Feasibility Study for a Sustainable Campus Using Solar PV Renewable Energy Technology: A Case Study at the National University of Samoa.

By: Faafetai Kolose
Submitted: July 2015
Abstract

Fossil Fuels have a significant impact on small island countries in the Pacific. Sustainable developments are key for the development of these countries. One such strategy involves using renewable energy resources that are locally available. This paper focuses on a feasibility study for a sustainable campus at the National University of Samoa using a grid connected PV system.

Information from eight years of historical energy consumption, seven weeks of energy load profile data and the potential rooftops of buildings for the two campuses (upper and lower) were analysed using RETScreen and HOMER software.

The pre-feasibility study by RETScreen revealed that it is possible to offset all the university electricity consumptions from solar panels from all the university rooftops buildings to achieve sustainable campus. Also, the HOMER feasibility analysis for 25 years shows that it is economically viable for the university to have its electricity supplied by a grid connected PV system. This is based on the feed-in-tariff of $0.25 AUD, electricity retail price of $0.50 AUD, a real interest rate of 8%, the average market price of the PV panel, battery and inverter.

However, it is not technically possible for the university to have such a system, due to the utility requirements unless energy storage is used. HOMER simulation revealed that system with batteries become more expensive and uneconomical for the university.

It is recommended that a strong support from the government is required for the National University of Samoa in order to achieve a sustainable campus through the use of a grid connected PV system. Also, more research is needed in the area of electrical energy storage in order to increase the solar PV penetration onto the diesel utility grid in the country.
Acknowledgements

I acknowledge and express my sincere gratitude to the following people for their contribution, which has assisted me in delivering this thesis.

1. *Thesis Supervisor* – Dr. Trevor Pryor of Murdoch University for sharing your expertise and knowledge, which guided me throughout the course of this project.


3. *Staff of the National University of Samoa* – Professor Fui Asofou So'o, Peseta Dr. Desmond Lee Hang, Tuala Amerika Siale, Taito John M Roache, Aloaina Galuvao Iluminado Aloaina, Mandria Sua, Timu Henry Simi, Agape P Seilala, and Dave Pouono.

4. *Assistant Chief Executive Officer, Energy Policy Division, MOF, Samoa* – Sione Foliaki.


6. *Principal Scientific Officer, Section Head Climate Services Section, Samoa* – Fata Lagomauitumua Sunny K. Seuseu.

Lastly, my family and friends for their encouragement, prayers and support.

Faafetai Kolose
Table of Contents

Title .................................................................................................................................................. 1

“Feasibility Study for a Sustainable Campus Using Solar PV Renewable Energy Technology: A Case Study at the National University of Samoa.” ................................................................. 1

Abstract........................................................................................................................................... 2

Acknowledgements.......................................................................................................................... 3

Acronyms.......................................................................................................................................... 7

1. Background and Research Question............................................................................................. 8
   1.1. Background ............................................................................................................................... 8
   1.2. Research Questions .................................................................................................................. 12
   1.3. Structure of the Dissertation.................................................................................................... 13

2. Literature Review............................................................................................................................ 13
   2.1. Developments in the PV Market and the Declining Costs of PV Modules ......................... 13
   2.2. The Growth of Solar PV Systems in the Pacific Island Countries (PIC) .............................. 16
   2.3. Grid-Connected PV for a Sustainable University Campus .................................................. 17

3. Methodology................................................................................................................................ 18
   3.1. Determining the Energy Consumption and the Energy Load Profile at NUS .................... 18
   3.2. Determining the Electricity to be extracted from Solar Renewable Energy Resources .... 19
   3.3. Analysing the technical and economic feasibility of different solar PV installation options 20

4. Results.......................................................................................................................................... 24
   4.1. Electricity Consumptions and Electricity Load Profile ........................................................... 24
   4.2. Electricity that could be Extracted from rooftops at NUS Buildings .................................... 31

5. Discussions................................................................................................................................... 49
   5.1. Economic Aspects of the Energy Supply Scenarios ............................................................... 49
   5.2. Technical Aspects of the Energy Supply Scenarios ............................................................... 50
   5.3. Social Barriers for Implementing Large-scale Solar Projects .............................................. 52
   5.4. Limitations of this Study ........................................................................................................ 53
   5.5. Benefits of Solar PV in Institutional Settings ....................................................................... 55

6. Conclusions.................................................................................................................................. 55

7. References .................................................................................................................................... 57

8. Appendices.................................................................................................................................... 63
   8.1. Appendix A: Upper Campus ................................................................................................. 63
   8.2. Appendix B: Lower Campus ................................................................................................. 63
   8.3. Appendix C: Battery Specification ........................................................................................ 64
List of Figures and Tables
Figure 1: Administration Budget ................................................................. 9
Figure 2: Electricity costs relative to the total administration running cost .................. 10
Figure 3: The National University of Samoa campuses ........................................ 11
Figure 4: Locations of Two Electrical Utility meters ............................................. 12
Figure 5: World Module Price Trends ................................................................ 14
Figure 6: Average PV Module Prices .................................................................. 14
Figure 7: Annual PV Installations from 2005 to 2014 .............................................. 15
Figure 8: Cumulative PV installations from 2005 to 2014 ........................................ 15
Figure 9: Global Grid Connected PV Market ........................................................ 16
Figure 10: Photovoltaic Specification ................................................................... 20
Figure 11: Simulation Model for HOMER ............................................................ 20
Figure 12: PV Input Specification ......................................................................... 21
Figure 13: Economic Inputs Setting ...................................................................... 23
Figure 14: HOMER Simulation Model with Batteries .............................................. 24
Figure 15: Yearly Total Electrical Unit Consumption at NUS ................................. 25
Figure 16: NUS Electricity Consumption Trend (2007-2014) .................................... 26
Figure 17: Max, Min, and Average Total Monthly Electricity Consumptions (2008–2014) 26
Figure 18: NUS Daily Electricity Load Profile in 30 minutes interval ....................... 27
Figure 19: NUS 12 Hour Daily Electricity Consumptions (kWh) ............................... 28
Figure 20: Lower Campus Estimated Daily Electricity Consumption ....................... 30
Figure 21: Upper Campus Estimated Daily Electricity Consumption ....................... 30
Figure 22: Estimated Average Monthly Energy Consumption at NUS ...................... 31
Figure 23: Solar radiation parameter at NUS .......................................................... 32
Figure 24: Sun Path Chart for NUS ...................................................................... 33
Figure 25: Monthly Average Daily Solar Radiation for different Slopes .................... 33
Figure 26: Column Graph for Monthly Average Daily Solar Radiation for different Slopes 34
Figure 27: Solar Electricity from the Largest Rooftop in the Upper Campus ............... 38
Figure 28: Solar Electricity Produced from the Largest Rooftop in the Lower Campus 38
Figure 29: Solar Electricity Produced from the Lower Campus Offsetting 2014 Electricity Consumptions ................................................................. 39
Figure 30: Solar Electricity from all Rooftops facing North ...................................... 39
Figure 31: Solar Electricity from all the Rooftops in the Upper Campus ..................... 40
Figure 32: Option 1 for Offsetting Electricity in the Upper Campus .......................... 41
Figure 33: Option 2: Solar Electricity to Offset all Electricity needed for the Upper Campus 42
Figure 34: Option 3: Solar Electricity required to offset all Electricity needed for the Upper Campus 43
Figure 35: Ideal Total Solar Electricity and the Maximum Electricity consumed from 2008–2014 44
Figure 36: Ideal Total Solar Electricity reduced by 25% and Maximum electricity consumption increased by 20% .......................................................... 45
Figure 37: Simulation Result for Option 4 ............................................................. 47
Figure 38: Simulation Output Details for Option 4 .................................................. 47
Figure 39: Monthly Average Electric Production from Option 4 ............................... 47
Figure 40: Base Case versus Current System, Option 4 ........................................... 48
Acronyms
ac - Alternating Current
ADO - Automotive Diesel Oil
dc - Direct Current
kWh - Kilo watt hour
LC - Lower Campus
NPC - Net Present Cost
NPV - Net Present Value
NUS - National University of Samoa
PV - Photovoltaic
UC - Upper Campus
PPA - Power Purchasing Agreement
1. Background and Research Question

1.1. Background

Since Samoa became independent in 1962, establishment of its own university was needed for the development of the country. Thus, in 1984, the National University of Samoa (NUS) was established to provide university education for all Samoans (Soo 2014). Today, the university is still developing. It has expanded into many different areas of study disciplines, new courses and programs have been designed and introduced, additional buildings constructed, and the enrolment intake is still growing. However, the expansion of the university comes with costs, one of them being electricity.

Figure 1 shows the average administration expenses from 2008-2014 for NUS. Clearly, 28% of the expenses is electricity. This electricity cost could have been increased in proportion to the increasing administration expenses from 2010 to 2014 (Figure 2), if it was not for the electricity saving strategy called “Dark Friday”, which was introduced and enforced by the university in the middle of 2008. “Dark Friday” is an energy conservation measure specifying that on every Friday, all lights, fans, and air conditioning units are turned off except essential equipment.
Figure 1: (Source: NUS 2010, NUS 2011, NUS 2012, and NUS 2013) Administration Budget
Although the “Dark Friday” strategy was very effective in keeping electricity costs at a constant level over the seven year period, according to the Director of Financial services, the university electricity bills are still considered very high. Given the current rate of expansion at NUS\(^1\), this strategy will become insufficient in the near future. Hence, there might be a possibility that NUS will have a second day of the week similar to “Dark Friday”; however, the likelihood of this is very minimal since occupants are already experiencing uncomfortable conditions resulting from “Dark Friday”.

Uncomfortable conditions in the tropical environment are high temperature and high humidity, and low level of lighting in office buildings on Fridays. Most of the office buildings were originally designed to operate with lights and air conditioning units. According to Sanaz and Samani (2012), poor lighting impedes students’ learning. These negative experiences raise a question for some people about whether a “Dark Friday” strategy is actually achieving the goal of a sustainable university campus.

Electricity costs are beyond the control of the university because they are mainly determined by oil products (Matt and Sugden 2010). Samoa’s gross electricity generation derived from Automotive Diesel Oil (ADO), an imported commodity, is 72% of the total electricity generation (MOF 2012a). Furthermore, any fluctuations in the oil market on a global scale consequently affects the electricity pricing in the country (MOF 2012b), thus affect NUS electricity bills.

Even though electricity cost is beyond the control of the university, the university can indirectly manage its consumption by using the energy conservation strategy “Dark Friday” and improving its energy efficiency\(^2\).

