10.8 KWP SOLAR PV SYSTEM AT A PRIVATE RESIDENCE IN BRUNEI-MUARA DISTRICT, BRUNEI DARUSSALAM
(Category: Off-Grid Power)

Submitted to Board of Judges on ASEAN Renewable Energy Project Competition
ASEAN Energy Awards 2016

By
BIT Computer Sdn Bhd
Brunei Darussalam

APPLICATION FORM

ASEAN Renewable Energy Project Competition
ASEAN Energy Awards 2016

Title of Activity / Project / Theme:

10.8KWP SOLAR PV SYSTEM AT A PRIVATE RESIDENCE IN BRUNEI-MUARA DISTRICT, BRUNEI DARUSSALAM

Category:	OFF Grid Power
Age of project:	1 year and 9 months
Source of energy/type of technology:	Solar PV

Applicant General Information	
Name of Company	: BIT Computer Sdn Bhd
Business Address	: A9, Urairah Complex, Kiulap, Bandar Seri Begawan Brunei Darussalam
Number of Employees	: 36
Age of Project	: 1 year and 9 months
Nature of Business	: Retailer for PCs, laptops and IT related items such as powerbanks (solar charger) and pendrives.
Contact Person Name Position Telephone Mobile phone Fax E-mail Project Address:	: Mr Loo Kuan Look : Manager : +6732231923/+6732231925 : +6738167885 : +6732231869 : Bitloo@yahoo.com No:51, Spg:80-49, Kg Pengkalan Gadong, Bandar Seri Begawan Brunei Darussalam

APPLICATION FORM

ASEAN Renewable Energy Project Competition
ASEAN Energy Awards 2016

Project Abstract:

According to IRENA, the global Solar PV penetration in the residential sector is gradually increasing year by year as the cost of solar PV and its balance of systems has become more affordable. Furthermore, Solar PV has become more attractive with the availability of Renewable Energy policy incentives such as ''Feed-in Tariff'' and ''Net-Energy Metering''.

However, in Brunei Darussalam, there is no Renewable Energy policy incentive in place. Hence, it is difficult to encourage solar PV installations in the country. Moreover, the cheap electricity tariff for residential sector (average tariff is USD 0.05 per kWh) and the 5% tax imposed on importation of Solar PV panels and inverters, further intensify the struggle to deploy Solar PV systems in Brunei.

An IT business owner, Mr Loo Kuan Look, has installed a 10.8kWp Solar PV system at his private residential house in Kampong Pengkalan Gadong in June 2014, with the aim of understanding the technicalities of Solar PV system, reducing the expensive electricity bill, reducing his share of carbon emission and also to educate others through the demonstration. He has dedicated most of his time in the last 3 years to set up a perfect Solar PV system at his residence through several iterations of 'trial and errors'. He has spent over US$30,000 of his disposable income on purchasing numerous Solar PV panels and balance-of-systems throughout the testing phase until the final design. The total cost of the final set up of the 10.8kWp system was just B$24,296.00 (US$18,379.41) which gives the effectiveness ratio of B$2249.63 per kW (US$1654.14 per kW)

Prior to the installation, the monthly electricity bill was about B$290 (US$213.24). After installing the Solar PV system, electricity expenses went down to B$187 (US$135.29) per month. A 35.4% reduction on monthly expenses for electricity was seen. In terms of energy consumption, this is equivalent to 27.5% reduction on grid electricity consumption from 3719kWh per month to 2695kWh per month.

In summary, this Renewable Energy project has shown that even without financial incentives, the project can still fly. The cost can be counter-balanced by the selection of affordable solar PV panels and balanced of systems. The space constraints can be mitigated with the creativity in making full use of available area to mount solar PV panels. In terms of human resource, Mr Loo has shown that the whole project can be done by a single person through innovative solar PV ''DIY'' (Do-It-Yourself) installation. This project also preaches the idea of 'learning by doing' and helps turning the individual into a responsible citizen by tackling climate change through reducing the reliance on fossil fuel for power generation.

