy generation, based on varying environmental conditions. The preliminary findings of rooftop solar PV installations in other locations around the world hints at the encouraging energy generation potential, however there is a significant gap in the literature and knowledge pertaining to PV technology and potential in Nova Scotia and the HRM. Additionally, specific studies of rooftop solar panel installation and energy potential in the area, with regards to residential buildings and commercial and institutional buildings, including the rooftops of places of worship, is sparse to non-existent. Without this body of work, no conclusions can made as to the potential energy generation that is capable from rooftop PV installations on places of worship in the HRM, which further emphasizes the relevance of conducting this study to begin creating a database.

## 3.0 Methods

### 3.1 Overview

The main goal of this study is to estimate how much solar electricity could be generated by installing solar panels on the rooftops of places of worship in the HRM. . By knowing this, it is possible to get a better understanding of how much solar energy could be generated if solar PV panels were installed on the rooftops of the buildings. To achieve the most accurate assessment of solar radiation on buildings in the HRM and accurate geographic positioning of the buildings, the study used multiple tools such as: the HRM Solar Map, Google Maps, and Google Earth, as well as in-person site assessments of the places of worship. The HRM Solar Map is an online tool that uses LiDAR (Light Detection and Ranging) to perform remote sensing of the area, creating an extremely detailed 3-dimensional image (National Oceanic and Atmospheric Association, 2014). This information was then given to Dalhousie University in Halifax, N.S, where the data was combined with a model of the sun's path over the year, in the HRM, to be able to predict the annual solar radiation that is cast on all buildings within the map, taking into account shading issues and obstructions (Halifax Regional Municipality, 2014). Google Maps and Google Earth are online programs, accessed through the web browser Google, using aerial and satellite imagery as well as other geographic data to represent the earth on a 3-dimensional scale (Science Education Resource Center, 2013). The onsite assessment of buildings will be elaborated on further in a later part of this chapter.

## 3.2 Study Area

The study area for this project is in the Halifax Regional Municipality (HRM), which is also defined as the County of Halifax, within Nova Scotia (Fig. 1). This area is made up of the city of Halifax, as well as surrounding communities such as Dartmouth, Sackville, and Bedford. As of the 2011 census, the HRM had a population of over 390,000 people, and represents the most densely populated area of the province by a wide margin (Statistics Canada, 2011). Because HRM is so large geographically, and the focus of the HRM Solar Map is within the Halifax Peninsula and surrounding area, the focus of the study will stay within the boundaries of the HRM Solar Map (see Fig. 2 & Fig. 3).

### 3.3 Study Design

The first step was to identify the street addresses of as many places of worship as possible within the boundary and then locate them accurately on a map (Google Maps & the HRM Solar Map). The use of the Canadian Church Directory as well as Google searches and the Yellow Pages was my primary way of initially finding places of worship in the HRM. Once each location was confirmed on the HRM Solar Map, a cataloguing could begin of all the church sites and their solar capability. This was be accomplished by inputting all data into an Excel spreadsheet for each individual site. I recorded:

- Site name, address, geographic coordinates
- Contact information (name, telephone number, email address)
- Roof type and dimensions
- Is it located on the HRM Solar Map – Yes or No
- Direction of roof in relation to south
- Angle of the roof
- Shade issues

Once the initial assessment of solar potential was recorded, I reviewed the database and noted which buildings had the most ideal conditions for PV installation. The ideal conditions were:

- A roof that is south facing, or no more than 45° off of south (preliminary assessment of directionality was based on a compass available with online aerial tools - Google maps/ HRM Solar map)
- Good solar radiation, as indicated by the HRM Solar Map

I visited 42 sites that looked ideal. Upon arrival at each site, I conducted ground truthing, specifically aimed at acquiring the accurate dimensions of the rooftop, the directionality that the building is facing, the pitch of the roof, the observation and documentation of the surrounding area with regards to obstruction of solar radiation (trees, tall buildings, etc.). All details were added to the ongoing list in the Excel spreadsheet. Roof angle was acquired through face on photographs of the gable end of the roof, measured with a protractor.

The sampling method used in this study is purposive investigation. I have chosen this type of sampling because my sites were selected based on their specific characteristics. By knowing what it is I am looking for in my sample there is no random component to my selection process, and as the study moved along, certain sites were selected or disregarded based on further on-site assessments and ground-truthing. Sites were disregarded if there were major problems, such as large amounts of shading. The way in which I sample is related to my objectives for the study and as such, my sampling methods could also be classified as criterion sampling, an extension of purposive sampling, based on the fact that I will be looking for sites that fit a specific criterion (Palys, 2008).

### 3.4 Validity & Reliability

Though there is little literature on rooftop PV installations for places of worship, rooftop PV installations in residential areas have been well documented through peer reviewed scientific studies. Brito et al., 2012, analyzed the PV potential of solar installations on residential buildings in urban regions, using LiDAR technology and data as their primary tool throughout the study (Brito, et al., 2012), while similar studies were conducted by (Redweik, Catita, & Brito, 2013) in which LiDAR was again a primary tool, used in conjunction with data acquired regarding shadowing and solar radiation obstructions around the study sites. A comprehensive study was conducted by (Santos et al., 2014) to illustrate the benefits of using LiDAR and GIS technologies to create a solar map of a city, in an effort to better understand where the most potential for solar energy was located. The similarities in the published studies of rooftop PV solar installations, to the study that will be conducted in the HRM, reinforces the reliability of this project, as the previously mentioned studies all successfully produced accurate results, and did not mention any issues using LiDAR technology. In addition to this, the online tools are available to anyone, and on site ground-truthing is a simple procedure anyone can follow, contributing to the overall strong reliability of this study

Previous studies such as (Wiginton et al., 2010) quantifying rooftop PV potential in urban areas, (Gadsden et al., 2003) and (Sorensen, 2001) assessing solar radiation levels on urban areas, and (Guindon, Zhang, & Dillabaugh, 2004) looking at urban mapping, all used the same or similar digital imaging technologies as the ones being used in this study of the HRM. Based on the consistent usage of these technologies in the past and the fact that all the technologies being used in this study are well developed and understood, I am confident in the validity of the methods chosen to accurately and effectively measure what is intended. Furthermore, once the methods were exercised in the field, in addition to the online technologies used, the validity and reliability of the methods was further solidified.

### 3.5 Data Analysis

Once the data was collected from all the sites, I used a software tool called RETScreen for analysis. RETscreen is a tool created by the Government of Canada to help model and analyze clean energy projects that are being designed, allowing decision-makers and professionals to determine whether or not a proposed renewable energy, energy efficiency, or cogeneration project makes financial sense (Natural Resource Canada (b), 2013). The program is used by over 350,000 people worldwide, with access to product, project, hydrology and climate databases (the latter with 6,700 ground-station locations plus NASA satellite data covering the entire surface of the planet), as well as links to worldwide energy resource maps, allowing decision makers to conduct, among other things, cost and energy analysis (Natural Resource Canada (b), 2013). One solar panel was selected as the template panel for all buildings to keep results consistent. The panel was the *Silfab SLA-270M*, a 270W monocrystalline silicon panel, measuring 1.65m x 0.99m (Silfab Solar, 2014). An individual panel costs approximately $250.00 (CAN). The size of the solar array was determined by calculating the surface area of each side of the rooftop and calculating how many panels could fit on the roof. The calculations were rounded down to the nearest whole number for each row and column of solar panels, meaning that the hypothetical panels being installed would not be over hanging on the roof. The data from each site was entered into RETScreen and the model was run. Once the results were created, a new spreadsheet was made with the new data, to comprehensively display how much energy can be generated per year by each site, how much it would cost to initially set up the solar array, the possible reduction of greenhouse gases from using the solar panels, as well as how long it would take to get a return on initial investment.

