# EVALUATION OF SOLAR PHOTOVOLTAIC PANEL PERFORMANCE AND ESTIMATION OF SOLAR ENERGY POTENTIAL IN KOTA KINABALU, SABAH


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**FACULTY OF SCIENCE AND NATURAL RESOURCES**
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**2017**

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**THESIS SUBMITTED IN FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE**

**FACULTY OF SCIENCE AND NATURAL RESOURCES**
**UNIVERSITI MALAYSIA SABAH**
**2017**

**DECLARATION**

I hereby declare that the material in this thesis is my own except for quotations, excerpts, equations and summaries, which have been acknowledged.

23th August 2017

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## CERTIFICATION

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23th August 2017

## ABSTRACT

The world is currently facing environmental damages partially caused by increasing in energy consumption from conventional energy sources such as fossil fuels. Hence, renewable energy such as solar energy, which is regenerated naturally, is currently receiving considerable attention for energy generation. To sustain electricity generation from solar energy, consistent solar radiation is preferable throughout the year, and complete information on the daily, monthly and yearly radiation profile are required for further development planning. Kota Kinabalu, the capital city located in the west coast of Sabah, was claimed to be one of the areas that receives the highest solar radiation every year in Malaysia. This research was carried out to assess the potential of electricity generation in Kota Kinabalu that may serves as guidelines for future planning. The global solar radiation was first measured and acquired for the year 2014 and 2015 in Kota Kinabalu. Concurrently, electrical power generation was assessed using solar photovoltaic panels at certain period of time. From these data, prediction was carried out to assess the potential electrical generation in Kota Kinabalu for that years. It was found that total energy received in 2014 was 1.6MWh/m$^2$ with the average of 133.4kWh/m$^2$ and the maximum peak of the global solar radiation was 1065.4W/m$^2$ on 2$^{nd}$ November 2014. On the other hand, the total global solar radiation received in 2015 was 2.1MWh/m$^2$ with the average of 175kWh/m$^2$ and the maximum peak was 1086.98W/m$^2$ on 12$^{th}$ March 2015. For electrical energy generation, it was found that the actual efficiency of energy conversion for uncooled and fixed solar photovoltaic panel was 13%. As a comparison, continuous cooling of the fixed solar panel had increased the efficiency to up to 16.7% whereas for uncooled dual tracking solar panel, the efficiency was slightly low which is 15.1%. With this efficiency, over 200kWh/m$^2$ of electricity could have been generated in each year in 2014 and 2015 using uncooled and fixed solar photovoltaic panel. On the other hand, almost 300kWh/m$^2$ could have been generated in 2014 and over 300 kWh/m$^2$ in 2015 when the solar panel was fixed but continuously cooled. However, just over 200kWh/m$^2$ and 300kWh/m$^2$ could have been generated in 2014 and 2015, respectively, when the solar panel has dual axis sun tracking system, without incorporating the cooling system. These amounts of electricity are quite substantial which shows the potential for developing solar energy power in Kota Kinabalu.