APPLICATION FORM

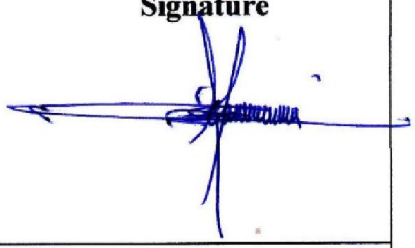
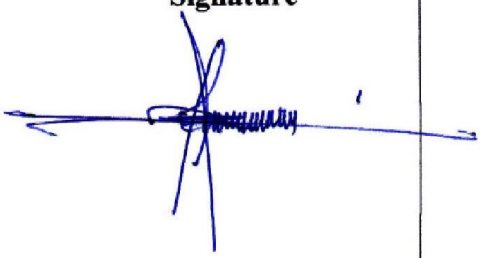
ASEAN Renewable Energy Project Competition
ASEAN Energy Awards 2016

CERTIFICATION AND ENDORSEMENT

BIT Computer Sdn Bhd, hereby agreed to allow the ASEAN Board of Judges and other experts that may be designated by ACE to visit the RE project site and verify the authenticity of the data. However, 2 weeks advance notice is required to allow for necessary arrangements.

We also hereby agree that ACE can publish the whole submission in ACE publications and website, without any prior consent of the owner of the RE project. If the submission will be published in other publications, the consent of the concerned RE project owner would be required.

We, the undersigned certified that the information given is true and accurate and prepared with the consent of the party/ies involved.

Applicant **Mr Loo Kuan Look** BIT Computer Sdn Bhd Telephone : +6732231923/+6732231925 Mobile phone : +6738167885 Fax : +6732231869 E-mail : Bitloo@yahoo.com	**Signature** 
Project Owner/Manager **Mr Loo Kuan Look** Manager, BIT Computer Sdn Bhd Telephone : +6732231923/+6732231925 Mobile phone : +6738167885 Fax : +6732231869 E-mail : Bitloo@yahoo.com	**Signature** 
Endorsed by RE-SSN Focal Point **Abdul Matiin Hj Muhd Kasim** Head of Renewable Energy Unit Energy and Industry Department, Prime Minister's Office Mobile phone: +6737177014 Tel: +6732384488 ext. 1442 Fax: +6732384444 E-mail: matiin.kasim@energy.gov.bn	**Signature** 

For further inquiries, please contact:
Mr. Christopher G. Zamora
ASEAN Centre for Energy
6th Floor, Jl. HR Rasuna Said, Blok X-2
Kav. 07-08 Kuningan, Jakarta 12950, Indonesia
Tel.: (6221 – 527-9332) Fax: (6221 – 527-9350)
E-mail: christopher@aseanenergy.org

APPLICATION FORM

ASEAN Renewable Energy Project Competition
ASEAN Energy Awards 2016

A. ORIGINALITY

Design

The 10.8kWp Solar PV system is initially designed to be grid-connected to provide stable and continuous electricity to the house. Prior to this, the house and its surrounding areas were prone to grid power outages which occurs twice a year on average and for a duration of 2-3 hours. Apart from resolving the reliability issues, the installation also intended to reduce the usage of grid electricity and hence, reducing the electricity bills. However, as it turns out, the system is capable of supplying most of the regularly-used loads in the house and therefore, it has been redesigned to a standalone connection, supplying only to specific areas in the house. The system also includes a total of 3200Ah deep-cycle batteries, which stores excess power in the batteries to provide enough electricity to the loads throughout the night or during cloud cover. The system is also coupled with inverters which is slightly oversized (12kWac) to ensure longevity of the inverters and to allow leeway for more panels to be installed.

Application

The 10.8kWp Solar PV system is currently powering appliances in 2 regularly used rooms (one office room inside the house and one room in the container cabin).

The total loads include:

- 5 units of lightings (fluorescent) and 3 units of air-conditioners (2 units of 1HP air-conditioner and 1 unit of 2 HP air-conditioner) which runs for 8 hours a day
- a medium-size refrigerator running 24 hours a day

However, the application of the system goes beyond delivering power. It has also turned into a solar PV demonstration house for public visitors such as students and solar PV enthusiasts to learn on any aspects of the Solar PV system as well as the technical details on the installation.

Approach

Mr Loo, the owner of the house, has dedicated most of his time in last 3 years to set up a perfect Solar PV system through numerous testing. Coming from a business background, Mr Loo has done background studies and due diligence in getting the highest quality equipment at the lowest cost. Without any electrical background, he has spent countless months on several Solar PV self-guide installation and sizing websites. The approaches are shown in the Gantt chart below:

Activities	2013	2014	2015	2016
Reducing electricity usage through energy efficiency and conservation measures (eg. through behavioural change)				
Due diligence and background study on cost, design and planning				
Purchasing of equipment (Panels and other balance of systems)				
‘’Trial and Error’’ on connection and different equipment				
Commissioning of finalised design				
Operation and Maintenance, capacity building on personnel and educating the public.				