The other possibility of controlling electricity costs is the use of solar panels on rooftops of the university buildings. Discussion with the Dean of the Faculty of Science, Dr Desmond Lee Hang and

---

\(^1\) The NUS has a 10 year Strategic Plan (2010–2020), where a lot has taken place in improving the university. New NUS buildings are currently being built and this will definitely increase electricity costs for the NUS.

\(^2\) 400 energy-efficient T5 light bulbs and 12 high efficiency air conditioning units were installed in the beginning of 2015.
the campus manager, MandriaSu’a indicated that there is a possibility of offsetting all their electricity consumption with photovoltaic power because there was an indication that the utility will buy back any excess electricity produced during daylight hours. Hence, there is chance of offsetting all of their electricity demands with the output of the PV system(s) during the daylight hours. However, anecdotal information indicates that there are issues with connecting significant levels of PV on diesel grids in such situations.

The NUS has two main campuses: the upper campus is mainly for teaching degree classes, whilst the lower campus is for technical classes (Figure 3). The electricity to these campuses are fed from the 22kV overhead power line through two separate pad transformers of 500kVA and then into the power control room. The power is regulated in the power control room before it is distributed to the rest of the university campus. The electrical utility meters 1 and 2 (Figure 4), which measure the electricity consumption of the two campuses, are installed between the pad transformer and the power control room.

Figure 3: (Source: Googlemap.com) The National University of Samoa campuses
1.2. Research Questions

1.2.1. Questions

Given the need of the university to reduce its electricity bills and improve its status as a sustainable university campus, three main questions are addressed in this dissertation. The questions are:

- Using a grid-connected PV system, is it possible to offset all the electricity at the National University of Samoa given the roof space?
- If it is possible to offset all of its electricity, how effective is it in terms of costs and technical aspects?
- What are some of the options available in overcoming some of the issues and barriers of implementing a large-scale grid connected PV system in an island nation such as Samoa?

1.2.2. Objectives

The learning objectives that I expect to achieve from the dissertation process are to:

- Develop skills in formulating, undertaking and reporting on a research project.
- Develop a broad understanding of the technical knowledge on how PV systems operate in large scales.
- Develop a network with the local electrical utility engineers, policy makers, and leaders of the community.
- Develop skills in collecting and analysing technical and economic data and drawing conclusions.
- Develop communication skills in informing and making recommendations to the leaders, NUS board and the government effectively.
1.3. Structure of the Dissertation

This paper is structured as follows:

Section 2 provides a literature review, which explains the developments of the PV market, the declining costs of PV modules and the growth of PV solar systems in the Pacific. Finally, some examples of grid-connected PV systems for a sustainable university campus will be discussed.

Section 3 presents the methods that were used to find the answers to the three key questions in this paper. This section is divided in three sub-sections. The first sub-section describes how the energy consumptions and the energy load profile in NUS campus are determined. The second sub-section is the solar renewable energy resource assessment. This is followed by modelling the amount of electricity produced from different available rooftops of the university buildings. The final sub-section explains the technical and the economic feasibility of the different energy supply scenarios – a grid connected PV system and a grid connected PV system with batteries.

Section 4 presents the results and findings in section 3.

Section 5 discusses the results, some of the benefits, and possible solutions to the barriers and issues with solar PV systems.

The conclusion summarises the findings and the answers to key questions in this paper.

2. Literature Review

2.1. Developments in the PV Market and the Declining Costs of PV Modules

The price of PV cells and modules in the world market has continuously declined, whilst the installation capacity and production has increased (Figure 5, 6 and 7). The decline in solar PV prices is mainly due to the R&D investment for PV efficiency improvements and large-scale economies in order to lower production costs in manufacturing plants mainly in China and Taiwan (Jager-Waldau 2014). Over the last five years, more than 70% of worldwide production has been in China and Taiwan (Jager-Waldau 2014).

Despite the increased price of solar PV observed in 2007–2008 due to a silicon shortage (Figure 5 and 6), the PV production continues to grow due to aggressive manufacturers in Taiwan and China (Mints 2012).
According to the PV Status Report 2014, by Jager-Walday (2014, 8), the increase in the PV installation capacity in 2013 (Figure 7 and 8) was mainly due to markets in Asia, South Africa and USA. About 39.8 GW was expected in 2013 and 47 GW in 2014.
In terms of cumulative photovoltaic instalment, the European Union (EU) is still taking the lead, which has 80.7 GW of the 140 GW global instalment (Jager-Walday 2014, 8).

Solar PV in large scales has managed to reach grid parity in a number of markets due to increases in oil prices, the decline of PV prices and strong international competition (Ulrich, Nygaard and Pedersen 2014). According to Bazilian et al. (2013), solar PV in large scales have become competitive with large-scale diesel generators, whose fuels are not subsidised by the government. The current change in the PV market and the learning experience creates an overcapacity of PV production that leads to further decline in the world PV market price (Jager-Walday 2014).
In 2013, new renewable energy investments in Europe fell by 42%, which is less than half the region’s 2011 record, while United States and Brazil, which are the largest markets among the Americas, fell by 9% and 55% respectively. However, Asia and the Oceania region continued to grow at 10% (PEW 2014).

This growth of the PV market is mainly in grid-connected systems in large scales (Jager-Walday 2014, 8), which is also revealed by the GTM research group (cited in Shiao and Moskowitz, 2014) – see Figure 9.

![Global PV Grid Connected Capacity by Market (GWdc), 2012-2018](image)

**Figure 9:** Source: GTM Research (Cited in Shiao and Moskowitz 2014.)

2.2. The Growth of Solar PV Systems in the Pacific Island Countries (PIC)

In small island nations in the South Pacific, the installed capacity of grid-connected PV systems is growing. The growth is due to several factors such as the need to increase energy security and energy supplies, increased access to electricity services, climate change abatement, and decreasing of fossil fuel dependency (SPC 2015, IRENA 2013a). Donor funding is readily available (Jan 2006, 3) and is a major contributory growth factor for grid connected PV systems for PIC given the poor economic situation of many Pacific Island Countries (PIC).

For instance, the US$50 million from UAE-Pacific Partnership Fund supports the various PV solar projects across the pacific islands: a 400 kW solar plant in Kiribati, 350 kW in Tuvalu, 501 kW in Vanuatu, 600 kW in the Marshall Islands, 600 kW in the Solomon Islands, 500 kW in Nauru and 434 kW in Palau. These projects are expected to finish between 2015 and 2016 (Engerati 2014).

The following are some of the examples of hybrid, standalone and grid-connected PV systems installed on some of the island countries near Samoa.
Tonga Islands:

Tonga’s experience with Solar PV is more than 20 years. There have been solar projects in the past but these usually failed. Failures were mainly due to lack of capacity building, lack of support and high maintenance costs. However, lessons learned from past projects are valuable for the new installed grid-connected PV solar projects in Tonga. In 2012, Tonga completed a 1.3 MWp plant, which was funded by NZAID, the European Investment Bank (EIB) and Meridian Energy Ltd of New Zealand (IRENA 2013b). In 2015, another plant of 1 MW solar power system with 1 MW lithium ion capacitors (TPL 2011) was completed. It is the first micro-grid system in the Pacific region (JICA 2015).

Niue:

The grid connected PV system capacity already installed in Niue is 52 kWp, which is equivalent to 2% of the total electricity generation. The rest of the electricity is from diesel generators. Although Niue has good solar resources, the solar grid-connected system is limited due to grid instability. However, an additional 200 kWp ground mounted PV solar grid-connected with batteries is expected on the island. This project is mainly funded by the Japanese Pacific Environment Community (PEC) Fund (IRENA 2013c).

Fiji:

The Fijian islands, southwest of Samoa, have seen a continuous growth of PV solar systems. Since Fiji has many islands, the installed systems are of different sizes and types, which mainly depend on the different settings for each island. Some systems cater for remote islands, such as solar PV with batteries, while others are hybrid systems of PV-battery-diesels. For example, Turtle Island in Fiji has a 228 kWp PV, 120 kW battery and 120 kW diesel (Clay 2014). It is claimed to be the first resort in the world to run 100% on renewable energy (FSMLLC 2015). Also, spread across the islands of Fiji are about 3,600 solar home systems already installed, and an additional 2000 systems were expected to be completed in 2013 (Raturi, n.d). In 2012, a grid connected PV system of 45 kW was completed in the marine campus at the University of the South Pacific. The system was expected to generate 10% of the electricity needs of the lower marine campus (USP 2015).

Tokelau:

In the north of Samoa are three Tokelau Islands, which have a population of 1,411. It claimed to achieve 150% of its electricity needs from renewable energy. The system comprised 4,032 photovoltaic panels and 1,344 batteries. Also, coupled to the PV system are generators that run on coconut fuel (Wilson 2014).

2.3. Grid-Connected PV for a Sustainable University Campus

One approach taken by many universities in working towards sustainable campuses is the use of solar PV renewable energy technology. Sustainable university campus was first addressed in the Stockholm Declaration in 1972, when it was realised that university campuses consume a lot of resources and that their impacts on the environment and human health is tremendous (Savely, Carson and Delclos 2007). After the Stockholm declaration were several other declarations that address the importance of having sustainable university campuses, which many universities around the world took part in (Habib and Abubakar 2008).
As defined by Habib and Abubakar (2008), a sustainable University campus should be a healthy campus environment, with a prosperous economy through energy and resource conservation, waste reduction and an efficient environmental management, and promotes equity and social justice in its affairs and export these values at community, national and global levels.

For example, a few universities who are already using solar PV technology are the University of Queensland’s St Lucia Campus (UQ 2015), Murdoch University (MU 2015) and the University of New South Wales (UNSW 2013) in Australia, the Princeton (PU 2015) and Cornell (CU 2015) Universities in the United States, and the University of the South Pacific in Fiji (USP 2015).

In 2011, the University of Queensland’s St Lucia campus installed a 1.2 MW solar grid-connected system. The system consists of 5000 Trina Solar 240 Wp, installed on four rooftops of the university buildings. It has eighty-five 12.5 kW three-phase inverters, four 5 kW single-phase inverters, one 8.4 kWp two axis tracking PV array and a Redflow battery of 200 kW for storage (Walker et al. 2011). The system can reduce 6% of the energy peak demand in the university during summer. This helps reduce pressure on the neighbouring utility network (UQ 2015). Furthermore, the solar PV connected system avoids 1750 tonnes of greenhouse gas emissions per year (UQ n.d).