# ABSTRAK

## PRESTASI PENILAIAN PANEL FOTOVOLTAN SOLAR DAN ANGGARAN POTENSI TENAGA SOLAR DI KOTA KINABALU, SABAH

*Dunia kini menghadapi pencemaran alam sekitar disebabkan oleh peningkatan penggunaan tenaga konvensional seperti bahan api fosil. Oleh itu, tenaga boleh diperbaharui seperti tenaga solar adalah tenaga dijana semula secara semulajadi dan mendapat perhatian untuk generasi penjanaan tenaga. Untuk mengekalkan penjanaan elektrik daripada tenaga solar, radiasi solar yang konsisten adalah lebih baik dan maklumat yang lengkap untuk radiasi harian, bulanan dan tahunan diperlukan untuk perancangan pembangunan selanjutnya. Kota Kinabalu ialah ibu kota yang terletak di pantai barat Sabah, merupakan salah satu kawasan yang menerima radiasi solar yang tertinggi setiap tahun di Malaysia. Kajian ini telah dijalankan untuk menilai potensi penjanaan elektrik di Kota Kinabalu yang boleh dijadikan panduan untuk perancangan masa depan. Radiasi solar global telah diukur dan diperolehi bagi tahun 2014 dan 2015 di Kota Kinabalu. Pada masa yang sama, penjanaan kuasa elektrik telah dinilai menggunakan panel fotovoltek solar pada tempoh masa tertentu. Daripada data tersebut, generasi potensi elektrik di Kota Kinabalu telah diramal dan dinilai pada tahun tersebut. Didapati bahawa, jumlah tenaga diterima pada tahun 2014 adalah 1.6MWh/m$^2$ dengan purata sebanyak 133.4kWh/m$^2$ dan nilai maksimum radiasi solar global adalah 1065.4W/m$^2$ pada 2 November 2014. Sebaliknya, jumlah tenaga radiasi solar global diterima pada tahun 2015 adalah 2.1MWh/m$^2$ dengan purata 175kWh/m$^2$ dan nilai maksimum iaitu 1086.98W/m$^2$ pada 12 Mac 2015. Untuk generasi tenaga elektrik, didapati bahawa kecekapan sebenar penukaran tenaga untuk sistem panel fotovoltek tanpa penyejukan dan paksi tetap adalah 13%. Secara perbandingan, kecekapan sistem penyejukan berterusan untuk panel solar yang tetap meningkat sehingga 16.7% manakala kecekapan penjejakan paksi dwi tanpa penyejuk sedikit rendah iaitu 15.1%. Dengan kecekapan tersebut, lebih 200kWh/m$^2$ elektrik telah dijana pada tahun 2014 dan 2015 menggunakan solar fotovoltek tanpa penyejuk dan paksi tetap. Sebaliknya, hampir 300kWh/m$^2$ pada tahun 2014 dan lebih 300kWh/m$^2$ pada tahun 2015 untuk panel solar sejuk berterusan tetapi tetap. Bagaimanapun, lebih 200kWh/m$^2$ and 300kWh/m$^2$ yang boleh dijana apabila panel solar menggunakan sistem penjejakan paksi dwi tanpa menggabungkan sistem penyejukan. Jumlah elektrik yang agak besar menunjukkan potensi untuk pembangunan tenaga kuasa solar di Kota Kinabalu.*

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## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AC | - | Alternating current |
| AM | - | Air mass |
| Btu | - | British Thermal Unit |
| c | - | speed of light |
| cm | - | Centimeter |
| $CO_2$ | - | Carbon dioxide |
| cos | - | Cosine |
| DC | - | Direct current |
| E | - | East |
| E | - | Equation of time |
| eV | - | Electron volt |
| FF | - | Fill factor |
| GW | - | Giga Watt |
| h | - | Hour |
| IV | - | Current voltage |
| K | - | Kelvin |
| km | - | Kilometer |
| kW | - | Kilo Watt |
| $kWh/m^2$ | - | Kilo Watt hour per meter square |
| m | - | Meter |
| $m^2$ | - | Meter square |
| mA | - | mili Ampere |
| min | - | Minutes |
| $MJ/m^2$ | - | Mega joule per meter square |
| MW | - | Mega Watt |
| $mW/cm^2$ | - | Mili Watt per centimeter square |
| N | - | North |
| PV | - | Photovoltaic |
| PV | - | Power voltage |
| S | - | South |
| SBE | - | Solar Beam Experiments |
| SDR | - | Symphonie Data Retriever |

| | | |
|---|---|---|
| sin | - | Sine |
| STC | - | Standard Test Conditions |
| T | - | Cell working temperature |
| tan | - | Tangent |
| UMS | - | Universiti Malaysia Sabah |
| V | - | Volt |
| W | - | West |
| $W/m^2$ | - | Watt per meter square |
| $Wh/m^2/d$ | - | Watt hour per meter square per day |
| Wp | - | Peak Watt |

## LIST OF SYMBOLS

| | | |
|---|---|---|
| % | - | Percent |
| ± | - | Plus minus |
| Σ | - | Sum/total |
| ° | - | Degree |
| °C | - | Degree Celsius |
| A | - | Ampere |
| A | - | Ideality factor |
| $\bar{G}$ | - | Global radiation |
| G | - | Irradiance |
| $\bar{G}_b$ | - | Direct radiation |
| $\bar{G}_{bt}$ | - | Beam radiation on tilted surface |
| $\bar{G}_d$ | - | Diffuse radiation |
| $\bar{G}_{dt}$ | - | Diffuse irradiance on tilted surface |
| $G_{oh}$ | - | Average extraterrestrial horizontal radiation |
| $G_{on}$ | - | Normal extraterrestrial radiation |
| $\bar{G}_r$ | - | Ground reflected |
| $G_{sc}$ | - | Extraterrestrial radiation |
| $\bar{G}_t$ | - | Global radiation on tilted surface |
| h | - | Planck's constant |
| $I_{cell}$ | - | PV cell output current |
| $I_d$ | - | Diode current |
| $I_{max}$ | - | Maximum current |
| $I_{MPP}$ | - | Maximum power point current |
| $I_{ph}$ | - | Photon current |
| $I_{PV}$ | - | PV panel output current |
| $I_s$ | - | Saturation of current diode |
| $I_{sc}$ | - | Short circuit current |
| $K_B$ | - | Boltzmann's constant |
| $n_p$ | - | Number of strings connected in parallel in panel |
| $n_s$ | - | Number of cell connected in series per string |
| $\phi_i$ | - | Interval electrical field |
| $P_{in}$ | - | Power input |