B. ENVIRONMENTAL CONSIDERATION

B.1 Amount of Emissions/Pollution Avoided

No.	Parameters	Value and unit		
		Before Solar PV installation	**After Solar PV installation**	**Reduction**
1	**Annual electricity consumption (from grid)**	44,628 kWh	32,340 kWh	**12,288 kWh**
2	**Annual CO_2 emission**	36,594.96 $kgCO_2$	26,518.8 $kgCO_2$	**10,076 $kgCO_2$**
3	**Annual electricity bill**	B$3,480	B$2,244	**B$1,236 (US$908.82)**
4	**Estimated CO_2 Abatement Cost**			**B$0.12 per $kgCO_2$ (US$0.09 per $kgCO_2$)**
5	**Estimated annual fuel (gas) saved at powerplants**			**166.6 mmBTU**
6	**Annual opportunity cost (extra revenue from gas exports)**			**US$1374.66**
7	**Number of trees that could absorb 10,076 kg CO_2/year**			**480**

B.2 Discussion on calculation

1. Annual (grid) electricity reduction

Annual grid electricity consumption before Solar PV installation = 3719 kWh X 12 months
= 44,628 kWh/year

Annual grid electricity consumption after Solar PV installation = 2695 kWh X 12 months
= 32,340 kWh/year

Annual grid electricity reduction = 44,628 – 32,340
= 12,288 kWh/year

2. Annual Amount of Carbon Dioxide (CO_2) Avoided

Average Grid emission factor for Brunei (ref. APERC) = 0.82 $kgCO_2$/kWh

Annual amount of CO_2 emission (before installation) = 44,628 kWh/year X 0.82 $kgCO_2$/kWh
= 36,594.96 $kgCO_2$

Annual amount of CO_2 emission (after installation) = 32,340 kWh/year X 0.82 $kgCO_2$/kWh
= 26,518.8 $kgCO_2$

Annual amount of CO_2 avoided = 36,594.96 $kgCO_2$ - 26,518.8 $kgCO_2$
= 10,076 $kgCO_2$/year

3. Annual electricity bill reduction

*Using figure 1 in Section G (page 13),
3719kWh = B$290 per month
2695kWh = B$187 per month

Annual electricity bill before Solar PV installation = B$290 X 12 months
= B$3,480

Annual electricity bill after Solar PV installation = B$187 X 12 months
= B$2,244

Annual electricity bill reduction = B$3,480 – B$2,244
= B$1,236 (US$908.82)/year

4. Estimated CO_2 abatement cost

Total cost of Solar PV and Balance of Systems = B$24,296.00 (US$18,379.41)

Estimated total cost of Solar PV and Balance of Systems over its lifetime (25 years) plus annual cost of operation and maintenance including inverter replacement (1% of capital cost per year) = B$30,370.00 (US$22,330.88)

Total amount of CO_2 avoided over 25 years = 10,076 $kgCO_2$/year X 25
= 261,900 $kgCO_2$

Estimated CO_2 abatement cost = B$30,370.00/261,900 $kgCO_2$
= B$0.12 per $kgCO_2$ (US$0.09 per $kgCO_2$)

5. Estimated fuel saved at powerplants

Annual power generated by 10.8kWp solar PV = 12,288 kWh
Power loss at transmission and distribution = 13% (Actual Brunei T&D losses)
Annual power saved from generation plants = 12,288kWh X 113% = 13,885.44kWh
Heat rate of simple cycle gas powerplants = 0.012mmBTU/kWh
Annual gas saved from generation plants = 13,885.44kWh X 0.012mmBTU/kWh
= **166.6 mmBTU** of gas

6. Opportunity cost (extra revenue from gas exports)

Current Asian gas price (Japan import price) as of March 2016 = US$8.25 per mmBTU
Annual revenue using gas market price = US$8.25 X 166.6 mmBTU
= US$1374.66

7. Number of Trees

Amount of CO_2 absorbed by one tree (mature tree) = 21 kg

Number of trees that could absorb 10,076 kg CO_2/year = 10,076 / 21
= 480 trees

C. SOCIAL CONSIDERATION

C.1 Benefits (User, Community, Country)

There are many socioeconomic benefits which are derived after the installation of the 10.8kWp Solar PV system:

A. Benefits to user

- Cheaper electricity bill
- Ameliorate conscience and reputation of the owner
- Labelled as green enthusiast and responsible resident within the community and country
- Set a great example amongst business owners and communities
- Increase reliability in terms of provision of electricity to the residence
- During power outages, the house can rely on the power from the Solar PV System
- Increase the understanding on how to size Solar PV system according to needs as well as how to select and connect the balance of systems in a proper manner
- Able to find out the cheapest and most effective Solar PV and its balance of systems.