The University of the South Pacific in Fiji has a grid connected PV system in the lower marine campus. The system has a capacity of 45 kW, which is fed straight to the lower campus’s three-phase distribution system. There are six inverters of 8 kW each, which are configured to supply 16 kW to each phase. The system was expected to supply 20% of the electricity need in the lower campus during peak period (USP 2015 and ClayEnergy n.d.).

3. Methodology

In order to answer the key questions set out in this dissertation, three specific tasks were carried out. The first task was determining the energy consumption and the energy load profile for the NUS campus. The second task was to use RETScreen software (NRC 2015) to determine the amount of electricity that can be produced from the rooftops of the university buildings. Also, a solar resource assessment was conducted and potential rooftops were identified in this section. Finally, HOMER software was used to investigate the technical and economic feasibility of the different rooftop options and energy supply scenarios that include batteries.

3.1. Determining the Energy Consumption and the Energy Load Profile at NUS

3.1.1. Determining the energy consumption

Historical electricity consumption for the university was obtained from electricity bills, utility reports and the annual financial reports for the last 8 years (2014–2007). There was missing data from NUS, and this was filled in with the help of the utility company.

3.1.2. Determining the energy load profile

3.1.2.1. Recordings

Two main meters, 1 and 2, that read electricity consumption for the two campuses were recorded by using small video cameras. The video cameras recorded 12 hours of daily reading from 7.00am to 7.00pm for 7 weeks. At the end of each day, the videos were downloaded onto a laptop for further analysis.

3.1.2.2. Analysing

VLC media player was used to analyse readings at every half hour for 12 hours for each day. Meter 2 in the upper campus has a multiplication factor of 320X. It means a change of 1 unit for...
on the utility meter is equivalent to 320 kWh. Meter 1 in the lower campus has a multiplication factor of 160X. Once all units were corrected to their corresponding value, a line graph was drawn to compare the loading profile for each campus.

3.1.2.3. Walk-through audit
A walk-through audit was done to identify the main electrical appliances that consume a lot of electricity. The number of electrical appliances and their specifications were obtained from the Promoting Energy Efficiency in the Pacific (PEEP) project carried out earlier by the university.

3.2. Determining the Electricity to be extracted from Solar Renewable Energy Resources
To determine the electricity that could be extracted from solar renewable energy resources, three activities were carried out. Firstly, a solar resource assessment and the seasonal variation were determined. Secondly, determining the potential rooftops for solar PV installations based on the roof surface area, slope, and orientation. The last task involved modelling the ideal electricity that could be obtained from the selected rooftops by using RETScreen software.

3.2.1. Assessment of the solar resources and seasonal variation on NUS campus
Data for solar resources for NUS was obtained from the NASA Surface Meteorology and Solar Energy Data Centre (http://eosweb.larc.nasa.gov/sse/). The website has calculated averages over 22 years, between July 1983 and June 2005, based on satellite data.

The solar sun path at NUS was plotted by using the Sun Chart Program from the University of Oregon in the United States (UOSRML 2015).

The monthly solar radiation received by different rooftop slopes on NUS buildings was determined by using spreadsheet solar04.xls developed by Dr Trevor Pryor at Murdoch University.

3.2.2. Finding potential rooftops for solar PV installations
General observations of the university campuses with the help of the Google Earth software (https://earth.google.com) gave potential rooftops. The potential rooftops were ones that had no or minimum shading and were on buildings that were relatively new and strong enough to support PV installation panels.

The surface area, slope and orientation of the potential rooftops were determined from the university architectural drawings and with the assistance of Google Earth software.

3.2.3. Modelling electricity produced from potential rooftops using RETScreen software
Finding the amount of electricity produced from the potential rooftops required the number of solar panels that can fit on a given roof surface. The number of solar panels was obtained by dividing the area of roof surface by the area of one module.

This research considered one of the largest PV panels, 320W. It is a mono silicon type PV, mono-Si-CSUN320-72M (Free Clean Solar 2015), from the manufacturer China Sunergy, which has an area of 1.94 m² (Figure 10). The silicon crystal flat plates were selected because of the large share in the global market of 85% to 90% (Australia. NEEN 2014). Also, the larger the system, the lower the price per watt (U.S. DOE 2012, 18).
The number of solar panels, site location, slopes and surface orientation were put into the RETScreen software. The output from the program is the amount of electricity produced from each rooftop. The simulation was repeated for all the potential rooftops. The results from each monthly simulation were added to see how much was required to offset all the electricity needs of the university.

3.3. Analysing the technical and economic feasibility of different solar PV installation options

Results from the prefeasibility study carried out in section 3.2 were used for the technical and economic feasibility simulations for the HOMER software. HOMER software was used because the RETScreen program cannot perform time-series simulations (Lampert, Gilman and Lilienthal 2015, 381). All dollars used in this dissertation are in Australian currency.

3.3.1. HOMER input model

The model for the HOMER simulation is given in Figure 11. According to this model, the HOMER program allows electricity produced on the ac bus to directly meet the load. If there is any surplus, it is fed straight to the utility grid for sale.

3.3.2. Primary load inputs

HOMER software needs hour-by-hour load input data for 24 hours for each month. This was done by manually distributing the average load over a 24 hour period each day for each month according to the typical load profile obtained from section 3.1.1. HOMER automatically synthesised unique patterns for each day by adding a user-specified amount of randomness. The 2014 monthly energy load consumptions were used in this analysis.
3.3.3. PV inputs

The PV used for the RETScreen analysis in section 3.2, the mono silicon type PV panel mono-Si-CSUN320-72M, was also used in the HOMER software.

The efficiency, nominal operating cell temperature, and temperature coefficients were entered into the HOMER program. Temperature becomes important as the PV is connected to the dc bus.

The power input for different PV array capacities were 825 kW, 835 kW, 847 kW and 1386 kW. These were found from section 3.2, the RETScreen prefeasibility study.

The cost function of the PV modules was obtained from the current market price (Free Clean Solar 2015). The lifetime of the system was set at 25 years, which is an acceptable industry lifetime (Augenbraun 2010, 17).

<table>
<thead>
<tr>
<th>Costs</th>
<th>Sizes to consider</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (kW)</td>
<td>Size (kW)</td>
</tr>
<tr>
<td>0.320</td>
<td>0.000</td>
</tr>
<tr>
<td>3.200</td>
<td>825.000</td>
</tr>
<tr>
<td></td>
<td>835.000</td>
</tr>
<tr>
<td></td>
<td>847.000</td>
</tr>
<tr>
<td></td>
<td>1386.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties</th>
<th>Output current</th>
<th>AC</th>
<th>DC</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime (years)</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Derating fraction [%]</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope (degrees)</td>
<td>4.8</td>
<td></td>
<td></td>
<td>Tracking system</td>
</tr>
<tr>
<td>Azimuth (degrees W of S)</td>
<td>-165</td>
<td></td>
<td></td>
<td>Consider effect of temperature</td>
</tr>
<tr>
<td>Ground reflectance [%]</td>
<td>20</td>
<td></td>
<td></td>
<td>Temperature coeff. of power (%/°C)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nominal operating cell temp. (°C)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Efficiency at std. test conditions (%)</td>
</tr>
</tbody>
</table>

The results in section 3.2.2. revealed that the slopes for the lower campus and upper campus were 4.8° and 21.8° respectively, which were used in the simulation. In the sensitivity analysis, slopes of 4.8°, 21.8° and 13.3° was used. 13.3° is the average slope of 4.8° and 21.8°.

The roof orientation is N 15° E, which is the same as the azimuth 195° W of S or -165° for HOMER.

The derating factor was assumed to be 90% (allowing for the effect of dirt, cabling losses etc) and the ground reflectance 20% (Figure 12).

3.3.4. Grid inputs

The grid sizes considered in the search space for this research were 800 kW, 1,000 kW, 1,500 kW and 2000 kW. The 800 kW was selected because the minimum option for PV arrangement found in section 3.2.2 was 825 kW, whilst the largest possible option for PV arrangement was 1386 kW. In the simulation exercises, oversize grids of 1500 kW and 2000 kW were also used.
In the grid inputs, the purchasing rate from the grid is $0.50 AUD and the sellback price is $0.25 AUD. This was according to the current power purchase agreement (PPA) in Samoa, as discussed with Sione Foliaki, the Assistant Chief Executive Officer of the Energy Policy Division, in Samoa. Other feed-in-tariff rates of $0.50 AUD, $0.75 AUD and $1.00 AUD were used for the sensitivity analysis.

3.3.5. Solar resources
The monthly average daily solar radiation was obtained from section 3.2.1. This was put into the HOMER program uses statistical processes to generate a synthetic hour solar radiation sequence for the 365 days of the year.

3.3.6. System control
The simulation time step (minutes) is set at 60 minutes and the dispatch strategy use is load following. In a load following dispatch strategy, HOMER dispatches the system’s controllable power source, the grid, “so as to serve the primary load at the least total cost each time step, while satisfying the operating reserve requirement” (Kansara and Parekh 2013, 154).

3.3.7. Temperature
There is a strong correlation between the temperature of the module and the electricity that it can generate. Hence, the monthly average ambient temperature data from the RETScreen software was used for the HOMER simulation; however, “HOMER models the PV array as a device that produces dc electricity in direct proportion to the global solar radiation incident upon it, independent of its temperature and the voltage to which it is exposed” (Lampert, Gilman and Lilienthal 2015, 381). When PV is connected to the dc bus, HOMER assumes that a maximum power point tracker is present in the system, thus ignoring the effect of the voltage.

3.3.8. Constraints
The system is grid-connected and it will have enough operating reserve from the grid; therefore, the capacity shortage is expected to be zero. However, a 10% maximum was set.

The operating reserve for solar output was set to 0% since it is a grid-connected system.
### 3.3.9. Economics

#### Figure 13: Economic Inputs Setting

The annual real interest rate in the country varies from time to time but according to some studies 8% is the typical rate to use for evaluating financial performance (Bailey, Chotimongkol and Isono 2007, 131). A lifetime of 25 years was assigned for the simulation. It is very difficult to assess the system’s fixed capital cost; however, since PV systems have low maintenance costs, a typical value of $500 AUD per year is assigned for operating and maintenance (O&M) cost (Figure 13).

#### 3.3.10. PV with battery

Finally, a battery storage for the PV system was included, although it is still considered to be expensive. This was to find out how the economic aspects of the grid connected PV system change from a grid connected PV system to a grid connected PV system with batteries. The battery specification is given in Table 1, while the full details are given in Appendix C.