Based on energy records of other churches, a comparison was made to illustrate how much energy can potentially be offset by clean solar energy instead of the standard energy being purchased from Nova Scotia Power. Energy records were difficult to acquire from churches in the HRM so instead Internet searches for church records and comparisons to households and similar buildings were done to try and create as effective a comparison as possible.

### 3.6 Limitations & Delimitations

The limitations of this study are:

1) The HRM Solar Map boundaries only allow for an accurate solar radiation assessment of a specific area of the HRM, not the entire HRM.
2) On-site evaluations & ground-truthing was predicated on the approval and permission of property owners. Difficulty acquiring power records lead to doing internet searches to find church energy records from different locations instead.
3) The overall size of churches cannot be verified as completely accurate because onsite measurement of the property was not conducted, and online measurement may have some small variation from the true measurements.

The delimitations of this study are:

1) I chose only a portion of the HRM as the study site; this may not represent the greater NS area, as I am only looking at the most populated part of the municipality.
2) I am only looking at places of worship, no other buildings of similar design or function are being considered in this study.
3) I chose to study rooftops, however I did not have any intention of gaining access onto the rooftops, for reasons of safety. This could have lead to some small details being overlooked on the rooftop.

# 4.0 Results

## 4.1 Solar power potential

All 42 sites had the potential to generate various amounts of power from rooftop PV solar panels (Fig. 4). Total energy generated varied based on how large the rooftop was as well as the direction that the roof was facing in relation to South (Table 1, see Appendix 4). The yearly total and average amount of energy generated from the optimal side of all 42 sites combined was 3,049.24 megawatt-hours (MWh) and 72.60 MWh respectively, while the secondary side generated a total of 2,169.16 MWh of energy in a year with an average energy output of 51.65 MWh. The optimal side refers to the side of the roof oriented closer to due south, while the secondary side refers the opposite side of the roof. A more specific breakdown of these results was also conducted to establish the annual solar energy production potential per square metre of rooftop area for each site (Table 2, see Appendix 5 & Fig. 5)

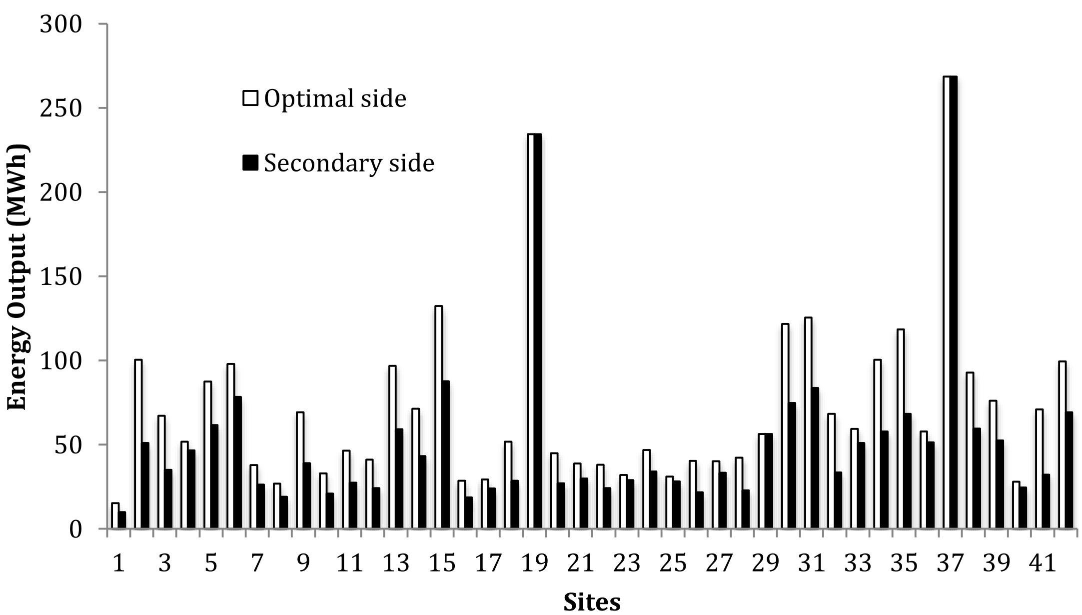

**Figure 4.** Total annual energy output (MWh) for each place of worship surveyed in the HRM.

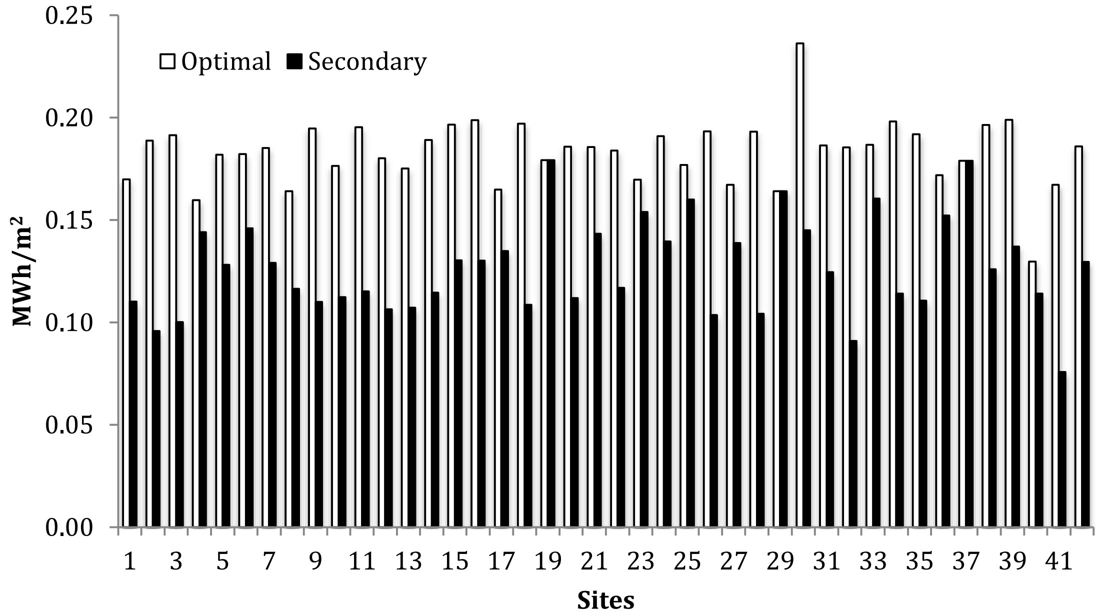


**Figure 5.** Total annual energy output per square metre (MWh/m$^2$y) of rooftop space for each place of worshiped surveyed in the HRM.