B. Benefits to community

- The residence has become an attraction site for the community (especially students, environmentalists and Renewable Energy enthusiasts) to learn on the detailed operation and installation of Solar PV and clean energy awareness
- Community can easily replicate the same Solar PV system set up and design with additional information of the true cost of the overall system.

C. Benefits to country

- Increase the Solar PV penetration in the residential sector and contribute to increase the share of Renewable Energy in the country
- Helps reduce country's carbon emission and reduce grid electricity emission factor
- Reduce the reliance on grid electricity and minimizing the use of gas at the power plants
- Increasing country's revenue through increasing gas exports (extra gas volume from the reduction of gas usage in domestic powerplants)
- Project can be used for research and study purposes, and also help promoting and incentivizing Solar PV installation through its demonstration
- Lessen the burden of Government to fund residential scale Solar PV demonstration.
- Help the Government in formulating policies towards residential scale Solar PV.

C.2 Community/People Participation

It is extremely rare to see medium Solar PV installation (more than 3kWp) in the residential sector, especially without Renewable Energy policy incentives such as Feed-In Tariff. It takes great courage, commitment and dedication to install a medium size Solar PV system (more than 10kWp) without receiving any huge financial benefits at the end of the day. However, Mr Loo has decided to challenge this status quo. He dedicated his time and effort as well as sacrificed his savings to purchase and set up a solar-PV system at his house for the benefit of the environment and also the public.

The project started off as a hobby and affection towards clean Renewable Energy and Solar PV. It then became a passion and avocation to educate the others. He has begun to train his staff (who are working with his IT company) in 2015 on the technical aspects of the operation, after undergoing the‘’learning by doing’’ experience.

Picture on the right shows Mr Loo, the owner of the house and Solar PV system, explaining the operation and set up of the solar PV systems inside the container cabin (100% powered by Solar PV) in attendance of local University students and Government officials

Since its commissioning in June 2014, the residence has been receiving a number of visitors from the Government, including the Energy and Industry Department, local businessmen, green NGOs, students and interested individuals. These visitors have enhanced their understanding on the overall operation of the solar PV system through the design, set up and implementation.

Mr Loo has also done a lot of experimentation on the Solar PV system. Examples of the studies done were; Investigating the output of different types of Solar PV panels (using Polycrystalline and Monocrystalline panels) and experimenting different types of storages including Car batteries (normal charging cycle) and deep-cycle batteries (shown in figure 7 in section G, page 15). He has shared the results with the visitors and has helped others (interested individuals who wishes to set up a Solar PV system) in terms of minimizing cost, choosing the right set up and sizing the Solar PV and balance of systems.

D. TECHNICAL, ECONOMIC & MARKET CONSIDERATION

D.1 Technical Design

Previous technology

Before the commissioning of the solar PV system, the house is fully powered by grid electricity which is delivered from simple-cycle gas turbines at the nearby power station.

Technology Applied

*Cost breakdown is shown in Figure 2 in section G (page 13)
*Simplified design is shown in Figure 3 in section G (page 13)

A. **Solar PV Panels (Ying-Li): 54 Polycrystalline PV Panels (10.8kWp)**

The rated capacity of each Chinese manufactured Ying-Li panel is 200W. Made up of polycrystalline silicon modules, with each panel measuring 1.5 m x 0.99m x 0.05 m. Each panel weighs around 18 kg. The efficiency of each panel is greater than 15%. Ying-Li panel are chosen due to its resilience in hot-climate such as in Brunei Darussalam, cost, market-availability and its low temperature coefficient (degradation of output in high temperatures).

B. **Solar Charge Controller (PWM): 3 Units**

The PWM controller, which is manufactured in China, is rated at 220 V/100 A. The purpose of the controller is to protect against overcharging, over-discharging and overload.

C. **Inverter (SUVPRT): 3 Units (12kW$_{ac}$)**

The 3 inverters are rated at 4 kW$_{ac}$ each with the aim of converting DC to AC. Slightly oversized to reduce overworking of the inverter and to allow more panels to be added. Its efficiency is greater than 90%. The inverters are manufactured by SUVPRT in China and are cheaper than other inverters of the same capacity.

