Photovoltaic Power from Commercial and Industrial Rooftops – Analysis for Cities of Brimbank and Hobsons Bay in Victoria, Australia

Mark A. NUCCIO[1], Cagil R. OZANSOY[1] and Zahir TARI[2]

[1]College of Engineering and Science
Victoria University, Melbourne, Australia
cagil.ozansoy@vu.edu.au,
[2]School of Computer Science & IT
RMIT University, Melbourne, Australia
zahir.tari@rmit.edu.au

Abstract

Climate-change concerns are driving governments to plan for the development and implementation of sustainable electricity generation systems. To aid with the task of reducing the continent's Greenhouse Gas (GHG) emissions alliances are being formed between local councils. The Western Alliance for Greenhouse Action (WAGA) is such an alliance formed by seven councils in Melbourne's west. One of the main goals of the alliance is the planning and development of hybrid renewable energy systems as environmentally friendly substitutes for the current coal-fired power stations, which at present supply the electricity consumed in the region. This paper presents the results of a study conducted to assess the solar electrical energy potential from identified commercial and industrial roofing within the alliance's municipalities. In this study, the analysis for the cities of Brimbank and Hobsons Bay is outlined. The results demonstrate that 1115 GWh of solar electrical energy can be generated annually in the two councils from commercial and industrial rooftops, which corresponds to an emissions savings of 1,359 ktonne CO_2 –e.

1. Introduction

Electricity generation in coal-fired central power stations is a major issue in Australia, much like the rest of the world, due to the increased concerns on climate change [1]. However, the Australian public is dedicated to playing a role in taking responsible action for investing in the low pollution economy of the future. Federal, state and local governments in Australia are planning schemes and implementing strategies to reduce Australia's GHG emissions and to provide a sustainable energy future for all Australians [2]. A major focus is on the planning and development of small-scale distributed electricity generation systems from renewable sources. WAGA is an alliance of seven councils in the western region of Melbourne, committed to working together to reduce their GHG emissions and those of Melbourne's western region. The alliance's objective is to assist with the transformation of the region's economy from climate damaging to climate friendly in a practical and transferable way ensuring economic development to proceed in a sustainable manner [3]. The development and implementation of hybrid renewable energy systems is at the heart of this strategy.

WAGA is working closely with researchers to analyse the region's renewable energy resources and generation capacity from these resources as a substitute for coal-fired generation. This paper outlines an internship project conducted at Victoria University by a final year Engineering student. The aim was to analyse the potential for generating solar energy from photovoltaic modules that can potentially be installed on identified commercial and industrial rooftops in two municipalities in Melbourne's west. The work in this paper presents the results of a preliminary investigation carried out to demonstrate how one of the cleaner energy sources, solar power, could theoretically generate enough power to substitute coal-fired generation.

1.1. Grid-Connected Photovoltaic Systems

Grid-connected Photovoltaic (PV) systems combine multiple PV modules with an inverter and a meter connected to the electricity grid as shown in Fig. 1. PV arrays can be integrated into the structure of a building, known as Building-Integrated Photovoltaics (BiPV), or placed on top of a structure such as a rooftop or a pole. With any fixed PV array, the path of the sun must be taken into account to maximize the amount of power generated from the system.

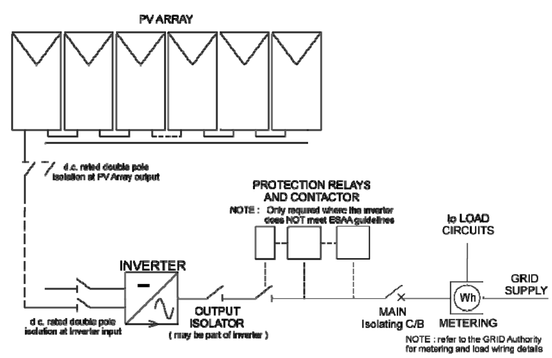

Fig. 1. Grid-connected PV system configuration [4]

Fig. 2 shows the apparent motion of the sun from a fixed point, in this case an observer. In Australia, the maximum insolation occurs at solar noon due true north. The shaded circles represent solar noon plus or minus three hours. This outlines the daily range for which most power is generated from a PV system. The summer and winter solstices determine the range of tilt for a fixed array where the rule of thumb is to fix the array at the location's latitude.