## 4.2 Costs, savings, and payback time

The cost of installing a solar array on the rooftops of places of worship within the HRM varied based on the area of the rooftop (Table 3, see Appendix 6). Higher costs were observed in sites with larger rooftop areas, consistent with the ability to install more solar panels per side. As a result, the size of a roof has a direct relationship with the installation cost and the subsequent energy that can be produced per year. The savings incurred by each site based on the solar array installed varied, with more savings being observed at sites with a larger solar array (Table 3, see Appendix 6). On average, the savings for the 42 sites were $10,966.74 and $7,756.64 (optimal side & secondary side). The average cost of installation for solar PV panels on the sites was $55,119.00 per side. The cost was calculated by taking the cost of one panel ($270.00 Canadian) and multiplying by the amount of panels that could be installed on each roof. When analyzing the initial cost against the yearly savings, a trend of roughly five to six years was observed, as the average time for an individual site to accumulate enough savings to equal their initial investment.

## 4.3 Roof direction and angles

Of the 42 sites surveyed, 26 sites were found to be south facing, or within 45° of south, and had a higher output of MWh/m$^2$ than the other 16 sites (Table 4). A change in the angle of individual roofs (as the panels are to be mounted flush with the rooftop) was not found to be significant, as most rooftops only gained energy output if the angle the solar panel was set at was less than the angle of the roof. Four exceptions were found in this comparison, having an average increase of 1.7 MWh per year, with an increase in the roof angle of between 5°-10°. The difference in energy output from the optimal side compared to the secondary side was much larger for south-facing roofs, while roofs that were facing a direction of 46° or more off of south tended to have a much smaller difference in yearly energy output between the optimal and secondary side (Table 5, see Appendix 7).

**Table 4.** Average energy output of solar panels on rooftops of places of worship within the HRM ($MWh/m^2y$).

| | *South facing (+/- 45°)* | *Non-south facing (Beyond 45°)* |
|---|---|---|
| Average $MWh/m^2y$ | 0.19 | 0.17 |

## 4.4 Energy production and demand comparison

I was unable to acquire power records for previous years from the places of worship surveyed in my study, however, power records were obtained for other places of worship (Table 6). Yearly energy demand varied greatly based on the size of the building, how old the building was, and what its main source of heating was. Though comparisons can be made between buildings of similar size, to establish energy usage against potential energy produced, for the most part, every building has unique energy demands, weekly and monthly usage of the building, and many other variable factors. Of the 42 sites surveyed, the smallest of the sites was $90.1m^2$, while the largest building was $1501.46m^2$, while the average size of the buildings surveyed was $388.83m^2$, while the average size of building for the 24 places of worship in the UK was $345.08\ m^2$. Though power records were not possible to acquire for the sites studied in the HRM, a comparison of annual energy demand against the area of the buildings, with regards to the places of worship in the UK, did show a correlation between the two variables, with an $R^2$ value of 0.83633 (Fig. 6). From this comparison the average annual energy demand per square metre for the 24 sites was found to be $0.1944\ MWh/m^2$ and overall, the average energy demand was 68.04 MWh per year.

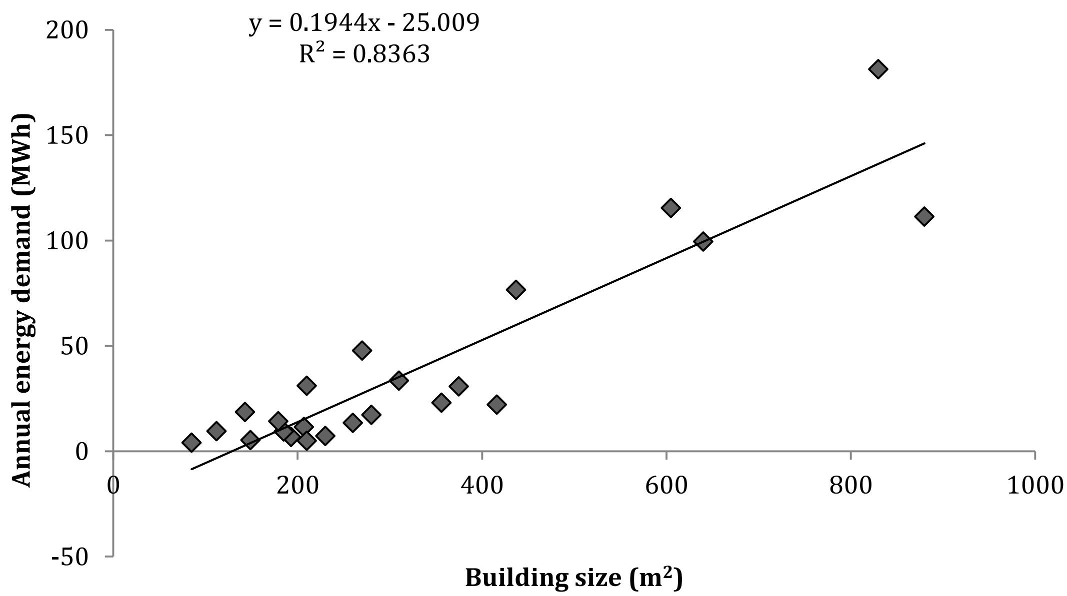


**Figure 6.** A comparison of annual energy demand and building size of 24 places of worship in the UK.

**Table 6.** Size, monthly usage, and yearly energy demand of places of worship in Europe (Diocese of Oxford, 2013).

| ***Building size ($m^2$)*** | ***Monthly usage (hours)*** | ***Annual energy demand (MWh)*** |
|---|---|---|
| 880 | 35 | 111.36 |
| 830 | 317 | 181.31 |
| 720 | 146 | 36.69 |
| 640 | 20 | 99.51 |
| 605 | 30 | 115.4 |
| 437 | 44.5 | 76.64 |
| 416 | 42 | 22.12 |
| 375 | 30 | 30.77 |
| 356 | 11 | 23.07 |
| 310 | 20 | 33.47 |
| 280 | 98 | 17.27 |
| 270 | 44 | 47.73 |
| 260 | 11 | 13.41 |
| 230 | 32 | 7.18 |
| 210 | 97.5 | 31 |
| 210 | 94 | 5.03 |
| 207 | 10.5 | 11.52 |
| 193 | 19 | 6.84 |
| 185 | 54 | 9.36 |
| 179 | 19 | 14.22 |
| 149 | 93 | 5.32 |
| 143 | 90 | 18.69 |
| 112 | 100 | 9.54 |
| 85 | 3 | 4.02 |

# 5.0 Discussion

## 5.1 Overview

In this study I examined the potential for generating energy from rooftop solar panels on places of worship within the HRM. The specific aim of my study was to address how much energy could potentially be created, how much it would cost to initially set up the solar panels on the rooftops, and how much money could be saved each year from the energy that was produced by the solar panels. An extension of these goals was to explore whether or not some churches could produce enough energy to be considered net producers of energy, and contribute energy back into the electrical grid in the HRM. The discussion of the results will look more closely at these issues outlined.