D. **Deep-cycle Batteries (NPP): 32 Units (3200Ah)**

The batteries are of a lead-acid type, which is rated at 100Ah each. 32 batteries are utilized to supply enough and continuous electricity to the load during night time and when there is limited sunlight. Deep-cycle batteries are used to endure constant charging and discharging in everyday use and has a longer lifespan compared to normal batteries. The NPP brand batteries are manufactured in China and are cheaper than any other deep-cycle batteries available

E. **Angle-iron mounting**

Since the solar panels are recommended to be placed almost flat to receive maximum sunlight (irradiance), the panels which are at 0^{o} tilt angle, can be easily mounted onto the flat roof using the generic angle-iron mounting. Due to its durability and cheap cost, it serves a perfect material for mounting the Solar PV panels.

D.2 Technical Performance

The final set up of the solar PV system was completed and commissioned in June 2014. The rated capacity of the system is 10.8kWp, which would have generated 94,608kWh annually. However, taking into consideration its capacity factor of 12%-13% for a typical solar-roof top PV system in Brunei Darussalam, the actual capacity is about 1.40kWp, which generates about 12,288kWh annually as shown in Figure 4 in section G (page 14). The Solar PV panel set up is, however, experiencing some shading from the nearby trees and buildings which contributes to the low capacity factor.

The inverters are purposely decentralized and oversized to optimize the load requirements at different places, prevents the inverters from overworking and to reduce internal wiring. In terms of reliability, the house and surrounding areas are prone to grid power interruption which occurs twice a year on average and for an average duration of 2-3 hours. This reliability issues were resolved using the deep-cycle batteries which has a longer lifespan than normal cycle batteries. Previously, normal-cycle batteries (car batteries) were used but they were not reliable enough to support the demand of the appliances, especially during night time. About B$7000 (US$5147) were spent on different kinds of batteries to examine which batteries are best to use with the system. The advantage of using angle-iron for mounting is due to its property which is durable and also cheap in terms of cost. The advantage of using angle-iron for mounting is due to its property which is durable and also cheap in terms of cost.

D.3 Investment Indicator

Financial Model	**Capital Investment:** B$24,296.00 (US$18,379.41) **Yearly O&M cost (1% of capital investment):** B$242.96 (US$183.79) **Yearly savings in Energy bill:** B$1,236 (US$908.82) **ROI:** 27% (over 25 years) **Project lifespan:** 25 years **Payback Period:** 24 years **Effectiveness ratio (cost/kW):** B$2249.63 per kW (US$1654.14 per kW) **Government revenue from gas sales over 25 years:** US$34,366.46 **Carbon abatement cost:** B$0.12 per kg$CO_2$ (US$0.09 per kg$CO_2$)

D.4 Financial Scheme/Livelihood Projects

In Brunei Darussalam, there is no Renewable Energy policy incentive in place such as Feed-in Tariff or Net-Metering, and hence, the overall project funding to borne the capital cost and operation and maintenance comes from the owner's own disposable revenue (income from IT business). This downside was counter-balanced in this home project by reducing CAPEX (capital expenditure) through the purchase of cheap panels and balance of systems. The project is further sustained through opportunity cost of savings in energy bill. However, the project will act as a perfect hedge if residential energy tariffs were to be reformed (increased) or if subsidies were to be reduced or removed. The current electricity tariff for residential sector is USD 0.05 per kWh on average.

D.5 Funder (Government and Non-Government)

The project is fully self-funded by the owner of the house. 5% importation tax on Solar PV panel and inverters was also paid by the owner of the house.

D.6 Market Size (Potential Within 5 Years)

Currently there are over 60,000 households in Brunei that can emulate the design of this system. There are also a few local vendors in Brunei which can offer installation and consultation on Solar PV systems and the demand for smaller systems (less than 3kWp) are currently growing. Given that 35% of the household consumption can be offset by the Solar PV system, the incorporation of this system throughout the populace would significantly reduce the gas consumption at the powerplants and reduce carbon emission significantly. Furthermore, given the current decreasing trend in price of solar PV modules and balance of systems, there will be potential deployment throughout the country within the next 5 years using a bigger system such as the 10.8kWp system. This can be further accelerated by the imminent intervention of Government financial policy incentive, given that Brunei is targeting 10% of its total power generation mix from renewable energy sources by 2035.