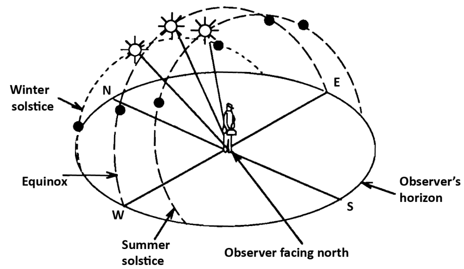

Fig. 2. Apparent motion of the sun from a fixed point in the southern hemisphere. Adapted from *Applied Photovoltaics [5]*.

1.2. Cities of Brimbank and Hobsons Bay

The city of Brimbank, in Melbourne's west, covers 123.38 km^2 and encompasses 25 suburbs. Brimbank plans to utilise its 4.32 km^2 of commercial and industrial roof space to cut its carbon footprint using grid-connected PV systems. These rooftops are marked in yellow within Fig. 3a. The city of Hobsons Bay covers an area of 64 km^2 and as shown in Fig 3b, 2.2 km^2 of commercial and industrial roof space has been identified as potential sites for the installation of PV systems in the municipality.

The analysis and calculation of the solar energy potential in the city of Brimbank, was carried out by determining the amount of solar insolation upon these commercial and industrial rooftops identified as possible sites for photovoltaic installations. The total rated electricity generation capacity for the identified roof top area was then determined based on the roof area specifications as well as ratings and dimensions of the chosen PV panels. The annual power output for the entire area to be covered with PV panels was then calculated taking into account the effects of changes in ambient temperature, insolation levels, and other factors. The emission savings that can be achieved from the proposed development have also been determined. It is important to take note that it is assumed all PV panels are angled at 30°, that they are grid-connected without any form of energy storage and that the entire roof area can accommodate the PV panels.

2. Calculating energy from the sun

The approach taken is as follows: first, the amount of solar radiation incident acting upon the roof tops was determined, and then the average air temperature for the location was obtained. This was followed with an estimate of the amount of energy that can be generated for a given roof area. The capacity factor was calculated, and GHG savings estimated.

2.1 Daily Solar Radiation and Air Temperature

Generating accurate production estimates necessitates local climate information. Data for Melbourne (latitude 37.8°N and longitude 145°E) was chosen for its relevant proximity to the municipality. Average daily power from the sun, listed in Table 1, was obtained from the Australian Solar Radiation Data Handbook [6] and average air temperatures were sourced from the Australian Bureau of Meteorology covering the years from 1855 to 2008 [7].

Table 1. Average daily insolation values and average maximum daily temperature values for Melbourne, VIC

Month	Insolation Horizontal (kWh/m²/d)	Air Temperature (°C)	Insolation Tilted 30° (kWh/m²/d)
Jan	6.67	25.90	6.61
Feb	5.94	25.80	6.39
Mar	4.53	23.90	5.42
Apr	3.17	20.30	4.25
May	2.11	16.70	3.08
Jun	1.69	14.00	2.58
Jul	1.89	13.40	2.86
Aug	2.56	14.90	3.50
Sep	3.58	17.20	4.44
Oct	4.83	19.60	5.39
Nov	5.89	21.90	6.00
Dec	6.53	24.20	6.33
Avg.	**4.11**	**19.80**	**4.75**

The values in Table 1 have been plotted in Fig. 4 to outline the air temperature and the effects of a 30° tilt angle when compared to a horizontal plane. Increasing the tilt angle optimises the array for winter generation whereas decreasing the tilt angle optimises the array for summer generation. This is only valid for a range of angles and will result in reduced energy generation if exceeded.

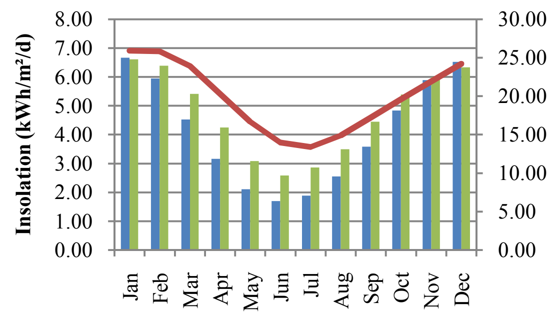

Fig. 4. Comparing horizontal and tilted panel insolation, and average maximum daily temperature

2.2 Energy Production

In order to estimate the annual energy production this paper uses the BP 3175 175W polycrystalline module [8]. Equations (1), (2), (3) and (4) take into account the losses associated with increased ambient temperature; module mismatch, 3% loss; module cleanliness, 4% loss; and inverter efficiency, 90% [9]. The temperature of the cell is calculated first to find the amount of power lost to increases in ambient temperature. This is due to the negative temperature co-efficient characteristic of a PV panel.

$$T_{cell} = T_{amb} + \left(\frac{\text{NOCT} - 20^{\circ}}{0.8}\right) S \qquad (1)$$

Where $\boldsymbol{T_{cell}}$ is the temperature of the PV cell, $\boldsymbol{T_{amb}}$ is the average daily maximum temperature, **NOCT** is the nominal operating cell temperature and S is the solar insolation.