## 5.2 Solar power potential

The most obvious result produced by this study was the fact that each of the 42 sites can produce some amount of energy over the course of a year. With a minimum of 15.3 MWh and a maximum of 234.41 MWh of estimated energy produced each year, there is a large range of potential energy to be generated. These statistics are based on the most accurate information possible from weather stations in the area, and takes into account the difference in sunlight throughout the year (Natural Resource Canada (b), 2013). However, the program (RETScreen) cannot account for changing weather patterns, meaning snowstorms, rainfall, and cloudy days, which could reduce the amount of overall sunlight being radiated on the panels over the course of the year. This means the results for each site should be seen as a best-case scenario, and it should be understood that the intermittency (highs and lows of energy production due to weather and other natural factors) makes PV panels a power source that is activated, maximized and minimized by nature and weather (Kemery, Beausoleil-Morrison, & Rowlands, 2012).

To put the energy production in perspective, 3,049.24 MWh of total energy produced in one year by all 42 sites, from the optimal side of their roofs, would be the equivalent of approximately 270 Canadian homes yearly consumption of electricity (Canadian National Geographic, 2012). When looking at the individual average, 72.60 MWh of energy per building (optimal side) would supply enough energy for approximately six to seven homes in Canada for one year (Canadian National Geographic, 2012). An important fact to keep in mind remains that in addition to the total energy and individual energy produced being based on ideal conditions throughout the year, there is also the need to finance the installation with the maximum amount of panels on each roof to achieve these results presented. Though it seems unlikely to presume all places of worship would have this kind of initial budget, the topic of discussion remains answering the question "How much potential is there for generating electricity through solar PV panels on the rooftops of places of worship in the HRM," and this data contributes to answering this question. With an estimated 333 buildings considered places of worship within the HRM, it is logical to take these initial energy production statistics and extrapolate conservatively that were all or the majority of the 333 building participating in rooftop solar panel projects, there would certainly be good potential for energy generation (Yellow Pages, 2015).

### 5.3 Cost, savings, and payback time

The initial cost of setting up a solar array varies based on how many panels a building decided to install. For the purpose of knowing the maximum possible energy output, each of the 42 sites was analyzed in RETScreen with the largest possible solar panel array that each roof could accommodate. The costs displayed in Table 2 reflects what it would cost to purchase all the necessary solar panels, but does not include any installation costs. Because the panels were inputted into RETScreen as fixed directly on to the roof, additional installation cost would be minimal, as no additional materials are needed in the form of a base for each panel, however, simple labour would need to be factored in, as the panels would need to be installed by a professional.

At an average cost of $55,119.00 per side for installation, the up-front cost could be an initial detractor for smaller places of worship, however the lowering price of solar panels as technology becomes more advanced and common place, coupled with incentives for the prospective buyer (to be discussed later), could make installing a solar array much more feasible (Branker, Pathak, & Pearce, 2011: Lu & Lang, 2010). The initial start up cost of a rooftop solar array has been identified as the major hurdle to the buyer, so using the data from this study could serve as a guideline for what size of solar array a particular place of worship could afford, and kind of energy output they could expect to get out of it (Branker, Pathak, & Pearce, 2011).

As with the cost of installation, the savings varied based on the amount of panels in the array. A consistent trend was observed however, no matter the size of the array, with an average payback time of five to six years, to produce enough energy to have offset the original investment based on money not spent buying energy from the grid. Factoring in the “ideal conditions” that this data is being produce under, it is important to consider that this time line may be unrealistic. Compared with other energy audits done of churches within the same size as most of the sites in this study, an estimate closer to 10 years would be a more realistic timeline for a full return on investment (Diocese of

Oxford, 2013). While a pay back period of roughly 10 years does seem like a long time, when considering that most solar arrays typically have a lifetime of 20-30 years, there is still ample time to not only make the initial investment back but begin to see the solar array make money (Alsema & Nieuwlaar, 2000). Adding to this, once the solar panels have been installed, there is little to no maintenance or investments that needs to be made moving forward, keeping the initial investment at a stable number.

Due to the nature of most places of worship being not-for profit, and/or funded by donations from its congregation, the motivation to install solar panels on the rooftops of the sites surveyed in this study would most likely be improved with the help of incentives. As previously mentioned, Nova Scotia has two incentives, net metering and FITs, however as PV solar panels do not fall under the acceptable power sources for FITs in Nova Scotia, the only available incentive for the places of worship is net metering. The restriction of a power source being capped at producing no more than one megawatt (1 MW) of power does not factor into this, as all 42 sites are below this limit (the largest array, 24 x 37 - 270W panels, produces 0.24 MW) (Nova Scotia Power, 2014). A further stipulation is also in place, stating that all participating properties must set up an array that will only meet its electricity consumption needs. It is unclear if this would be a problem for some of the buildings in this study, as power records were not available, and would be a very important factor to investigate and consider before applying for the program or investing in a rooftop solar array. When comparing the average size of the 24 sites in the UK with the average size of the HRM sites, they are almost the exact same ($388.83m^2$ and $345.08m^2$). By this logic, it is possible to make a broad assessment that the buildings in the HRM could potentially have roughly the same average annual energy demand as the sites in the UK (68.04 MWh). Keeping with this line of thinking, this would suggest that with an average annual energy output of 72.60 MWh for the 42 sites in the HRM, it is possible that on average, the places of worship that were surveyed in this study would be able to establish a solar array that meets the guidelines of the net metering program. For buildings within this study that do comply with this stipulation, it could be an added incentive to know that if their building is not in use for extended periods of time, some money can be generated from selling energy back the grid, contributing to a quicker pay back period.

## 5.4 Roof direction and angles

It comes as no major surprise that the buildings with a rooftop that faced within 45° or less of south had a higher energy production, as outlined by many previous studies such as: Li & Lam, 2007; Kemery, Beausoleil-Morrison, & Rowlands, 2012. The fact that there is such a large difference in energy production on the opposite side of those roofs is logical as well, as due north is the furthest possible orientation away from south. This means the 26 sites with these characteristics would not be advised to put solar panels on the secondary side of the roof, as the initial cost to install panels on the secondary side is the same as the optimal side, but the return on investment would be much less, in some cases almost half. Installing solar panels on both sides (or multiple sides) of a roof is not unheard of, and if the initial setup costs are possible, the remaining 16 sites in this study could benefit from both sides of their roof collecting solar energy. As a result of the two sides having almost the same energy production each year, the buildings could potentially achieve a faster pay back compared to a north/south facing house with panels on both sides (Solar Direct Canada, 2015; Solar Panel Buyers Guide, 2012).

A solar panel angled at approximately 45° has been found to be the most effective angle to capture the sun's rays, however a variation of up to 15° in either direction has been found to still be effective throughout the year (Kelly & Gibson, 2011). Within this study, only nine sites had roof angles that were outside of this range, which could account for the adjustment of the roof angle in the RETScreen analysis not being significant for the majority of sites. This result helps to strengthen the case for moving forward with a solar array on rooftops, considering there is no need to purchase any kind of base to adjust the angle for the panels, which is consistent with almost all potential sites.