D.7 Local Manufacturing/Content of System

In this project, most of the equipment are manufactured in China such as the batteries, inverters, charge controllers and the solar PV panel itself. The angle-iron mounting, connectors and wiring comes from different countries within the ASEAN region. However, the installation is solely done by the owner of the house himself without the help of his 36 employees working under his company.

D.8 Amount of Fossil Energy Avoided

Currently the solar PV system generates 12,288kWh of electricity annually. With the actual grid transmission and distribution losses about 13%, this would offset 13,885kWh of electricity from the power generation plants per year. Since the generation plants are simple cycle, with a heat rate of 0.012mmBTU per kWh, this would save about 166.6 mmBTU of natural gas per year.

D.9 Life of Project

The life of the project is 25 years, taking into account the Solar PV panel lifespan of 25 years and the inverter replacement every 8 years. The cost of inverters have been amortized over the 25 years.

E. OPERATING & MAINTENANCE SCHEME

E.1 Operation Hours (Day/Month/Year)

The solar PV system operates throughout the year without any need to change the settings. The system is operating at full capacity for at least 3 to 5 hours during the daytime where there is sunshine (high irradiance). In case of inclement weather (without sunlight), the system's battery can supply the back-up electricity for 2 consecutive days (day and night) with the current load demand. The Solar PV panels output starts producing power at 6:30am and peaks at midday (12pm-1pm) and stops generating at 6:30pm.

The appliances using the Solar power are:

- 5 units of lightings (fluorescent) running 8 hours a day
- 3 units of air-conditioners (2 units of 1HP air-conditioner and 1 unit of 2 HP air-conditioner) which runs for 8 hours a day
- a medium-size refrigerator running 24 hours a day

The inverter system also shows the kWh produced, battery percentage charging status and the status of the overall connection. This makes it easier to monitor and control the system.

E.2 Maintenance Scheme (In-House, Contracted Out Service, Government, Others)

All maintenance work are carried out in-house by the owner himself. The work includes cleaning the panels as well as checking the status of the balance of system (especially the batteries) which occurs yearly and monthly respectively. The owner has looked up some guidelines from the internet on how to maintain the Solar PV system and applied it in his maintenance scheme. As the house is situated inland, sedimentation and dirt accumulation on the panels is low and thus, maintenance requirement is minimal. The inverter system is also equipped with temperature sensor so it can be protected from over-heating.

E.3 Other Maintenance Measures (Training, After-Sales Service)

After a year of setting up the system and maintaining the system. It was time to transfer the knowledge to others. The owner of the system starts to train (in-house) some of his employees working in his company on the installation, operation and maintenance of system in 2015. The solar PV and its balance of systems have different range of warranties from a 10 year period offered by Ying-Li solar panels to a 5 year period warranty on the SUVPRT inverters. However, no training services were offered to Mr Loo from the manufacturers albeit purchasing large number of Solar PV panels from the manufacturer.

E.4 Local Service Content

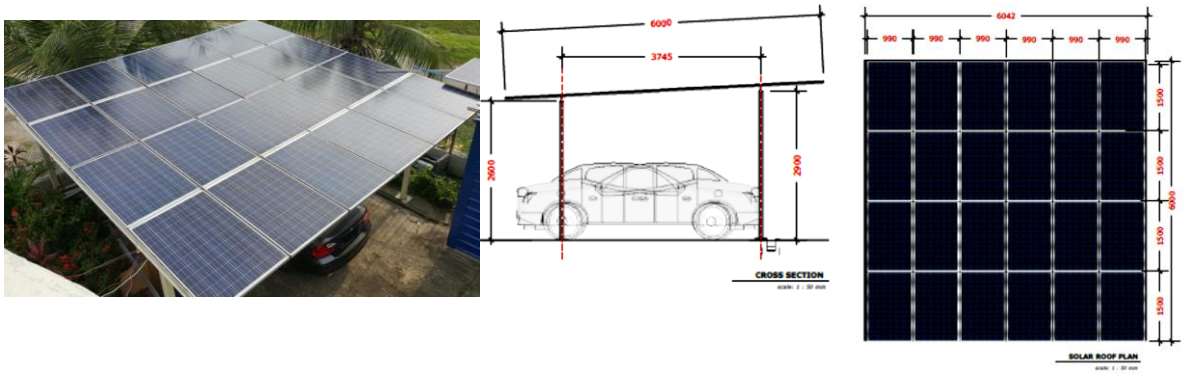
Some of the employees who has undergone the in-house training are local. With his supervision, these local staff have developed their expertise on the maintenance and operation of the system. With that, there is a huge opportunity for these staff to develop further their expertise on other solar PV systems in Brunei, while transferring their knowledge to the younger generations and increase capacity building in the future. There are also a number of visitors (potential solar PV vendors and installers) who wish to learn how to install and operate the system. The owner has given training and capacity building opportunities to these visitors at no cost. He believes there is potential for locals to set up service companies for installation, consultation, operation and maintenance of the Solar PV system as the whole set of procedures is fairly straight-forward as shown in the project.