#### Table 1: Battery Specification

<table>
<thead>
<tr>
<th>Battery</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Surrette 4KS25P</td>
</tr>
<tr>
<td>Float Lifetime</td>
<td>12 Years</td>
</tr>
<tr>
<td>Batteries per string</td>
<td></td>
</tr>
<tr>
<td>Nominal capacity</td>
<td>1900 Ah</td>
</tr>
<tr>
<td>Nominal energy capacity of each battery</td>
<td>7.60 kWh</td>
</tr>
<tr>
<td>Capital cost</td>
<td>$1500/quantity</td>
</tr>
<tr>
<td>Replacement cost</td>
<td>$1500/quantity</td>
</tr>
</tbody>
</table>
The Surrettee 4KS25P battery cost varies between $1200 - $1700 AUD per unit (Makbul, Hiendro and Bouchekara 2014) and (Wholesale Solar 2015).

The battery sizing was done by using the following formula.

Equation 1

\[
\text{Required battery capacity (kWh)} = \frac{\text{number of days of autonomy} \times \text{Daily Load}}{\text{Death of discharge allowed} \times \text{efficiency of the battery}}
\]

The float lifetime of the battery is 12 years. The depth of discharge allowed in this study is 30%, which is half of the maximum depth of discharge. The number of cycles at this level is about 4250, which is about 12 years before it fails, assuming that charge and discharge occurs each day.

One, two and three days were considered for days of autonomy for a standalone mode. Also, storage may be useful for buffering the electric grid when there is a sudden change of solar renewable resources. The efficiency of the battery was 80%.

---

4. Results

4.1. Electricity Consumptions and Electricity Load Profile

4.1.1. Electricity consumptions at NUS

Electricity bills, utility reports and annual financial reports for the past 8 years (2007–2014) were used to obtain the university electricity consumptions. The utility company helped fill in some of the missing records at NUS.
The energy consumption trend at NUS for the past 8 years gave no evidence that there was any increase in electricity usage despite the university’s enrolment increase over this period. Figure 15 shows the decline of electricity consumption from 2007 to 2009 and then continues at about the same level right up to 2014. It seems that the electricity conservation, “Dark Friday”, undertaken by the university explains the drop from 1,070,000 kWh in 2007 to 822,240 kWh in 2009. “Dark Friday” and other conservation measures undertaken by the university enabled it to maintain its electricity consumption at around 700 MWh and 800 MWh per year onwards.

In terms of electricity consumption per month over the past 8 years, the total electricity consumption varies a lot from month to month. As seen in figure 16, the upper campus variation dictates the total monthly load profile over the past 8 years. That is, the shape of the waveform in the total electricity consumption is more responsive to whatever load profile is in the upper campus.

Between 2008 and 2014, the electricity consumption per month in the lower campus was less varied compared to the upper campus. The variation consumption for lower and upper campus is around 10,000kWh – 20,000kWh and 40,000kWh – 70,000kWh respectively.
Figure 16: NUS Electricity Consumption Trend (2007-2014)

There is missing data in December 2012 in Figure 16. This is when the government cleared off all electricity charges due to a cyclone that occurred in that period.

Moreover, in Figure 16, it shows distinct periods where the university breaks for the New Year’s Holidays, and the beginning and at the end of the two semesters. The mid-semester breaks during each semester can also be seen in some of the years such as 2007, 2009, 2011 and in the second semester in 2008 and 2014. These are shown by a single drop in electricity consumption during the semesters (April/May and September).

Figure 17 represents the maximum, minimum and average monthly electricity consumption from 2008–2014. The year 2007 was excluded as it was treated as an outlier. All the monthly electricity consumption from the past 7 years (2008–2014) can fit between the minimum and the maximum curve (see Appendix D).
It appears from Figure 17 that the electricity consumption’s highest peak always occurs in the first semester. Electricity consumptions as a function of temperature and relative humidity might be the reason why the highest peak in the second semester is always lower than the first semester, as seen in the graphs (Appendix E); however, this is too early to draw conclusion because the change in temperature throughout the year is only about 1°C and the change of relative humidity is only 5%, as seen in the graphs. Further investigation about the role of temperature, humidity and thermal mass is beyond the scope of this paper.

4.1.2. Electricity consumption load profile for NUS

The graph in Figure 18 show the daily load variation for 12 hours (7am – 7pm) for seven consecutive weeks from mid-January 2015 to the end of February 2015. Note that the minimum load for the next 12 hours (7pm – 7am) should be around 20 kWh, but not 0 kWh as seen in the graph.

![NUS Energy Load Profile per 30 minutes](image)

**Table 2: Descriptions of Activities for each Period (Figure 18)**

<table>
<thead>
<tr>
<th>Duration Period</th>
<th>Kinds of Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>University closes.</td>
</tr>
<tr>
<td>B</td>
<td>University starts operating but there are no classes.</td>
</tr>
<tr>
<td>C</td>
<td>University enrolment week with the start of a Samoan Language crash course for Science students on Tuesday 27th January.</td>
</tr>
<tr>
<td>D</td>
<td>2nd week for Samoan class crash course.</td>
</tr>
<tr>
<td>E</td>
<td>University in full operation with the start of the first semester. First, Second and Third week of lectures.</td>
</tr>
</tbody>
</table>

**Period A:** It is clearly seen that period A represents the university closure. Electrical energy consumed in this period is the lowest compared to all the other weeks. This is, of course, due to most electrical appliances being turned off, except refrigerators and other air-conditioned rooms that house critical equipment.
**Period B:** This period represents the start of the university operations. In the first day of this period there is high electrical energy consumption and then it declines throughout the rest of the week. There were no classes held during this period.

**Period C:** This is the university enrolment week. On its second day, a Samoan Language crash course begins, which has about 200 students.

**Period D:** This represents the second week of the Samoan crash course. The university has not begun full operation.

**Period E:** This represents the start of semester 1 for 2015 – the first, second and third week of classes. The electricity consumption during these periods was higher than expected. The real peak power during these periods is around 200 kW and 100 kW for the upper campus and the lower campus respectively.

The NUS 12 Hour Daily Energy Consumption chart (Figure 19, trend line) shows an increase of electricity consumption from the first week until the seventh week of the study. The electricity consumption for the first three weeks of classes tends to increase every week for the upper campus, while the lower campus seems to remain constant at around 500 kWh. However, as seen in Figure 16 and Figure 17, it is most likely that both campuses will continue to increase their electricity consumption every week until mid-April/May, where the mid-semester break occurs and a drop of electricity is expected as seen in the previous years.

![NUS 12 Hour Daily Energy Consumption (kWh)](image)

*Figure 19: NUS 12 Hour Daily Electricity Consumptions (kWh)*
4.1.3. Walk-through energy audit
The Walk-through Energy Audit carried out during this period revealed that air conditioning systems were the main cause for high electricity consumption for both campuses. Although there were heavy industrial machineries in the technical workshops in the lower campus, they were not in use at the time of the energy audit³.

Buildings that use air conditioning units were identified to be consuming a lot of electricity. The buildings that were consuming a lot of electricity are summarised in Table 3.

Table 3: University Buildings identified to be consuming a lot of electricity.

<table>
<thead>
<tr>
<th>Campus</th>
<th>Building</th>
<th>Description of Office</th>
<th>Average Daily Estimated Energy Consumption (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOWER CAMPUS</td>
<td>A</td>
<td>University Administration Office</td>
<td>675</td>
</tr>
<tr>
<td></td>
<td>F &amp; H</td>
<td>Computer labs and Staff offices</td>
<td></td>
</tr>
<tr>
<td>UPPER CAMPUS</td>
<td>A</td>
<td>Staff Offices</td>
<td>2291</td>
</tr>
<tr>
<td></td>
<td>B &amp; C</td>
<td>Science &amp; Computer Labs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>Library and Printing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>Two lecturer theatres</td>
<td></td>
</tr>
</tbody>
</table>

Based on Table 3, the following charts show how much electricity used by the air conditioning units compares with the other electrical appliances. In the lower campus 66% of the 675 kWh is used for the air conditioning systems, whilst in the upper campus 79% of the 2291 kWh is used (see Figure 20 and 21). The total daily estimated energy consumption (kWh) is about 3000 kWh. This amount may seem to be an overestimation when compared to Figure 19. The calculation has taken into account the few buildings listed in Table 3 and the approximate hours of operation based on period C (see Table 2 and Figure 18). One reason for the overestimation value may be due to the complex loading cycles of air conditioning units, which vary from time to time and which depend on several factors such as duty cycle, thermostat setting, ambient temperature and humidity. Nonetheless, the 3000 kWh is still acceptable if the graph in Figure 19 is extrapolated.

³ Technical classes in the three weeks were mainly on the introductory level. No machine in the technical workshop was used.
In addition, a rough estimation for the average monthly energy consumptions (87,906 kWh to 108,906 kW) at the university demonstrates that air conditioning units is the reason for high electricity consumption on campus. The estimated values are higher than the actual electricity consumption shown in Figure 16. Once again, this may be due to the air conditioning units’ different loading at different times.
Furthermore, general observations during the time of the study confirmed that air conditioning units used a lot more electricity than any other electrical appliances. For example, the electrical meter for building A in the power control room was registering more electrical units consumed than any other buildings during period E (refer to Table 2 and Figure 18).

4.2. Electricity that could be Extracted from Rooftops at NUS Buildings
This section presents findings of the RETScreen software simulations on the amount of electricity that can be obtained from the selected rooftops. The results of how many rooftops are required to offset all the electricity needs of the university are also presented in the last section, section 4.2.3. However, there are inputs that need to be determined first for the RETScreen software simulation. These inputs are the potential rooftops, area of roof surfaces, slopes, surface orientation, and the type and required number of solar panels for each rooftop. This is given in section 4.2.2, whilst section 4.2.1 presents results of the solar resource assessment and the seasonal variation.

4.2.1. Solar resource assessment and seasonal variation on NUS campus
Data was taken at a latitude of 13.85° south and longitude of 171.75° west from the averages over 22 years provided by the NASA website. The data was within the boundaries of 13° and 14° south and 172° and 171° west. The results of the solar radiation parameters are given in Figure 21. Figure 21 shows that the monthly average daily insolation on a horizontal surface varies between 4.5 kWh/m²/day to 6 kWh/m²/day throughout the year, while the clearness index varies between 0.47 and 0.6. The solar radiation on the horizontal surface is lowest during the month of June and highest in the month of October. The clearness index is highest during the months of July and August, and lowest in January. Hence, from the two radiation parameters, the solar radiation at the NUS site is considered very good.