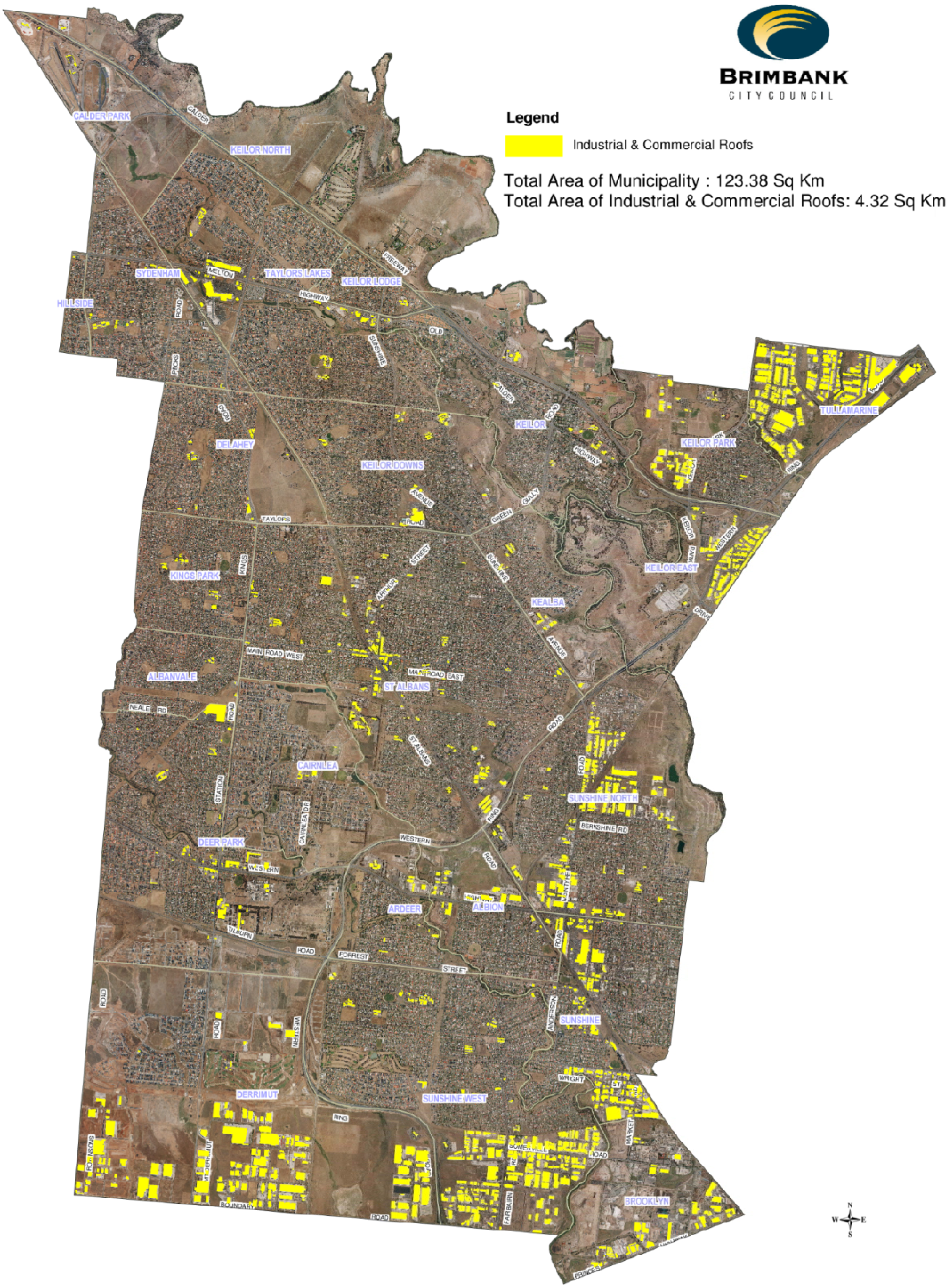

Fig. 3a. Brimbank's proposed area for grid-connected PV systems [10]