F. REPLICABILITY

F.1 Relevance, Impact, Efficiency

The system can be replicated to a number of residential houses in Brunei with standalone or hybrid modification. The owner of the system has proven that the installation of Solar PV can be performed by one single person as demonstrated in his home project. Since the connector has the concept of ‘’plug and play’’, it is fairly simple to connect the balance of systems and solar PV panels together.

Space constraints is always the main issue when it comes to Solar PV installation in residential areas. A 10.8kWp system using 200W module panel dimension (1.50 m x 0.99m) will utilize an approximate 80m^2 of roof space (horizontal). However, in this project, the owner has demonstrated that the problem related to space can be mitigated.



As shown in the above picture and detailed design, the solar panels utilized the garage roof which is slightly tilted at 5^o facing to the south to receive maximum sunlight. This detailed design developed by himself with reference to structural information from the internet was successfully put together by himself. 26 of the total 54 module panels were utilizing the garage roof space while another 12 module panels were placed on the horizontal roof of the container cabin. This leaves another 16 solar module panels which then easily utilizes about 24m^2 of his house roof space. Since there are a lot of households which have car garages, this innovative design can be mimicked to mitigate the area constraints issues.

The standalone design and set up could be adopted by houses in remote areas such as in Kg Sukang and Kg Melilas where there is no grid access and the panels could potentially be ground-mounted. The installation of this system provides significant potentials for the development of both on-grid and off-grid solar PV systems in residential, commercial and industrial sector in Brunei.

F.2 Cost Effectiveness (No, Low, High Cost)

The overall project itself (from testing phase to final design stage) was not that cost-effective as there were additional expenses spent on testing different types of batteries and inverters. The economics of the project was also less feasible due to the cheap residential tariff (avg. at US0.05 per kWh) and due to the unavailability of policy incentives such as tax exemption on importation of solar PV panels and its components as well as financial incentives such as Feed-in Tariff or Net-metering. However, looking at the project itself compared to other existing solar PV installation in Brunei, and also looking at the final design, where only B$24,296.00 (US$18,379.41) were spent for the Solar PV system, it is proven more cost effective in contrast to local vendors who offers higher cost (more than B$30,000 for 10kWp system including storage). The system will also be cost-effective if it were to be installed in remote areas, where transmission and distribution power lines are very expensive and diesel generators are very tedious and costly. In terms of comparison to smaller systems (eg. 3kWp and 5kWp), the 10.8kWp is also more cost-effective due to the economies of scale.

F.3 Sustainability of Project

The project is deemed sustainable throughout its lifespan due to:

- The abundance of solar irradiation in Brunei Darussalam, especially at the project site.
- In terms of structural integrity and sustainability, the solar PV system in place durable and well-tested with no signs of deterioration after nearly 2 years of installation.
- In terms of reliability, the system continues to provide continuous and sustainable electricity 24-7 even during grid power outages or even night time.
- The solar PV system requires low maintenance and no feedstock, thus the system is financially sustainable to be operated
- The solar PV system's lifespan is about 25 years
- In terms of environmental sustainability, the system continues to avoid 10,076 kgCO_2 emission per year.

F.4 Lead by example (Dedication to Solar PV deployment in Brunei Darussalam)

Mr Loo has led by example through implementing this sustainable and rewarding project. It is hoped that his work will motivate and enable others, especially those with extra disposable income, to follow suit. The project also helps visitors to better understand the importance of conserving the energy and environment through the use of Renewable Energy technologies. Unlike other practices, his approach in going solar is not sizing the PV system first, but trying to reduce electricity usage through conservation and efficiency measures. He has also transformed his container cabin unit to a Solar-PV training room for capacity building exercises and other Solar PV studies for his employees and visitors. What initially started as a small project, turns out to be an educational hub for Solar PV which gives a large impact to the economy, public and nation as a whole.