![Estimated average monthly energy consumption](image-url)
4.2.1.1. Solar sun path at NUS

The solar sun path at the NUS site (Figure 22) was plotted by using the Sun Chart Program from the University of Oregon in the United States (UOSRML 2015). The chart shows that the sun spent most of the time during the year in the northern part of the sky with respect to the NUS campus. The different solar paths during the year are limited by the two solstices in June 21 and December 21.
4.2.1.2. Monthly average daily solar radiation for different slopes

**Different Daily Solar Radiation at Different Slope at Azimuth Angle of -165°**

![Graph showing the monthly average daily solar radiation at different slopes.](image)

- **Daily solar radiation - HORIZONTAL**
- **Daily solar radiation - tilted UPPPER CAMPUS (21.8)**
- **Daily solar radiation - tilted at LATITUDE**
- **Daily solar radiation - tilted LOWER CAMPUS (4.8)**

**Figure 25: Monthly Average Daily Solar Radiation for different Slopes**
Figure 23 shows the different daily solar radiation received for the different slopes: slope at 4.8° for the lower campus; slope equal to the latitude, 13.85°; slope at 21.8° for the upper campus; and the horizontal surface, 0°. The radiation received by the different slopes (Figure 24) was derived from the spreadsheet solar04.xls developed by Dr. Trevor Pryor at Murdoch University. The results are similar to the NASA website.

During the middle of the year, solar radiation is higher when surfaces are tilted at angles equal to the latitude (13.85°) and 21.8° than when the angles are 4.8° and the horizontal surface. However, the total annual solar radiation received by the different slopes are all similar. It means that any slope of 21.8°, 13.85°, 4.8° and 0° for solar panels would give the similar annual result.

4.2.2. Potential rooftops for solar PV installations

Based on the ageing, shading and building orientation, the potential rooftops were found. All the rooftops that are ideal for collecting solar energy are facing north 15° east. The surface area of each rooftop, the slopes and the number of solar panels required for each rooftop is summarised in Table 5. Please refer to Appendix A and Appendix B which show the buildings used for this study. It is to be noted that in Appendix B there are potential buildings in the lower campus that were excluded because they do not belong to the university.
### Upper Campus Buildings

<table>
<thead>
<tr>
<th>Rooftop Square Area (m²)</th>
<th>Slope</th>
<th>Number of PV mono-Si-CSUN320-72M panels</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>168.48</td>
<td>21.8°</td>
</tr>
<tr>
<td>B</td>
<td>142.56</td>
<td>21.8°</td>
</tr>
<tr>
<td>C</td>
<td>142.56</td>
<td>21.8°</td>
</tr>
<tr>
<td>D</td>
<td>20.925</td>
<td>21.8°</td>
</tr>
<tr>
<td>E</td>
<td>155.52</td>
<td>21.8°</td>
</tr>
<tr>
<td>G</td>
<td>204.12</td>
<td>21.8°</td>
</tr>
<tr>
<td>H</td>
<td>535.68</td>
<td>21.8°</td>
</tr>
</tbody>
</table>

### Lower Campus Buildings

<table>
<thead>
<tr>
<th>Rooftop Square Area (m²)</th>
<th>Slope</th>
<th>Number of PV mono-Si-CSUN320-72M panels</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>574.00</td>
<td>4.8°</td>
</tr>
<tr>
<td>B</td>
<td>780.44</td>
<td>4.8°</td>
</tr>
<tr>
<td>C</td>
<td>764.27</td>
<td>4.8°</td>
</tr>
<tr>
<td>D</td>
<td>792.58</td>
<td>4.8°</td>
</tr>
<tr>
<td>E</td>
<td>780.44</td>
<td>4.8°</td>
</tr>
<tr>
<td>F</td>
<td>742.50</td>
<td>4.8°</td>
</tr>
<tr>
<td>G</td>
<td>544.50</td>
<td>4.8°</td>
</tr>
</tbody>
</table>

#### 4.2.3. RETScreen simulation on the amount of electricity that can be produced from the NUS site

Using the RETScreen software, the following results for solar electricity produced per month for the upper and the lower campus were obtained (Table 5, 6 and 7).
### Table 5: Electricity Produced for Slopes facing North in the Upper Campus

<table>
<thead>
<tr>
<th>Building</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Month</strong></td>
<td><strong>Electricity produced from each roof tops per month (MWh)</strong></td>
<td><strong>Month</strong></td>
<td><strong>Electricity produced from each roof tops per month (MWh)</strong></td>
<td><strong>Month</strong></td>
<td><strong>Electricity produced from each roof tops per month (MWh)</strong></td>
<td><strong>Month</strong></td>
<td><strong>Electricity produced from each roof tops per month (MWh)</strong></td>
</tr>
<tr>
<td>January</td>
<td>3.076</td>
<td>2.611</td>
<td>2.611</td>
<td>0.358</td>
<td>2.861</td>
<td>3.756</td>
<td>9.872</td>
</tr>
<tr>
<td>February</td>
<td>2.929</td>
<td>2.487</td>
<td>2.487</td>
<td>0.341</td>
<td>2.725</td>
<td>3.577</td>
<td>9.401</td>
</tr>
<tr>
<td>March</td>
<td>3.217</td>
<td>2.731</td>
<td>2.731</td>
<td>0.374</td>
<td>2.993</td>
<td>3.928</td>
<td>10.326</td>
</tr>
<tr>
<td>April</td>
<td>3.284</td>
<td>2.788</td>
<td>2.788</td>
<td>0.382</td>
<td>3.055</td>
<td>4.010</td>
<td>10.540</td>
</tr>
<tr>
<td>May</td>
<td>3.302</td>
<td>2.803</td>
<td>2.803</td>
<td>0.384</td>
<td>3.072</td>
<td>4.032</td>
<td>10.597</td>
</tr>
<tr>
<td>June</td>
<td>3.188</td>
<td>2.706</td>
<td>2.706</td>
<td>0.371</td>
<td>2.965</td>
<td>3.892</td>
<td>10.230</td>
</tr>
<tr>
<td>July</td>
<td>3.441</td>
<td>2.921</td>
<td>2.921</td>
<td>0.400</td>
<td>3.201</td>
<td>4.201</td>
<td>11.044</td>
</tr>
<tr>
<td>August</td>
<td>3.612</td>
<td>3.066</td>
<td>3.066</td>
<td>0.420</td>
<td>3.360</td>
<td>4.409</td>
<td>11.590</td>
</tr>
<tr>
<td>September</td>
<td>3.563</td>
<td>3.025</td>
<td>3.025</td>
<td>0.414</td>
<td>3.315</td>
<td>4.351</td>
<td>11.436</td>
</tr>
<tr>
<td>October</td>
<td>3.539</td>
<td>3.004</td>
<td>3.004</td>
<td>0.412</td>
<td>3.292</td>
<td>4.321</td>
<td>11.359</td>
</tr>
<tr>
<td>November</td>
<td>3.190</td>
<td>2.708</td>
<td>2.708</td>
<td>0.371</td>
<td>2.967</td>
<td>3.894</td>
<td>10.237</td>
</tr>
<tr>
<td>December</td>
<td>3.099</td>
<td>2.630</td>
<td>2.630</td>
<td>0.360</td>
<td>2.883</td>
<td>3.783</td>
<td>9.945</td>
</tr>
<tr>
<td><strong>Annual (MWh)</strong></td>
<td><strong>39.440</strong></td>
<td><strong>33.478</strong></td>
<td><strong>33.478</strong></td>
<td><strong>4.586</strong></td>
<td><strong>36.689</strong></td>
<td><strong>48.154</strong></td>
<td><strong>126.576</strong></td>
</tr>
</tbody>
</table>

### Table 6: Electricity Produced from Slopes facing South in the Upper Campus

<table>
<thead>
<tr>
<th>Building</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Month</strong></td>
<td><strong>Electricity produced from each roof tops per month (MWh)</strong></td>
<td><strong>Month</strong></td>
<td><strong>Electricity produced from each roof tops per month (MWh)</strong></td>
<td><strong>Month</strong></td>
<td><strong>Electricity produced from each roof tops per month (MWh)</strong></td>
<td><strong>Month</strong></td>
<td><strong>Electricity produced from each roof tops per month (MWh)</strong></td>
</tr>
<tr>
<td>January</td>
<td>3.423</td>
<td>2.905</td>
<td>2.905</td>
<td>0.398</td>
<td>3.184</td>
<td>4.179</td>
<td>10.984</td>
</tr>
<tr>
<td>February</td>
<td>3.021</td>
<td>2.565</td>
<td>2.565</td>
<td>0.351</td>
<td>2.811</td>
<td>3.689</td>
<td>9.696</td>
</tr>
<tr>
<td>March</td>
<td>2.974</td>
<td>2.524</td>
<td>2.524</td>
<td>0.346</td>
<td>2.766</td>
<td>3.631</td>
<td>9.544</td>
</tr>
<tr>
<td>April</td>
<td>2.603</td>
<td>2.209</td>
<td>2.209</td>
<td>0.303</td>
<td>2.421</td>
<td>3.178</td>
<td>8.353</td>
</tr>
<tr>
<td>May</td>
<td>2.249</td>
<td>1.909</td>
<td>1.909</td>
<td>0.262</td>
<td>2.092</td>
<td>2.746</td>
<td>7.218</td>
</tr>
<tr>
<td>June</td>
<td>1.986</td>
<td>1.686</td>
<td>1.686</td>
<td>0.231</td>
<td>1.847</td>
<td>2.425</td>
<td>6.374</td>
</tr>
<tr>
<td>July</td>
<td>2.196</td>
<td>1.864</td>
<td>1.864</td>
<td>0.255</td>
<td>2.043</td>
<td>2.682</td>
<td>7.049</td>
</tr>
<tr>
<td>August</td>
<td>2.642</td>
<td>2.243</td>
<td>2.243</td>
<td>0.307</td>
<td>2.458</td>
<td>3.226</td>
<td>8.479</td>
</tr>
<tr>
<td>September</td>
<td>3.071</td>
<td>2.607</td>
<td>2.607</td>
<td>0.357</td>
<td>2.857</td>
<td>3.749</td>
<td>9.856</td>
</tr>
<tr>
<td>October</td>
<td>3.530</td>
<td>2.996</td>
<td>2.996</td>
<td>0.410</td>
<td>3.284</td>
<td>4.310</td>
<td>11.329</td>
</tr>
<tr>
<td>November</td>
<td>3.506</td>
<td>2.976</td>
<td>2.976</td>
<td>0.408</td>
<td>3.261</td>
<td>4.281</td>
<td>11.252</td>
</tr>
<tr>
<td>December</td>
<td>3.531</td>
<td>2.997</td>
<td>2.997</td>
<td>0.411</td>
<td>3.284</td>
<td>4.311</td>
<td>11.331</td>
</tr>
<tr>
<td><strong>Annual (MWh)</strong></td>
<td><strong>34.732</strong></td>
<td><strong>29.482</strong></td>
<td><strong>29.482</strong></td>
<td><strong>4.039</strong></td>
<td><strong>32.309</strong></td>
<td><strong>42.405</strong></td>
<td><strong>111.465</strong></td>
</tr>
</tbody>
</table>
Table 7: Electricity Produced from Roof tops in the Lower Campus