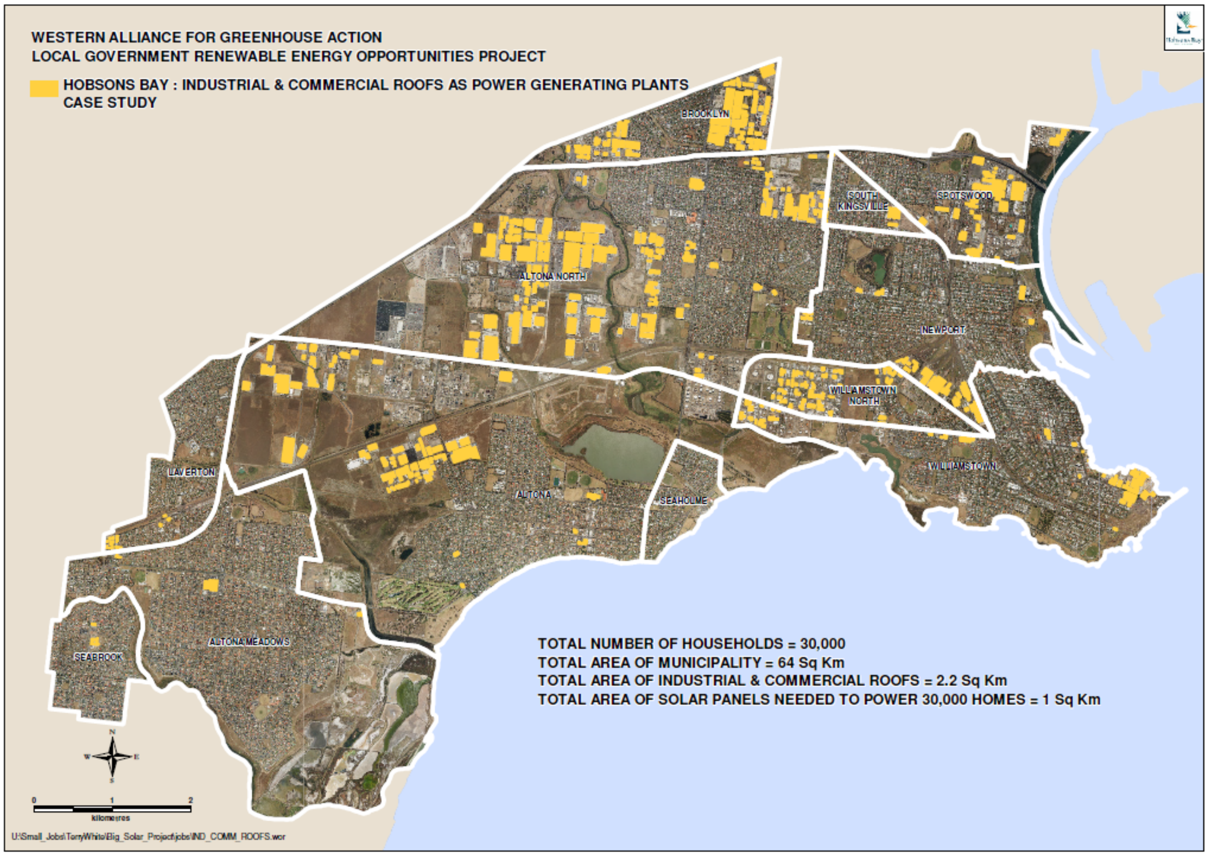

Fig. 3b. Hobson Bay's proposed area for grid-connected PV systems [11]

The amount of power that the array can produce can be calculated from (2) using the now known temperature of the cell and rated power of the array. The rated power of the array is calculated by dividing the area of the panel by the area to be covered and multiplying by the rated power of each panel. Eq. (3) is used to calculate the amount of power leaving the inverter.

$$P_{dc} = P_{array}[1 - \mathrm{TC}(T_{cell} - T_{std})] \qquad (2)$$

$$P_{ac} = P_{dc}\,\eta_c \qquad (3)$$

Where $\boldsymbol{P_{dc}}$ is the derated dc power, $\boldsymbol{P_{array}}$ is the rated dc power of array, $\mathbf{TC}$ is temperature coefficient of $\boldsymbol{P_{max}}$ and $\boldsymbol{T_{std}}$ is the standard test conditions cell temperature. $\boldsymbol{P_{ac}}$ is the derated ac power and $\boldsymbol{\eta_c}$ is the conversion efficiency accounting for module mismatch, module cleanliness and inverter efficiency.