| | | |
|---|---|---|
| $P_{MPP}$ | - | Maximum power point power |
| $P_{out}$ | - | Power output |
| $P_\lambda$ | - | The energy radiated per unit time per unit area |
| $q$ | - | Electron charge |
| $R_b$ | - | Geometric factor |
| $R_s$ | - | Series resistant |
| $R_{sh}$ | - | Shunt resistant of the cell |
| $t_c$ | - | Convert civil time |
| $t_s$ | - | Solar time |
| $V_{cell}$ | - | PV cell output voltage |
| $V_d$ | - | Diode voltage in Volts |
| $V_{max}$ | - | Maximum voltage |
| $V_{MPP}$ | - | Maximum power point voltage |
| $V_{oc}$ | - | Open circuit voltage |
| $V_{PV}$ | - | PV panel output voltage |
| W | - | Watt |
| $x_1$, $x_2$ | - | x-intercept |
| $Z_c$ | - | Time zone East of GMT |
| $\beta$ | - | Surface inclination |
| $\gamma$ | - | Surface azimuth angle |
| $\gamma_s$ | - | Solar azimuth angle |
| $\delta$ | - | Declination of the sun |
| $\eta$ | - | Efficiency ratio |
| $\theta$ | - | Incident angle |
| $\Theta_z$ | - | Zenith angle |
| $\lambda$ | - | Wavelength of light |
| $\mu$ | - | Micro |
| $\mu$A | - | Micro Ampere |
| $\pi$ | - | pi |
| $\rho$ | - | Rho |
| $\varphi$ | - | Phi |
| $\psi$ | - | Line of longitude |
| $\omega$ | - | Hour angle |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

Energy is necessary in all aspect of commercial as well as activities manage by human. Energy generation is one of the main issues in economic and social growth worldwide. Contamination of the environment and climate change are huge challenges faced humankind. Concurrently, Earth is facing environmental destruction caused by increasing energy utilization from high contaminating energy sources, such as oil, gas and coal. The environmental harm such as global warming, green-house effect and others can be minimized with renewable energy source.

Currently, our world is facing huge challenges with the increasing usage of main energy. The increasing of the main energy usage in worldwide is as shown in Figure 1.1.