## 5.5 Energy production and demand comparison

Each building surveyed during this study is unique and is difficult to compare to any other building. From square footage, to the type of heating used, the overall usage of the building week by week, or when the building was built, the ability to compare energy used versus energy produced can only be accurately assessed with the individual power records of each site. By knowing how much energy could potentially be created and comparing this to the average energy that is consumed per month, or year, it would be very clear whether or not any particular place of worship could offset some or all costs from their power bill, or even produce excess power beyond the energy demanded, making it a net producer. This is relevant because the current regulations of the Nova Scotia Power net metering program do not allow for buildings to be net producers, however, were some of the buildings able to produce enough excess power to make a legitimate energy contribution back to the grid, the case could be made that Nova Scotia Power should review their policies and consider making amendments to the net metering guidelines. Nova Scotia Power does allow buildings who produce excess power to use the excess against power used at another location, under the same billing information, so there is potentially an avenue for places of worship who were net producers to offset energy bills from a neighboring building registered to the group as well (Nova Scotia Power, 2014).

Though the power records displayed in Table 6 do not allow for direct analysis of the 42 sites surveyed in this study, the information does help to provide some insight into the range of energy demand a place of worship may have over the course of a year. The 24 sites presented in Table 6 represent buildings built as far back as the $11^{th}$ century and as recently as 1961 (Diocese of Oxford, 2013). With churches analyzed in this study dating back as far as 1750 (St. Paul's Church, 2015), some simple parallels can be drawn between the energy demand data acquired from energy audits in table 6 and the energy production data from the 42 sites. These comparisons could be based on the fact that most of the churches in both categories are made of stone, tend to have older building dates and are within the same size range. By using the average annual energy demand of the 24 UK sites (68.04 MWh), compared with the average annual energy production of the 42 sites in the HRM (72.6 MWh on the optimal side), a small amount of energy appears to be produced each year on average. While this broad conclusion cannot stand on its own as definitive results, it does allow for the simple estimate that some of the places of worship within this study could be net producers on a small scale, or at least net zero, meaning their energy output could offset their energy demand. This conclusion would vary from site to site based on factors previously mention such as roof size and energy demands, however with the lack of power records unique to each site included in this study, it is the next best option with regards to an energy demand and output comparison.

## 6.0 Suggestions for future research

There are several suggestions for future research that could be made. Firstly, although this study has established initial power generating capacity for some places of worship within the HRM, past and current power records should be acquired and used in conjunction with the power generation potential data from each site. This would establish a more accurate and informative analysis of the capacity for places of worship in the HRM to not only generate power to offset their own power bills, but potentially for the places of worship to become net producers of energy. With this kind of information available, decision makers for each property would be better informed as to the feasibility of investing in a solar panel array on their property and the potential benefits and costs that would be associated with the decision. An extension of this suggestion would be to delve deeper into the usage(s) of each building that is being studied, in order to better understand where the energy demand from each building is coming from. With an improved understanding of how much energy a building uses, in conjunction with how the building is being used, more comprehensive and helpful suggestions could be made to each building as to how feasible a solar array installation would be for their building, and how the building could potentially cut down on its power bill, helping to make for better energy production versus consumption.

To continue the progress of this study, broadening the scope of how many sites are surveyed could be beneficial. By acquiring more data from additional sites, a more accurate and representative report could be created to answer the question of how much potential there is to generate power through rooftop solar panels of the places of worship in the HRM. The ultimate goal of this study was to create a report that would be representative of places of worship throughout the entire HRM, however as previously stated, with an estimated 333 places of worship within the limits of the HRM, this was not possible to do within this study. Though I believe this study has begun to establish a representative report on the energy generating capacity of places of worship, it has also highlighted how unique every building is, thus making it important to gather information on as many buildings as possible to truly get an accurate understanding of the power generation capacity of these buildings throughout the HRM.

Should this report be carried on in the future and more data acquired, it could be useful to present the information to Nova Scotia Power, municipal and provincial government departments, as well as to the public. Currently the parameters regarding net metering do not allow for buildings to be net producers, limiting them to installing only enough panels (or another form of energy generation) to offset their own energy demand. With the size of some places of worship, it is very possible that some rooftops could accommodate enough solar panels to become net producers. In the present day, with all the concerns regarding environmental responsibility, it seems logical to at least explore the possibility that some buildings within Nova Scotia should be granted the ability to be net producers, helping to contribute to cleaner sources of energy. In addition to the review of the net metering guidelines, further research should be done to establish how many places of worship own more than one property under the same billing account. Although an amendment to the net metering rules would be beneficial for some buildings to produce more energy, understanding which places of worship have multiple properties under one account could help property decision makers better understand if investing in a solar array on one of their properties could benefit multiple properties in the long run.

Finally, should conclusive results come out of further research, I would strongly recommend the publishing of the results, to potentially begin, or contribute to the literature and database regarding the energy generation of solar panels on the rooftops of places or worship. Throughout this study, the lack of research pertaining specifically to this topic of solar energy generation on the rooftop of places of worship made for challenging moment when the research hit road blocks, as there was no prior research or methods to try and follow or build upon. Although there is a breadth of information regarding rooftop solar PV installation and research, the contribution of data and research specific to places of worship could be a very beneficial addition to the scientific pool moving forward.

# 7.0 Conclusion

This study examined the potential for generating energy through the installation of PV solar panels on the rooftops of the HRM. Previous literature was not available regarding this specific topic, making for a challenging situation at times, however, the ability to contribute information and data towards a subject with little previous research was a motivating factor.

Forty two sites were identified and surveyed to understand the size of the building, the area of the roof, the angle of the roof, and which direction(s) the roof faced for each site. The question put forth for this study was “How much potential is there for generating electricity through solar photovoltaic panels on the rooftops of places of worship in the HRM?”. I attempted to answer this question by estimating how many solar panels could be installed on each roof and calculating how much energy would be created through the solar array over the course of a year. With the help of a computer program, taking into account weather patterns from the region throughout the year, and the information gathered, yearly energy production, initial costs, and yearly savings results were produced.

Through the process of this study, it became clear that studying places of worship did not allow for much comparison between buildings, as each property had very unique characteristics. A review of energy audits done on other places of worship reinforced this fact, with an emphasis on how often the building was used, it's heating source, and the construction of the building itself, playing a major role in overall energy demand.

Overall, the study provided results to conclude that there is certainly potential to generate energy from solar panels installed on rooftops of places of worship. However, the next question that needs to be answered, of whether it is enough energy to offset some or all of the energy demand from each building, or produce excess power beyond a buildings energy demands, remains unclear. While a comparison between the UK sites and the sites in the HRM did reveal some initial positive results with regards to offsetting energy demands, it is not conclusive without the power records for each individual site. The fact that a lot of places of worship are fairly large, old buildings, leads to the possibility that there could be a lot of room for efficiency upgrades applied to the buildings, which could reduce total energy demand and create better overall results for total net energy production. Furthermore, when taking into account the costs associated with these 42 sites generating energy, the fact that most buildings have been around and in use by the various religious congregations for decades, if not longer, lends itself to the fact that there is ample time to make back the initial investment over the years or decades to come. As outlined in this study, pay back periods for the sites would probably occur before the 20-30 year life of the solar panels has occurred, and should decision makers for places of worship decide to wait before investing, the trends being observed currently show that solar panels are coming down in price and becoming more efficient.