G. FIGURES, TABLES, PHOTOS

1. Residential Electricity Tariff

Tier	From (kWh)	To (kWh)	B$/kWh	USD/kWh
Tier 1	0	600	0.01	0.007
Tier 2	601	2000	0.08	0.059
Tier 3	2001	4000	0.10	0.074
Tier 4	> 4000		0.12	0.088

Figure 1 above shows the table of current electricity tariff (shown in Brunei dollars and US dollars) for residential sector, which follows a progressive tariff structure. (*Exchange rate US$1 = B$1.36)

2. Cost breakdown and details of Solar PV and balance of systems

Items	Manufacturer	Capacity /Rating per unit	Quantity	Total capacity / rating	Cost (Brunei Dollars)
Solar PV panels (Poly-crystalline)	Ying-Li (China)	200W	54	10.8kWp	13,540.00
Solar charge controller	PWM (China)	12V/24 V 30A	3	3 X 12V/24V 30A	156.00
Deep-Cycle Batteries	NPP (China)	100Ah	32	3200Ah	7,586.00
Inverters	SUPVR (China)	4kW	3	12kW$_{ac}$	2,450.00
Mounting, Cabling and Connector	Generic				564.00
Total Cost (Brunei Dollars)					B$24,296.00
Total Cost (USD)					US$18,379.41

Figure 2 above shows the table of breakdown of costs, rating and brands of the Solar PV and its balance of systems. *All prices included 5% tax on Solar PV panels and other balance of systems.

3. Solar PV system design

Figure 3 above shows the 10kWp Solar PV system design set up and some of the appliances within the house which benefits from the solar power

4. 2015 monthly Solar PV generation

Month / Year	Daily Solar Radiation (Horizontal) (kWh/m^2/day)	Daily Solar Radiation (Tilted) (kWh/m^2/day)	Monthly Energy Generation from Solar PV (kWh/month)
January	4.79	4.62	971.49
February	4.96	4.85	1012.79
March	5.54	5.48	1137.71
April	5.51	5.54	1140.81
May	5.02	5.10	1044.79
June	4.75	4.85	991.11
July	4.84	4.93	1008.66
August	5.03	5.08	1043.76
September	4.95	4.93	1020.02
October	4.96	4.87	1003.85
November	4.76	4.61	967.36
December	4.67	4.49	945.68
Yearly (Average)	**4.98**	**4.95**	**1024.00**
Total yearly generation			**12,288 kWh per year**

Figure 4 above shows the table of actual monthly Solar PV generation recorded for the whole year of 2015 from the 10.8kWp Solar PV System.

5. Solar PV and the balance of systems

Figure 5 above shows the Solar PV panels mounted on the container cabin's rooftop and car garage (creatively optimizing the available space) and other balance of systems such as charge controller and inverter which shows the status of the connection

6. Visitors from University students and Government officials

Figure 6 above (left) shows visitors from Universiti Teknologi Brunei (UTB) and officials from Energy and Industry Department, Prime Minister's Office with the owner of the Solar PV system, Mr Loo Kuan Look. Above (right) shows Mr Loo explaining to the visitors the overall system operation and design inside the container cabin which is 100% powered by Solar PV.

7. Batteries used:

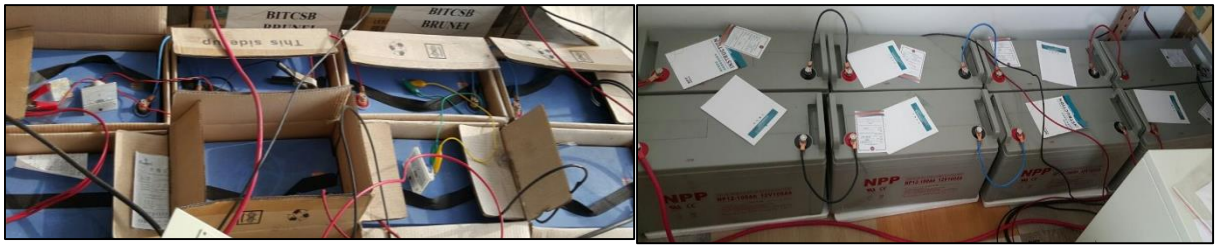


Figure 7 above (left) shows the normal cycle car batteries which were previously used during the testing phase. Above (right) shows the NPP manufactured deep-cycle batteries which is currently used in the final design of the solar PV systems.

8. Installation of Solar PV panels:

Figure 8 above (left) shows Mr Loo adding some final touches during the Solar PV installation on top of the container cabin in 2014. Above (right) shows the complete project of 10.8kWp solar system.