<table>
<thead>
<tr>
<th>Month</th>
<th>Building</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td></td>
<td>11.522</td>
<td>15.70</td>
<td>15.35</td>
<td>15.94</td>
<td>14.70</td>
<td>14.92</td>
<td>10.936</td>
<td>14.18</td>
</tr>
<tr>
<td>March</td>
<td></td>
<td>11.224</td>
<td>15.30</td>
<td>14.95</td>
<td>15.52</td>
<td>15.30</td>
<td>14.53</td>
<td>10.654</td>
<td>13.81</td>
</tr>
<tr>
<td>August</td>
<td></td>
<td>11.695</td>
<td>15.94</td>
<td>15.58</td>
<td>16.18</td>
<td>15.94</td>
<td>15.14</td>
<td>11.101</td>
<td>14.39</td>
</tr>
<tr>
<td>October</td>
<td></td>
<td>12.701</td>
<td>17.31</td>
<td>16.92</td>
<td>17.57</td>
<td>17.31</td>
<td>16.45</td>
<td>12.055</td>
<td>15.63</td>
</tr>
<tr>
<td>November</td>
<td></td>
<td>11.894</td>
<td>16.21</td>
<td>15.85</td>
<td>16.45</td>
<td>16.21</td>
<td>15.40</td>
<td>11.289</td>
<td>14.64</td>
</tr>
<tr>
<td>Annual (MWh)</td>
<td></td>
<td>135.438</td>
<td>184.56</td>
<td>180.43</td>
<td>187.32</td>
<td>184.56</td>
<td>175.38</td>
<td>128.551</td>
<td>166.66</td>
</tr>
</tbody>
</table>

4.2.3.1. Rooftops required to offset all the electricity in NUS

The amount of electricity produced from each rooftop was then added to meet the monthly load for the two campuses. The electricity consumption in 2014 was used as a reference.

The analysis begins by using the largest rooftop that tilted and faced north. The largest rooftop in the upper campus is building H, which has a roof area of 535.68 m². In the lower campus it is building D, which has an area of 792.58 m².
The results revealed that the electricity from the largest rooftop in the upper campus was not sufficient to satisfy the electricity need of the upper campus as shown in Figure 27.

However, in the lower campus, the electricity generated from its largest rooftop, building D, was only sufficient to satisfy the last 6 months of the year 2014, but it still needs an additional rooftop in order to completely meet the load in the first 6 months (refer to Figure 28). This was attained when the second largest roof area, building B, was added as seen in Figure 29.
Meanwhile, when all the north-facing rooftops in the upper campus were added, the amount of electricity from solar radiation is a large shortfall (refer to Figure 30).

In order for the upper campus to completely meet the load, several options were investigated. The best option would be the one that is most economical and technically viable.
4.2.3.1.1. Option 1: Utilising all rooftops in the upper campus and some from the lower campus

The first option is utilising all the rooftops in the upper campus that face north and south. However, utilising all the surfaces is still short of the required electrical energy as seen in Figure 31. The first six months need additional solar rooftops and this is possible by adding rooftops from the lower campus.

**Figure 31: Solar Electricity from all the Rooftops in the Upper Campus.** Note: Nf – total electricity produced from all rooftops facing north. Asterisk * - rooftops facing south.

Hence, the third largest rooftop, building C, from the lower campus was added to the upper campus. Most of the load was satisfied, on average, except a small shortfall in the month of February as seen in Figure 32, which could be solved by introducing some sort of energy management measures.
4.2.3.1.2. Option 2: Utilising only all the north-facing rooftops in the upper campus, with some from the lower campus

In the second option, instead of using the south-facing surfaces in the upper campus as was done in option 1, the north-facing surfaces in the lower campus were used instead. There were six out of eight rooftops available in the lower campus that could be utilised as the first two rooftops (B and D) were already taken to satisfy the load in the lower campus. Also, all the rooftops in the lower campus were facing north, which were better than rooftops facing south in the upper campus.

As seen in Figure 33, only three surfaces from buildings E, F and G from the lower campus were added in order to meet the load in the upper campus, compared to the seven surfaces facing south in the upper campus as in Figure 31.
Figure 33: Option 2: Solar Electricity to Offset all Electricity needed for the Upper Campus

With reference to Figure 28 and Figure 33, it is evident that the rooftops in the lower campus are large enough to harness more energy from the sun compared to the upper campus. This was also seen in Figure 29, which shows that only two surfaces were required to satisfy the energy needed for the lower campus. Thus, a third option is to use all the surfaces in the lower campus to meet all the loads for both campuses.

4.2.3.1.3. Option 3: Using only the roof surfaces in the lower campus to meet all the load in the university

In the third option, two out of eight surfaces from the lower campus were used to meet the load in the lower campus (see Figure 29). This left the lower campus with six more surfaces that needed to be utilised. Figure 34 shows that five rooftops, buildings C, E, F, H and A, from the lower campus managed to meet the load required for the upper campus. Hence, a total of seven rooftops from the lower campus can satisfactorily meet the entire load for the university campus (D, B, C, E, F, H and A), without using any rooftops from the upper campus. Therefore, it is possible to use only the rooftops from the lower campus to meet the electricity need for the entire university campus.
4.2.3.1.4. Option 4: Using all the potential roof surfaces available on the university campus

If all the rooftops are considered for generating electricity, then 1,386 PV panels can be installed. The electricity from this is higher than the maximum monthly load (refer to Figure 17) from the past 7 years (2008–2014). Figure 35 indicates an ideal amount of solar electricity that could be produced from all the rooftops of the two university campuses relative to all the maximum monthly electricity demands from the past seven years, 2008–2014, (see Figure 17).
Even if a loss of 25% in the PV system and a 20% increase in the maximum monthly load demand is assumed for the past 7 years (2008–2014), the electricity from solar panels is still sufficient to satisfy the energy needed for the university, as seen in Figure 36. Hence, from this preliminary analysis, the university campus should be able to offset all of its electricity needs on both campuses.
**Figure 36:** Solar Electricity reduced by 25% and Maximum electricity consumption increased by 20%

### 4.2.3.2. Summary for solar panels needed to offset the electricity needs of the university

<table>
<thead>
<tr>
<th>Meeting the Load</th>
<th>Description</th>
<th>Number of Panels</th>
<th>Total Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lower Campus only</strong></td>
<td>Solar panels on building D and B.</td>
<td>810</td>
<td>259,200</td>
</tr>
<tr>
<td><strong>Option 1: Upper Campus only</strong></td>
<td>Solar panels (north and south facing rooftops) plus panels from the lower campus building C.</td>
<td>1,799</td>
<td>575,680</td>
</tr>
<tr>
<td><strong>Option 2: Upper Campus only</strong></td>
<td>Solar panels on the upper campus facing north only, plus panels from the lower campus buildings E, F and G.</td>
<td>1,767</td>
<td>565,440</td>
</tr>
<tr>
<td><strong>Option 3: Upper Campus only</strong></td>
<td>Solar panels from the lower campus only to meet the load in the upper campus.</td>
<td>1,835</td>
<td>587,200</td>
</tr>
<tr>
<td><strong>Option 4: All the potential rooftops</strong></td>
<td>All solar panels on all potential rooftops.</td>
<td>4,331</td>
<td>1,385,920</td>
</tr>
</tbody>
</table>

Table 8 is the summary for all the solar panels required to meet the load on campus.
4.2.3.2.1. Solar panels supply scenario options for NUS campuses

Table 9: Solar Panels Supply Scenario Options for NUS campuses

<table>
<thead>
<tr>
<th>Solar PV Supply Scenario</th>
<th>Descriptions</th>
<th>Number of Solar Panels</th>
<th>Total PV solar power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1</td>
<td>Lower campus + Upper Campus (Option 1)</td>
<td>2,609</td>
<td>835</td>
</tr>
<tr>
<td>Option 2</td>
<td>Lower campus + Upper Campus (Option 2)</td>
<td>2,577</td>
<td>825</td>
</tr>
<tr>
<td>Option 3</td>
<td>Lower campus + Upper Campus (Option 3)</td>
<td>2,645</td>
<td>847</td>
</tr>
<tr>
<td>Option 4</td>
<td>Lower campus + Upper Campus (Option 4)</td>
<td>4,331</td>
<td>1,386</td>
</tr>
</tbody>
</table>

Table 9 is the options for the different solar Grid connected PV system supply scenarios. These options will be used in section 4.3.

4.3. Technical and Economic Feasibility of the Different Energy Supply Scenarios

The result of the prefeasibility analysis by the RETScreen software in section 4.2 proved that solar panels on university buildings can offset all the university’s electricity needs. However, the analysis was based on the monthly average. It did not take into consideration the daily dynamic characteristics of the electrical load on campus. Also, it did not consider the daily variability of the solar resources. The HOMER program was used to simulate the hour-by-hour data, both in the electrical load of the university and the variability of the solar resources.

4.3.1. HOMER simulation outcome for Option 1 to Option 4 (in section 4.2.3.1.1—4.2.3.1.4.)

The HOMER simulation revealed that the optimum system is option 4. However, Table 10 lists four different options (1–4) PV energy supply scenarios. There were 120 simulations and 72 sensitivities values. Overall there are 84 output values produced by the HOMER program and only four are listed in Table 10 based on the least cost of energy (COE) for each option.