Moving forward, should places of worship invest in a solar array on their rooftop, the implications beyond the potential energy generated are worth noting as well. Because most places of worship are a gathering place for the public, through sermons and other events day to day, the visual effect of solar panels on the rooftop, in addition to dialogue between those that frequent the buildings, regarding the solar panels and their contributions to energy in the building or surrounding properties, could have a positive effect. If there is more conversation regarding solar panels and renewable energy, there is a greater likelihood more people will become aware of clean energy sources, and potentially interested in investing in one the those technologies for their own property.

The limitations of this study lie in the inability to connect energy production against energy demand on a site-by-site basis. As a result of this limitation, it is possible that the results will not be taken quite as seriously, as they may be seen as incomplete. However the goal of this study was to establish a preliminary database of what is possible in terms of energy generation, in an effort to help make the decision of investing in rooftop solar panels easier for those in charge of their respective properties. Though this limitation does reduce the effectiveness of the results at creating a complete picture, it does still allow the individual property owner, or manager, to compare the results of this study to their own power records, and understand the potential and limitations of their building.

Although there is still more research and work to be done regarding solar arrays on the rooftops of places of worship in the HRM, this study has been able to successfully demonstrate that the potential for energy generation throughout the entire year is possible. The initial cost would seem to be the biggest hurdle for any prospective investor to interested in an array on their building, however the initial results put forth in this study appears to demonstrate that over the lifetime of the solar panels, the initial investment would be more than paid back in the end. While there are still questions left to be answered, the main questions of this study can be answered, that there is indeed good potential for generating solar energy from rooftop solar arrays on places of worship in the HRM. Although this appears to be one of the first studies of its kind within the HRM, it has many possible implications for starting further research, interest, and discussion in the matter of producing energy from clean sources, both on a small scale and large scale, within the HRM. Through the findings of this study, the HRM not only has potential to produce power from rooftop panels on places of worship, but grow that potential through better understanding and further research of the topic for places of worship and buildings of any kind within the HRM.