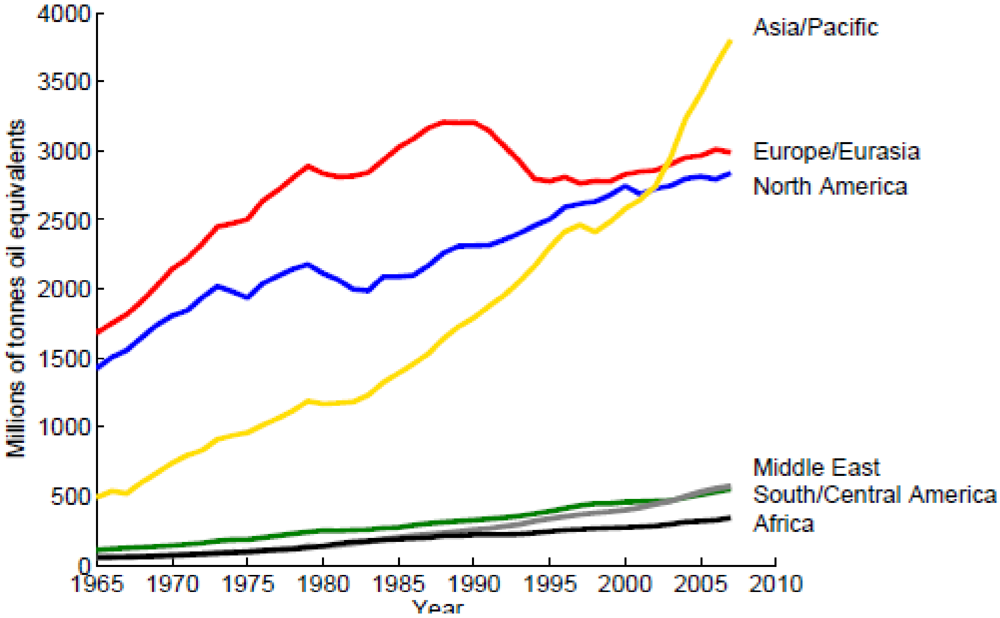


**Figure 1.1: Main energy use in different regions of the world between 1965 and 2007**

Source : Statistical review of world energy



Figure 1.1 shows the growth of main energy use throughout the last 40 years in different place of the world. Europe and North America ranked for the major parts all over the period. On the other hand, over the last periods, there has been a noticeable rise in Asia and the Pacific, follow by economic growth in India and China. This development is estimated to speed up (International Energy Agency, 2008). The existing combination of main resources is greatly controlled by fossil fuels as shown in Figure 1.2. The leading usage of fossil fuels is liable for the two main complications with the current energy system. Oil, natural gas and coal make up as much as 88% of the used resources. Fossil fuels are made over long periods and despite new resource deposits may be revealed, the utilization of the resources is rapidly than the propagation (Kraushaar, 1993). Supporters of Peak Oil declare that the oil manufacture is near or at its maximum and that the world will experience speed up in reduction amount of oil production in the upcoming future (Höök, 2009). Combustion of these fuels creates energy which is transformed into electrical energy. As the product of incineration, it will increase the pollutants such as carbon dioxide and sulphur dioxide that lead to several pollution problems.

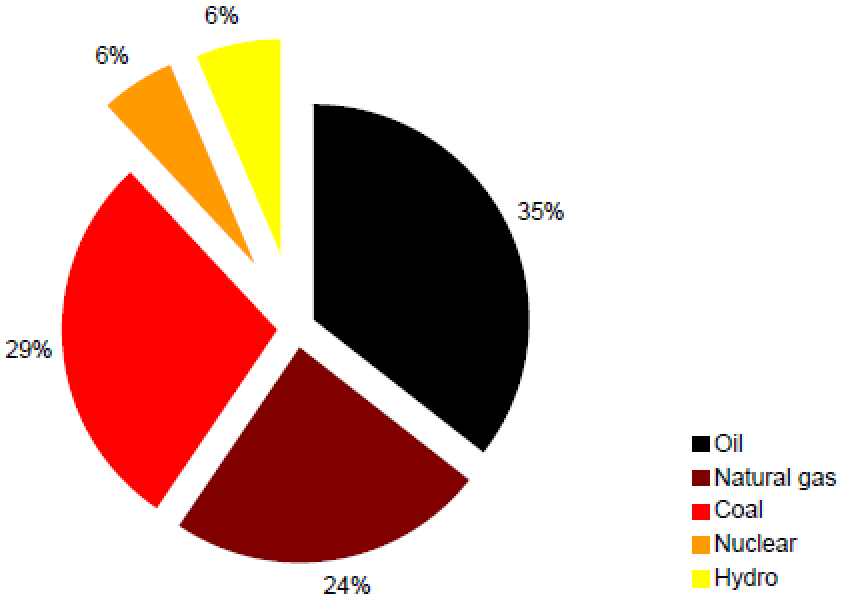


**Figure 1.2: Contribution of different resources to the total main energy claim in the world in 2007**

Source : Statistical review of world energy



Intergovernmental Panel on Climate Change, IPCC, expects that the increase in global mean temperature throughout the 21st century will be less than 1°C from the era of 1980-1999. Whenever the $CO_2$ concentrations continue at the year 2000 levels, but probably as high as 6°C with the most horrible situation (IPCC, 2007). The expected implications for the climate, ecosystems and society are profound include sea level rise, freshwater dearth, corrosion, risky weather events and causing straining on world economy (IPCC, 2007).

The possibility of severe environmental and economic problems can be improved by alternative energy that is renewable energy. Renewable energy resources have enormous potential and can satisfy the present world energy demand. It is also the solution for a sustainable, clean, cheaper energy and environmentally friendly since they have a much lower environmental effect than conventional sources (Salsabila, 2013 and Bulent, 2015). Categories of renewable