Table 10: HOMER Simulation Outcome for Option 1–4

<table>
<thead>
<tr>
<th>Option</th>
<th>PV (kW)</th>
<th>Converter (kW)</th>
<th>Grid (kW)</th>
<th>Initial capital</th>
<th>Operating cost ($/yr)</th>
<th>Total NPC</th>
<th>COE ($/kWh)</th>
<th>Renewable fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1386</td>
<td>1000</td>
<td>2000</td>
<td>$3,079,000</td>
<td>-286,506</td>
<td>$20,617</td>
<td>0.003</td>
<td>0.93</td>
</tr>
<tr>
<td>3</td>
<td>847</td>
<td>800</td>
<td>2000</td>
<td>$2,070,500</td>
<td>-84,150</td>
<td>$1,172,215</td>
<td>0.145</td>
<td>0.87</td>
</tr>
<tr>
<td>2</td>
<td>835</td>
<td>500</td>
<td>2000</td>
<td>$1,752,500</td>
<td>-49,696</td>
<td>$1,222,002</td>
<td>0.152</td>
<td>0.87</td>
</tr>
<tr>
<td>1</td>
<td>825</td>
<td>500</td>
<td>2000</td>
<td>$1,737,500</td>
<td>-47,380</td>
<td>$1,231,724</td>
<td>0.153</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Using the current rates in Samoa, a purchasing rate from the grid of $0.50 AUD and a sellback price of $0.25 AUD, the best system is option 4, which has the lowest total net present cost (NPC) of $20,617 (Table 10). However, none of the options were able to achieve a positive total net present value within the lifetime of the system. Although, the initial capital cost in option 4 is expensive, it becomes cheaper during the lifetime of the project. All four options were saving operating costs every year but were not enough to achieve a total net present value (NPV), a revenue for the university during the lifetime of the project.
If the system is considered for monthly net metering (buyback rate equals purchase rate for electricity, $0.50/kWh) then it will have a negative NPC for option 4 or positive NPV, $4,382,855 as seen in Figure 37. Note that the PV slope used in this analysis is 13.3°. It is the average of the two slopes for the buildings in NUS. As mentioned in section 4.2.1.2, the annual yield of the different slopes from 0° to 21.8° is similar (Figure 25 and 26).

Figure 37: Simulation Result for Option 4

The results show that university will have a total NPV of $4,382,855.

Figure 38: Simulation Output Details for Option 4

The amount of grid sales is 70%, and 30% is used for the AC primary load. The portion of the system’s total energy production originating from solar resources is 93%, which is excellent (Figure 38). The plot as seen in Figure 39 revealed a significant portion of electric power from PV compared to the grid.

Figure 39: Monthly Average Electric Production from Option 4

The simple payback period is 3.03 years, and the return of investment (ROI) and the internal rate of return (IRR) have high positive values of 32.0% and 32.8% respectively (refer to Figure 40). The discounted payback period is 3.61 years. These financial parameters indicate that this is an excellent investment.
The life cycle cost (LCC) of the PV project is much lower than electricity from diesel. For the base case, which is a grid-connected system only, the total NPC after 25 years will be $4,038,001, whilst the total NPC for the grid connected PV system is -$4,382,855.

The other PV energy supply scenarios, options 3, 2 and 1, also gave positive total NPV (refer to Table 11). Therefore, it is seen that the net metering at the rate of $0.50/kWh for a grid connected PV system for NUS is economically viable for all options 1 to 4.

**Table 11: Simulation Outcome for all the Options 1-4 Energy Supply Scenario**

<table>
<thead>
<tr>
<th>Options</th>
<th>PV (kW)</th>
<th>Converter (kW)</th>
<th>Grid (kW)</th>
<th>Initial capital</th>
<th>Operating cost ($/yr)</th>
<th>Total NPC</th>
<th>COE ($/kWh)</th>
<th>Renewable fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1386</td>
<td>1400</td>
<td>2000</td>
<td>$3,479,000</td>
<td>-736,489</td>
<td>-$4,382,855</td>
<td>-0.543</td>
<td>0.93</td>
</tr>
<tr>
<td>3</td>
<td>847</td>
<td>800</td>
<td>2000</td>
<td>$2,070,500</td>
<td>-302,812</td>
<td>-$1,161,946</td>
<td>-0.144</td>
<td>0.87</td>
</tr>
<tr>
<td>2</td>
<td>835</td>
<td>800</td>
<td>2000</td>
<td>$2,052,500</td>
<td>-293,256</td>
<td>-$1,077,938</td>
<td>-0.134</td>
<td>0.87</td>
</tr>
<tr>
<td>1</td>
<td>825</td>
<td>800</td>
<td>2000</td>
<td>$2,037,500</td>
<td>-285,197</td>
<td>-$1,006,913</td>
<td>-0.125</td>
<td>0.87</td>
</tr>
</tbody>
</table>

4.3.2. **HOMER simulation outcome for Options 1–4, with batteries**

Using equation 1, which is given in section 2.3.1.9, the battery sizing was obtained as given in Table 12. The dc bus considered in this case was 416V (assuming 415V ac in the three phase power supply system).
Table 12: Battery Sizing

<table>
<thead>
<tr>
<th>Number of days of autonomy</th>
<th>Battery size (kWh)</th>
<th>Battery size (Ah) with inverter efficiency (90%)</th>
<th>Strings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8750000</td>
<td>23427.0415</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>17500000</td>
<td>46854.083</td>
<td>27</td>
</tr>
<tr>
<td>3</td>
<td>26250000</td>
<td>70281.1245</td>
<td>37</td>
</tr>
</tbody>
</table>

Considering Option 4, a PV supply scenario with the current PPA, if there were no batteries in the system then the initial capital cost was $3,079,000, and at the end of the lifetime of the system, the total NPC was $20,617 (refer to Figure 41). However, if batteries were included in the system, the initial capital cost was $4,701,400 and the total NPC was $2,675,129. The total NPC in a PV grid-connected system with battery is very expensive compared to a grid connected PV system only (see Figure 39).

Figure 41: Grid connected PV system only versus grid connected PV system with batteries

However, if monthly net metering was considered for the grid connected PV system with battery system, this becomes promising, as given in Figure 42. Both systems, a grid connected PV system and a grid connected PV system with batteries, produced negative total NPC values or positive total NPV.

Figure 42: Net Metering per month grid connected PV system only versus grid connected PV system with batteries

4.3.3. Feed-in-tariff sensitivity analysis

The HOMER simulation revealed that if the feed-in-tariff is increased by an increment of 25%, the total net present cost (NPC) becomes negative and they all become economically viable. Option 4 is still the most optimum system, followed by option 3, 2, and 1. When batteries are included in the grid connected PV system, it will follow the same order of option 4, 3, 2 and 1.

5. Discussions

5.1. Economic Aspects of the Energy Supply Scenarios

The prefereability analysis done by RETScreen analysis in section 4.2.2. reveals that the solar PV panels can supply 100% of the electricity needs of the university, regardless of which energy supply
scenario was used, option 1 to 4. On the other hand, the HOMER simulation shows that option 4 (section 4.3.1) was the cheapest option. This simulation was based on the utility electricity purchase rate is $0.50 AUD and the selling rate is $0.25 AUD (Table 13).

Table 13: Summary of HOMER Simulation for supply scenario

<table>
<thead>
<tr>
<th>Options</th>
<th>PV (kW)</th>
<th>S4 KS2SP</th>
<th>Converter (kW)</th>
<th>Grid (kW)</th>
<th>Initial capital ($k)</th>
<th>Operating cost ($/yr)</th>
<th>Total NPC ($k)</th>
<th>COE ($/kWh)</th>
<th>Renewable fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1386</td>
<td>1000</td>
<td>2000</td>
<td>2000</td>
<td>$3,079,000</td>
<td>-335,075</td>
<td>-$497,850</td>
<td>-0.062</td>
<td>0.93</td>
</tr>
<tr>
<td>3</td>
<td>847</td>
<td>800</td>
<td>2000</td>
<td>2000</td>
<td>$2,070,500</td>
<td>-140,667</td>
<td>$568,911</td>
<td>0.071</td>
<td>0.87</td>
</tr>
<tr>
<td>2</td>
<td>835</td>
<td>800</td>
<td>2000</td>
<td>2000</td>
<td>$2,052,500</td>
<td>-135,889</td>
<td>$601,915</td>
<td>0.075</td>
<td>0.87</td>
</tr>
<tr>
<td>1</td>
<td>825</td>
<td>500</td>
<td>2000</td>
<td>2000</td>
<td>$1,737,500</td>
<td>-104,447</td>
<td>$622,551</td>
<td>0.077</td>
<td>0.87</td>
</tr>
<tr>
<td>4 with battery</td>
<td>1386</td>
<td>1352</td>
<td>1000</td>
<td>2000</td>
<td>$4,701,400</td>
<td>-236,170</td>
<td>$2,180,339</td>
<td>0.27</td>
<td>0.93</td>
</tr>
<tr>
<td>3 with battery</td>
<td>847</td>
<td>1352</td>
<td>800</td>
<td>2000</td>
<td>$3,692,900</td>
<td>-47,573</td>
<td>$3,185,069</td>
<td>0.395</td>
<td>0.88</td>
</tr>
<tr>
<td>2 with battery</td>
<td>835</td>
<td>1352</td>
<td>800</td>
<td>2000</td>
<td>$3,674,900</td>
<td>-43,883</td>
<td>$3,206,459</td>
<td>0.398</td>
<td>0.87</td>
</tr>
<tr>
<td>1 with battery</td>
<td>825</td>
<td>1352</td>
<td>800</td>
<td>2000</td>
<td>$3,659,900</td>
<td>-41,141</td>
<td>$3,220,729</td>
<td>0.399</td>
<td>0.87</td>
</tr>
<tr>
<td>Grid only</td>
<td></td>
<td></td>
<td></td>
<td>2000</td>
<td>$0</td>
<td>378,275</td>
<td>$4,038,001</td>
<td>0.501</td>
<td>0</td>
</tr>
</tbody>
</table>

If the utility removes feed-in-tariffs sometime in the future, then none of the options are financially viable, as revealed by the HOMER simulation. For example, (Figure 43) if the feed-in-tariff rate is removed, then the optimal system is option 1 and it has a positive total NPC value. The total NPC is higher at the end of the lifetime of the system than its initial capital cost. This means that the system is not economically viable.

Figure 43: Option 1 with no Feed-in-Tariff

Thus, it is essential that some kind of government policy is in place to keep the feed-in-tariff scheme for longer periods in order for large grid connected PV system projects to become economically viable.