## Acknowledgements

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# Appendix 1

**Figure 1.** Halifax Regional Municipality boundaries (shaded area) within Nova Scotia, Canada (Wikipedia, 2014).

# Appendix 2

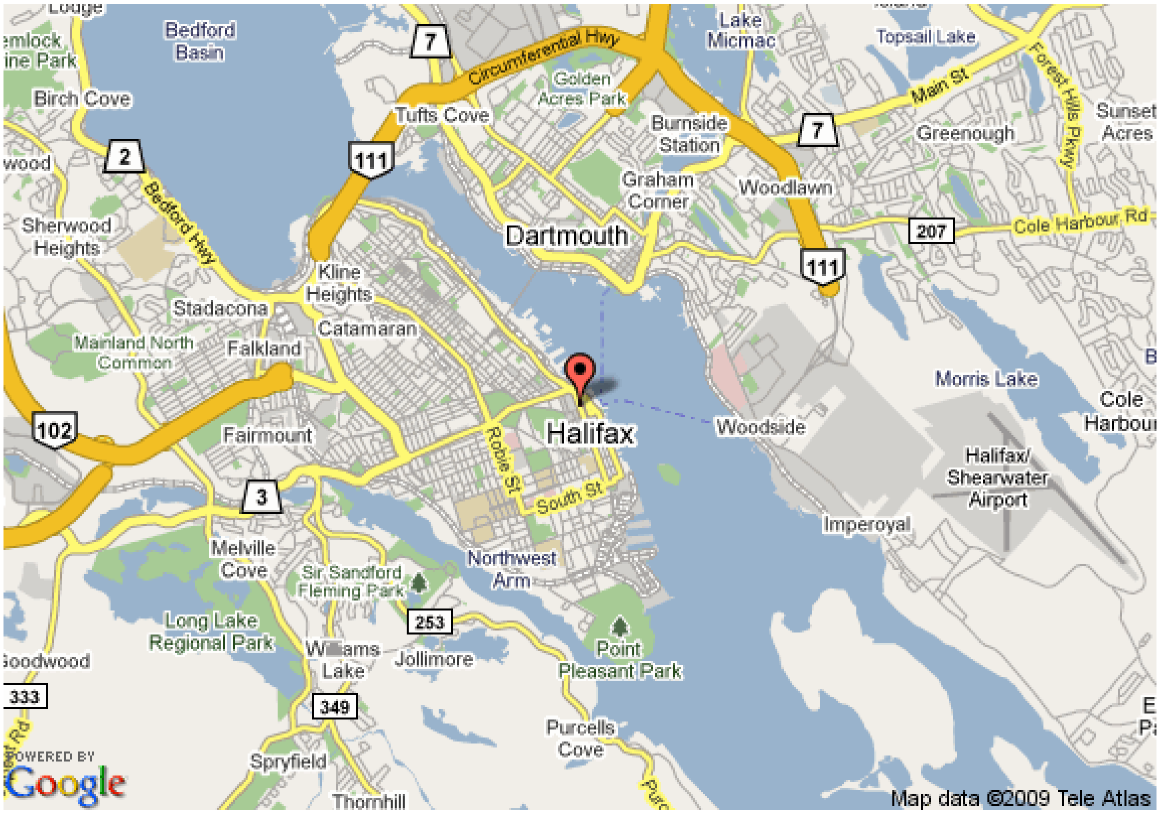


**Figure 2.** Map of Halifax peninsula, Dartmouth, and surrounding area (Canada Alive, 2013).

# Appendix 3

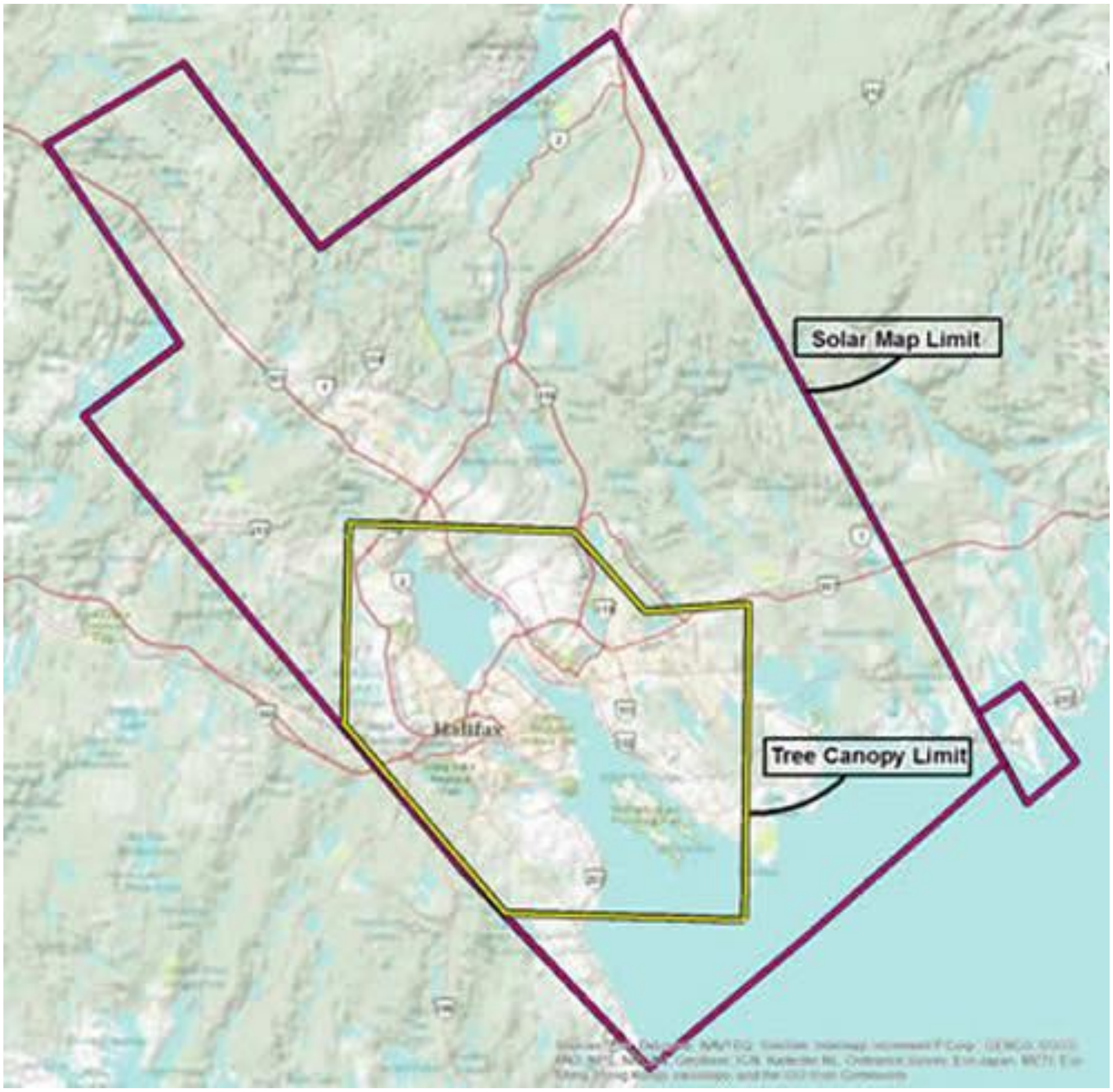


**Figure 3.** Map showing the geographic boundaries of the HRM Solar Map and boundaries of data regarding tree cover/shading (Halifax Regional Municipality, 2014).

# Appendix 4

**Table 1.** Direction of the rooftop(s) for each of the places of worship in the HRM surveyed.

| Site | Roof direction | Site | Roof direction | Site | Roof direction |
|---|---|---|---|---|---|
| 1 | 178°S/358°N | 15 | 159°S/339°N | 29 | 90°E/270°W |
| 2 | 158°S/338°N | 16 | 23°N/ 203°S | 30 | 147°SE/327°NW |
| 3 | 0°N/180°S | 17 | 70°E/250°W | 31 | 152°SE/ 332°NW |
| 4 | 101°E/281°W | 18 | 13°N/193°S & 88°E/268°W | 32 | 0°N/180°S |
| 5 | 53°NE/ 233°SW | 19 | 100°E/280°W | 33 | 60 NE/ 240 SW |
| 6 | 115°SE/ 295°NW & 143°SE/323°NW | 20 | 170°S/ 350° | 34 | 155°SE/ 335°NW |
| 7 | 156° SE/321° NW | 21 | 133°SE/ 313°NW | 35 | 144°SE/324°NW |
| 8 | 149°SE/ 329°NW | 22 | 170°S/350°N | 36 | 77°E/ 257°W & 150°SE/330°NW |
| 9 | 14°N/ 194°S | 23 | 51°NE/ 231°SW | 37 | Flat |
| 10 | 147°SE/ 327° NW | 24 | 177°S/357°N | 38 | 156° SE/321° NW |
| 11 | 0°N/180°S & 77°E/ 257°W | 25 | 136°SE/316°NW | 39 | 145°SE/ 325°NW |
| 12 | 0°/90°/180°/270° | 26 | 165°S/345°N | 40 | 124° SE/304° NW & 41°NE/ 221° SW |
| 13 | 47°NE/ 227°SW | 27 | 70°E/250°W | 41 | 245°SW & 288°W & 335°N |
| 14 | 0°N/180°S | 28 | 17°N/197°S | 42 | 55°NE/ 235°SW |

# Appendix 5

**Table 2.** Roof area and annual energy output from 42 places of worship in the HRM.

| *Square footage* | *Output (optimal)* | *Output (Secondary)* | *MWh/m²* *(optimal)* | *MWh/m²* *(Secondary)* |
|---|---|---|---|---|
| 90.09 | 15.3 | 9.93 | 0.17 | 0.11 |
| 531.53 | 100.3 | 50.91 | 0.19 | 0.10 |
| 350.75 | 67.12 | 35.12 | 0.19 | 0.10 |
| 323.65 | 51.69 | 46.63 | 0.16 | 0.14 |
| 480.38 | 87.4 | 61.54 | 0.18 | 0.13 |
| 537.32 | 97.87 | 78.44 | 0.18 | 0.15 |
| 204.14 | 37.79 | 26.36 | 0.19 | 0.13 |
| 163.39 | 26.82 | 19.01 | 0.16 | 0.12 |
| 355.39 | 69.17 | 39.1 | 0.19 | 0.11 |
| 186.96 | 32.98 | 21.01 | 0.18 | 0.11 |
| 238.09 | 46.5 | 27.43 | 0.20 | 0.12 |
| 227.64 | 41.03 | 24.21 | 0.18 | 0.11 |
| 552.65 | 96.82 | 59.25 | 0.18 | 0.11 |
| 377.58 | 71.4 | 43.24 | 0.19 | 0.11 |
| 672.69 | 132.26 | 87.69 | 0.20 | 0.13 |
| 143.92 | 28.61 | 18.74 | 0.20 | 0.13 |
| 177.71 | 29.3 | 23.96 | 0.16 | 0.13 |
| 262.77 | 51.79 | 28.55 | 0.20 | 0.11 |
| 1308.10 | 234.41 | 234.41 | 0.18 | 0.18 |
| 242.19 | 44.99 | 27.11 | 0.19 | 0.11 |
| 208.82 | 38.77 | 29.93 | 0.19 | 0.14 |
| 207.14 | 38.09 | 24.2 | 0.18 | 0.12 |
| 188.27 | 31.94 | 28.97 | 0.17 | 0.15 |
| 244.97 | 46.76 | 34.17 | 0.19 | 0.14 |
| 175.88 | 31.11 | 28.15 | 0.18 | 0.16 |
| 208.89 | 40.38 | 21.65 | 0.19 | 0.10 |
| 240.38 | 40.2 | 33.35 | 0.17 | 0.14 |
| 219.17 | 42.33 | 22.84 | 0.19 | 0.10 |
| 343.70 | 56.4 | 56.4 | 0.16 | 0.16 |
| 514.96 | 121.7 | 74.66 | 0.24 | 0.14 |
| 672.63 | 125.43 | 83.72 | 0.19 | 0.12 |
| 368.35 | 68.35 | 33.5 | 0.19 | 0.09 |
| 317.66 | 59.32 | 50.96 | 0.19 | 0.16 |
| 506.49 | 100.33 | 57.74 | 0.20 | 0.11 |
| 617.27 | 118.41 | 68.27 | 0.19 | 0.11 |
| 336.93 | 57.92 | 51.28 | 0.17 | 0.15 |
| 1501.46 | 268.6 | 268.6 | 0.18 | 0.18 |
| 472.92 | 92.88 | 59.58 | 0.20 | 0.13 |
| 382.62 | 76.14 | 52.45 | 0.20 | 0.14 |
| 216.27 | 28.06 | 24.66 | 0.13 | 0.11 |
| 424.51 | 70.97 | 32.2 | 0.17 | 0.08 |
| 534.61 | 99.4 | 69.24 | 0.19 | 0.13 |