The amount of power leaving the inverter annually is then calculated as in (4).

$$E = P_{ac}(sun\ hrs/day)(days/month) \qquad (4)$$

Where $\boldsymbol{E}$ is the total energy generated and sun hrs/day is the insolation e.g. 4.75 kWh/m²/d = 4.75 h/day [9].

2.3 Capacity Factor and GHG Emission Savings

Since PV relies on a fuel source that is absent for half the day, its capacity factor tends to be much lower than other energy sources. Annual capacity factor is calculated by dividing the annual energy generated by the annual rated capacity and the number of hours in a year (8760) as in (5)[9].

$$CF = \frac{E_{annual}}{8760\,P_{ac}} \qquad (5)$$

CO_2-e savings is calculated by multiplying the GHG coefficient by the annual energy produced by the PV system as in (6) [12]. GHG coefficients are calculated for each state in Australia based on the type of fuel used at their power stations. Victoria has a high coefficient due to heavy reliance on brown coal.

$$\mathrm{GHG} = 1.22\,E_{annual} \qquad (6)$$

Where 1.22kg CO_2-e is the GHG coefficient for Victoria in 2008 [13] and E_{annual} is the annual energy produced by the system. Note that the GHG released when manufacturing the PV system is not considered.

3. Analysis of Results

Using (1-4) and a spreadsheet, Fig. 5 has been created detailing the generation potential per month from 3.429 million PV modules which annually produce 739 GWh of electricity. This equates to an emissions saving of 901,000 tonnes of CO_2-e per year. The total capacity of the system is 430 MW (P_{ac}) with a capacity factor of 0.196. In the case of the Hobsons Bay municipality, the analysis has shown that an energy yield of 376 GWh of electricity per year can be generated from the available roof space using 1.74 million PV modules in the municipality with an emission savings of 458,000 tonnes of CO_2-e. The total derated ac power of the system is 220 MW with a capacity factor of 0.196.

The results demonstrate that 1115 GWh of solar electrical energy can be generated annually in the two councils from commercial and industrial rooftops, which corresponds to an emissions savings of 1,359 kilotonnes CO2 –e. This corresponds to a total capacity of 650 MW with a capacity factor of 0.196. The only drawback is that approximately 5.16 million PV modules must be used.

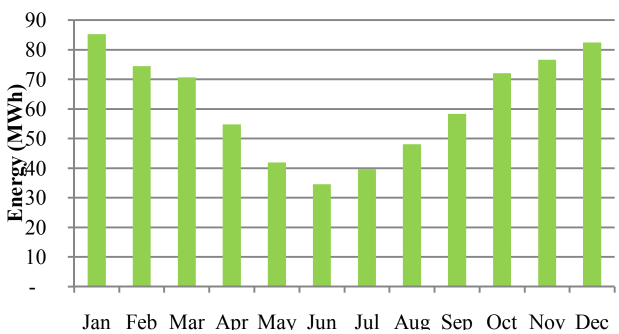

Fig. 5. Monthly energy generation for entire roof space.

WAGA region consumes around 1000 MW of power on average annually. This is equivalent to the rated power output capacity of the Loy Yang B Power Station, which is the state's newest base load power station producing 1026 MW of electricity using brown coal from the adjacent Loy Yang open cut mine. The results obtained in this paper show the massive magnitude of the PV system (5.16 million PV modules) that would be required to substitute only 65% of this capacity not bearing in mind the intermittency and other technical issues (such as energy storage) that would be associated with such a massive implementation. The results demonstrate that PV on its own can't practically substitute for coal-fired generation and must definitely be accompanied by wind and gas-fired generation if energy from cleaner sources is required. The results demonstrate why it is such a big challenge to move away from the traditional centralised generation approaches.

4. Conclusion

Photovoltaic power has huge potential in Australia. The main requirements of sunshine and land are abundant making it an ideal place for PV installations. The method outlined within this paper provides an accurate forecast into the annual energy generation possible for a given PV array including calculations for capacity factor and carbon emissions.

1115 GWh of solar electrical energy can be generated annually from an area of 6.52 km^2 commercial and industrial rooftops. This corresponds to an emissions savings of 1,359 kilotonnes CO2 –e. The total derated capacity of such a system would just be 650 MW, no sufficient on its own for the area, with a capacity factor of 0.196. The only major drawback is that approximately 5.16 million PV modules must be used to build such a system, which is rather impractical and not realistic.

5. Acknowledgement

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