5.2. Technical Aspects of the Energy Supply Scenarios
The Samoa electrical peak load is around 16 MW to 17 MW, which usually occurs in the afternoon. According to the utility (EPC) engineers, because of the variability of the solar resources, only 20% of the peak load (16MW – 17MW) from solar PV panels is allowed on the grid. This is to allow spinning reserves for the generators and hydro to ramp up quickly when electricity from solar is not available to meet the load demand in the country. This means only 3.2 MW to 3.4 MW of electricity from a grid connected PV system is allowed onto the grid. Currently, the 20% reservation for a solar grid
connected PV system is already fulfilled by all the solar PV projects in the country. These projects were commissioned at the end of 2014 and in the beginning of 2015. Some of the PV projects are owned by the private sector and some by the utility company. All the solar PV projects are monitored by the utility company from the main control centre using the latest Supervisory Control and Data Acquisition (SCADA) system, which was commissioned in October 2014.

According to a discussion with Perelini, a project manager for the renewable energy section of the utility company, “What is needed for solar PV to increase penetration onto the grid is storage. Samoa has abundant solar resources, but the more grid connected PV system onto the grid system the more unstable the grid becomes. It will be a good option for Samoa if batteries or any storage systems are cheap.”

Since, there are no more reservations available for a grid connected PV system, a system for NUS is not possible.

So, what are the options available to overcome some of the issues and barriers for such grid connected PV systems to be implemented in the country? An energy storage system is the key in overcoming the barriers that limit the penetration of solar PV on the grid. Energy storage is classified into four categories as given in Figure 44, but the first three are mainly for electrical energy.

![Energy Storage Technologies](image)

**Figure 44: Energy Storage Technologies (Source: Ma, Yang, and Lin Lu 2014)**

Batteries are definitely one option but the costs will not make it viable for Samoa, as seen in the HOMER simulation at NUS. The second option is hydro storage, using excess electricity from PV to pump water up to the hydro dams. Electricity from renewable energy resources, such as wind, for pumping water for hydro storage is found to be cheaper than batteries (Forcey and McConnell 2014),(Forcey and Dargaville 2015). Currently, the capital cost is $100 to $200 US per kWh for hydro storage compared to $200–$500 US per kWh targeted by the battery manufacturers by 2025 (Forcey and McConnell 2014).

The pumped hydro storage concept is not a new technology. There are several places in the world that use pumped hydro as storage such as “the Bath County Virginia facility with 3 GW of generation capacity and 30 GWh of stored energy,”(Forcey 2014). In Australia are Shoalhaven (240 MW), Wivenhoe (500 MW), and Tumut 3 (600 MW), which have been operating for more than 30 years. The La Muela in Spain and Tianhuangping in China are other examples (Patrick et al. 2014).

In Samoa, the capacity of hydro during dry season becomes low, from 10.00 MW to 4.40 MW, because of the low water level in the hydro dams (Table 14). During this period the diesel consumption increases.
Table 14: (Source: Toimoana 2006) Hydro Power Station Capacity

<table>
<thead>
<tr>
<th>Hydro Power Station</th>
<th>Capacity Wet Season (MW)</th>
<th>Capacity Dry Season (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaoa</td>
<td>1.00</td>
<td>0.30</td>
</tr>
<tr>
<td>Fale o le Fee</td>
<td>1.60</td>
<td>0.40</td>
</tr>
<tr>
<td>Samasoni</td>
<td>1.50</td>
<td>0.40</td>
</tr>
<tr>
<td>Lalomauga</td>
<td>3.20</td>
<td>0.80</td>
</tr>
<tr>
<td>Talelefaga</td>
<td>2.70</td>
<td>2.50</td>
</tr>
<tr>
<td><strong>Total Hydro</strong></td>
<td><strong>10.00</strong></td>
<td><strong>4.40</strong></td>
</tr>
</tbody>
</table>

Hence, if excess electricity from grid connected PV systems is utilised for pumped hydro storage, the capacity of hydro during the dry season will increase and the diesel fuel consumption will decrease. It is expected that this will lead to the drop of electricity price. Also, the cost of energy (COE) during the lifetime of this system should be lower than batteries, because the hydro dams lifetime are longer than batteries.

The third option is flywheel energy storage systems (FESS) for solar, which are competitive with chemical batteries (Abbezzot et al. 2013), (Berry 2009, 35). The flywheel technology is seen as well-scaled for systems with a discharge duration of 15 minutes to 1 hour when electricity from the renewable energy resources is not available (Johnson et al. 2010, Dinwoodie 1980, Hasegawa et al. 2009).

Both energy storage technologies, pumped water and flywheel storage, are matured technologies for wind and they can be used in Samoa for large solar PV systems. Nonetheless, a feasibility study for their viability is required, since these energy storage technologies can only operate when solar is present. Unlike wind which may be available anytime of the day.

Another way to help increase solar PV penetration on the grid is forecasting (Lorenz et.al 2009), however such technique involves a lot of resources, which is beyond the current ability of Samoa.

5.3. Social Barriers for Implementing Large-scale Solar Projects

Land issues have always been a problem with the utility and the local people. Hence, it will be difficult to implement large ground-mounted PV solar projects on customary owned land. The normal strategy used by the government in the past for utility projects to be implemented on customary owned sites was providing incentives, like free electricity for a certain period of time, or cash payment. This will maintain social stability with the people in the community. Every time these incentives are removed, conflicts arise between the government and the people (Keresoma 2013), (Ilia 2015), (RNZI 2004).

Therefore, if the customary-owned land is used for large PV projects, the government should provide incentives to overcome social conflicts. Incentives will add value to the projects because people will have a sense of ownership and they will look after these infrastructures.
5.4. Limitations of this Study

5.4.1. Data limitations

Electricity consumption at NUS is recorded by at least 10 utility electrical meters, but only two main electrical meters were used for this study because these two main utility meters measure the main electrical feeds to the two campuses.

The other eight electrical meters were measuring load from a low voltage line of 240V, single phase. Also, since all the electrical meters are located at different parts of the university campus, it is impossible to record all of them at once. Hence, for simplification, only two main electrical meters were used in this study, which were recording at least 85% to 95% of the total electrical load. They were also recording peak loads (Figure 45).
5.4.2. Energy audit limitations

The technical electrical equipment for the technical courses that run on three-phases were excluded during the walk-through audit as they were not in operation at the time. However, speaking to the technical instructors for these courses, although the machines are heavy duty, they only run during laboratory classes.

5.4.3. Economic limitations

Cost of fuel varies from time to time, hence the electricity price, discount rate and inflation rate changing over the years. Different authors gave different costs for a grid connected PV system, such
as fixed costs and operating and maintenance costs (O&M) (Kansara and Parekh 2013), (ITP 2013, 73), (Nand and Raturi 2013, 111), (ATPS 2013, 16). These costs will also be different for NUS settings.

5.5. Benefits of Solar PV in Institutional Settings

• Employing Solar PV on the university campus will help improve its image and branding. Universities that are striving for sustainability have better ranking (Augenbraun 2010, 17), (Grinsted 2011, 34).

• There is a better chance of more students applying to universities that have sustainability programs (Chimack and Lindsey 2011, 7).

• Solar PV data can be useful for research and for classroom exercises or laboratory activities. Furthermore, there will be opportunities to educate prospective students about renewable energy technology and how it can reduce greenhouse gas emissions on campus (Chimack and Lindsey 2011).

• Installing PV on campus will assist and support the Samoa Energy sector plan 2012–2016 vision (MOF 2012a).

• NUS has limited land space; therefore, using rooftops is essential. Since the university is continuing to expand, rooftop space is an ideal place to implement solar panels.

• Also, utilising the rooftops at NUS will not have any issues to social equity surrounding customary or village owned sites. It has been an ongoing problem between the government and the villages.

• The orientation of the rooftops are in the north-south direction, which is an ideal location for solar PV projects.

• The electricity it generates will offset the retail electricity cost from the utility company. Hence, it will reduce electricity expenses for the university and will create a revenue opportunity for the university.

• This is the only renewable energy source accessible for the university.

• Solar PV structures do not have dynamic loading on the building structure that may weaken the building structures.

• Since there are no moving parts, it has low maintenance costs.

• No noise pollution during the PV operation and it would not affect classes.

6. Conclusions

In conclusion, a grid connected PV system for a sustainable campus at the National University of Samoa is not technical and economical viable, despite the results from RETScreen and HOMER analysis that it is achievable.

However, on the technical side, a grid connected PV system is not possible. Firstly, a net metering scheme is not allowed by the utility due to the technical issues that arise from such a system. Secondly, the allowed portion of electricity from a solar grid connected PV system onto the utility grid in the country is already filled. Hence, a grid connected PV system for NUS is not possible unless storage is in place to stabilise power output for the utility grid.
If battery storage is considered in the system and at the current feed in tariff it will become expensive and uneconomical for the university. Therefore, a grid connected PV system for the university is not technical and financial attainable.

On the other hand, if the university wants to have a system to improve its branding as a sustainable university campus, the government supports is required through grants, financial aids, and policy mechanisms, in order for the grid connected PV system to become technically and economically viable.

Despite there being abundant natural solar resources available in Samoa, the technical aspects of the grid connected PV system and the utility grid sets the upper limit for grid penetration. Energy storage is the key for increasing penetration of large scale PV system in the country. Two energy storage system (ESS), grid pumped hydro storage and flywheel energy storage, were considered. Still, a feasibility study for these applications is required for Samoa. It is recommended that more research for energy storage is required for the country in order to increase the use of renewable energy resources in the country.
7. References


8. Appendices

8.1. Appendix A: Upper Campus

Source: www.googlemap.com (Buildings A, B, C, D, E, G and H at the upper campus)

8.2. Appendix B: Lower Campus

Source: www.googlemap.com (Buildings A, B, C, D, E, F, G and H at the lower campus)
8.3. Appendix C: Battery Specification

<table>
<thead>
<tr>
<th>Description</th>
<th>Gas/electricity Consumption (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Surette 4K25P</td>
</tr>
<tr>
<td>Voltage</td>
<td>4 V</td>
</tr>
<tr>
<td>Round trip efficiency</td>
<td>80 %</td>
</tr>
<tr>
<td>Min. state of charge</td>
<td>40 %</td>
</tr>
<tr>
<td>Life time</td>
<td>&lt;1 yr</td>
</tr>
<tr>
<td>Max. charge rate</td>
<td>&gt;1 A/hr</td>
</tr>
<tr>
<td>Max. charge current</td>
<td>&gt;1 A/hr</td>
</tr>
<tr>
<td>Lifetime throughput</td>
<td>10,563 kWh</td>
</tr>
<tr>
<td>Suggested value</td>
<td>10,494 kWh</td>
</tr>
</tbody>
</table>

8.4. Appendix D: Min, Max and Average (2008-2014)
Appendix E: Temperature, Humidity versus Electricity Consumption