# Appendix 6

**Table 3.** The dimensions of potential solar panels installed on 42 places of worship in the HRM, as well as the initial cost and money saved per year.

| Site | Solar panels per side | Total price of array ($) per side | Total money saved per year ($) Optimal side | Total money saved per year ($) Secondary side |
|---|---|---|---|---|
| **1** | 9 x 5 | 11,250 | 2,287 | 1,484 |
| **2** | 22 x 14 | 77,000 | 14,991 | 7,609 |
| **3** | 33 x 6 | 49,500 | 9,637 | 5,249 |
| **4** | 20 x 9 | 45,000 | 7,727 | 6,970 |
| **5** | 19 x 15 | 71,250 | 13,064 | 9,198 |
| **6** | 12 x 13 | 39,000 | 14,627 | 13,161 |
| **7** | 12 x 10 | 30,000 | 5,725 | 3,939 |
| **8** | 16 x 5 | 20,000 | 4,009 | 2,849 |
| **9** | 17 x 12 | 51,000 | 10,338 | 5,844 |
| **10** | 14 x 7 | 24,500 | 4,931 | 3,141 |
| **11** | 17 x 8 | 34,000 | 6,951 | 4,101 |
| **12** | 12 x 10 | 30,000 | 6,133 | 3,619 |
| **13** | 19 x 17 | 80,750 | 14,471 | 8,855 |
| **14** | 19 x 11 | 52,250 | 10,637 | 6,464 |
| **15** | 30 x 13 | 97,500 | 19,769 | 13,107 |
| **16** | 5 x 17 | 21,250 | 4,277 | 2,802 |
| **17** | 10 x 10 | 25,000 | 4,380 | 3,581 |
| **18** | 17 x 9 | 38,250 | 7,741 | 4,267 |
| **19** | 31 x 25 | 193,750 | 35,045 | 35,045 |
| **20** | 12 x 11 | 33,000 | 6,726 | 4,053 |
| **21** | 15 x 8 | 30,000 | 5,796 | 4,474 |
| **22** | 16 x 7 | 28,000 | 5,693 | 3,618 |
| **23** | 17 x 6 | 25,500 | 4,774 | 4,330 |
| **24** | 14 x 10 | 35,000 | 6,991 | 5,107 |
| **25** | 10 x 10 | 25,000 | 4,711 | 4,208 |
| **26** | 10 x 12 | 30,000 | 6,036 | 3,236 |
| **27** | 15 x 9 | 33,750 | 6,009 | 4,986 |
| **28** | 9 x 14 | 31,500 | 6,329 | 3,415 |
| **29** | 25 x 8 | 50,000 | 8,431 | 8,431 |
| **30** | 23 x 13 | 74,750 | 18,191 | 11,159 |
| **31** | 25 x 15 | 93,750 | 18,748 | 12,513 |
| **32** | 17 x 12 | 51,000 | 10,216 | 5,075 |
| **33** | 21 x 9 | 47,250 | 8,866 | 7,617 |
| **34** | 20 x 15 | 75,000 | 14,996 | 8,639 |
| **35** | 23 x 16 | 92,000 | 17,702 | 10,207 |
| **36** | 10 x 20 | 50,000 | 8,658 | 7,667 |
| **37** | 24 x 37 | 222,000 | 40,155 | 40,155 |
| **38** | 12 x 23 | 69,000 | 13,886 | 8,907 |
| **39** | 23 x 10 | 57,500 | 11,383 | 7,841 |

| | | | | |
|---|---|---|---|---|
| **40** | 9 x 13 | 29,250 | 5,689 | 3,686 |
| **41** | 17 x 14 | 59,500 | 10,587 | 4,819 |
| **42** | 27 x 12 | 81,000 | 14,860 | 10,351 |

# Appendix 7

**Table 5.** Comparison of rooftop direction (in regards to degrees off of due south) and yearly energy output of rooftop solar panels on places of worship in the HRM.

| Degrees off of south | MWh / year (Optimal side) | MWh/ year (Secondary side) | Degrees off of south | MWh / year (Optimal side) | MWh/ year (Secondary side) |
|---|---|---|---|---|---|
| **-2** | 15.3 | 9.93 | **-47** | 38.77 | 29.93 |
| **-22** | 100.3 | 50.91 | **-10** | 38.09 | 24.2 |
| **0** | 67.12 | 35.12 | **51** | 31.94 | 28.97 |
| **-79** | 51.69 | 46.63 | **-3** | 46.76 | 34.17 |
| **53** | 87.4 | 61.54 | **-44** | 31.11 | 28.15 |
| **65** | 97.87 | 78.44 | **-15** | 40.38 | 21.65 |
| **24** | 37.79 | 26.36 | **70** | 40.2 | 33.35 |
| **31** | 26.82 | 19.01 | **17** | 42.33 | 22.84 |
| **14** | 69.17 | 39.1 | **90** | 56.4 | 56.4 |
| **33** | 32.98 | 21.01 | **-33** | 121.7 | 74.66 |
| **0** | 46.5 | 27.43 | **-28** | 125.43 | 83.72 |
| **0** | 41.03 | 24.21 | **0** | 68.35 | 33.5 |
| **47** | 96.82 | 59.25 | **60** | 59.32 | 50.96 |
| **0** | 71.4 | 43.24 | **-35** | 100.33 | 57.74 |
| **-21** | 132.26 | 87.69 | **-24** | 118.41 | 68.27 |
| **23** | 28.61 | 18.74 | **-103** | 57.92 | 51.28 |
| **-110** | 29.3 | 23.96 | **Flat** | 268.6 | 268.6 |
| **13** | 51.79 | 28.55 | **-24** | 92.88 | 59.58 |
| **-80** | 234.41 | 234.41 | **-35** | 76.14 | 52.45 |
| **-10** | 44.99 | 27.11 | **-56** | 28.06 | 24.66 |
| **-47** | 38.77 | 29.93 | **35** | 70.97 | 32.2 |
| **-10** | 38.09 | 24.2 | **55** | 99.4 | 69.24 |