100kW grid-connected renewable energy system design for an educational campus in Tarlac: A step towards green energy campus development

Adam Rombaoa
Mechanical Engineering Department, De La Salle University-Manila, Metro Manila, Philippines
adam_rombaoa@dlsu.edu.ph

Abstract. This paper discussed the design of a grid-connected renewable energy system for an education institution. One-year energy consumption and the hourly load of the institution were determined to design the energy system. HOMER Pro and What’sBest! 16.0 for Microsoft Excel optimization tools were used in the design, consisting mainly of wind turbines and solar PV. Weibull probability function and the simplified irradiance model were used to predict the wind turbine and solar PV power output in the Microsoft Excel spreadsheet. Results showed that the mean velocity at 50 m reference height is 3.886 m/s. The annual solar PV system energy produced based on the HOMER Pro simulation and What’sBest! was found to be 170,939 kWh/yr and 189,454 kWh/yr, respectively. HOMER Pro and What’sBest! iteration results showed that the optimum number of components are 303 and 0 for solar PV and wind turbine, with net present costs of Php 23,388,612 and Php 22,769,478, respectively. With this optimum result, emissions can be reduced by up to 51%, a financial saving of at least Php 1,970,145 per year can be achieved with payback period of 5 years.

1. Introduction
For the last couple of centuries, the progress of man - industrialization in the nineteenth and the large-scale urbanization in the twentieth - has given rise to global modernization. However, there is another price the Earth has paid for modernization rightly requires immediate attention. This is global warming. For this generation, with the devastating effect of global warming and climate change looming over us, there is a need for the energy industry to find energy sources free of carbon dioxide pollution. The Renewable Portfolio Standard (RPS), a regulation that requires the increased production of energy from renewable energy resources, places an obligation on electricity supply companies to produce a certain fraction of their electricity from renewable energy resources. Among these renewables, wind and solar energy are at the forefront of the drive to significantly reduce the greenhouse gasses to meet the carbon dioxide (CO$_2$) limit. This is largely because we know that if we can replace fossil fuel with wind and solar energy for generated electricity, we can significantly reduce CO$_2$ emissions [1]. Small-scale shifts to renewable energy utilization are a milestone. Different researchers have done studies to optimize energy production and reduce ozone-depleting substances to date. In the year 2011, a study of a hybrid alternative power system appropriate for a remote area in Orissa State, India, consists mainly of micro-hydro plant, wind turbines, diesel generator units, solar PV panels, and battery storage was conducted [2]. Furthermore, different optimization techniques and available applications are being used nowadays.

Content from this work may be used under the terms of the CreativeCommons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under licence by IOP Publishing Ltd
for ease of better design of renewable energy systems because oversizing causes higher system costs, and under-sizing causes insufficient power supply [3].

On the other hand, this study considered Tarlac State University (TSU) to design a renewable energy system considering net-metering for renewable energy at maximum power reliability and minimum cost. Its San Isidro campus is the potential location for solar PV and wind turbine installation because it has the largest available land area amongst the other TSU campuses.

2. **Material and Methods**

The method of research used is descriptive-evaluative and the plan of action of the study was divided into four sections.

2.1. **Assessment of TSU-San Isidro electric load & energy usage for one year**

The area under study’s one-year energy usage was determined to estimate the load to serve for the optimum renewable energy system design. The statement of account (SOA), which contains the electric bill and energy consumption, was requested to the TSU administration and the connected loads were then determined based on the actual rating of devices, appliances, and equipment being used by all rooms.

2.2. **Solar PV & wind turbine power computations and renewable energy system configuration**

Before solving for the solar PV and wind turbine power output, solar and wind resource assessments were performed. HOMER Pro was used for solar resource assessment and Windographer for wind resource assessment. PV array power output $P_{pv}$ was then calculated using equation (1), also called the simplified irradiance model [4], [5] expressed as

$$P_{pv} = \eta_{pv} A_{pv} G_T$$

(1)

where $\eta_{pv}$ is the conversion efficiency and $A_{pv}$ is the solar PV area. The efficiency and area of the solar PV used are 16.97% and 1.94432 m$^2$, respectively. $G_T$ is the hourly total incident radiation on the solar PV (inclined surface). $G_b$ is the sum of beam radiation ($G_b$), ground-reflected radiation ($G_r$), and diffuse radiation ($G_d$). The mathematical models used for these three variables were based on the review of the previous works [6]–[14]. Equation (2) was used for the beam radiation on inclined surface expressed as

$$G_b = R_b G_{bh}$$

(2)

where $R_b$ is the ratio of hourly radiation received by an inclined surface to beam radiation on a horizontal surface. $G_{bh}$ is the hourly direct radiation on a horizontal surface expressed as

$$G_{bh} = G_H - G_{dh}$$

(3)

$G_H$ is the global horizontal solar radiation (also called total radiation), and diffuse radiation ($G_{dh}$) on horizontal surfaces. $G_H$ and $G_{dh}$ where solve in terms of the hourly clearness index which was gathered during solar resource assessment.

The ground-reflected radiation model used is given by equation (4)

$$G_r = G_H \rho_g \left[ 1 - \cos \theta \cos \beta \right]$$

(4)

where $\rho_g$ is the ground reflectance (also called ground albedo) and is typically equal to 0.2 [15]. Angle $\beta$ is the tilt angle (in degree) of the solar PV. According to the study of [16], the optimum tilt angle of solar PV in the Philippines can be calculated by multiplying 0.812117 correction rate to the latitude, which is equal to 12.59°. While HOMER Pro uses HDKR (Klucher & Reindl, and Hay & Davies) model, the present study used the Perez model for $G_d$ as it was found to be the most accurate model for Singapore [17], the country near the Philippines, and cited in other study [8]. Perez model for $G_d$ is given by equation (5)

$$G_d = G_{dh} \left[ \frac{1 + \cos \beta}{2} (1 - F_l) + F_l \frac{c^'}{d} + F_2 \sin \sin \beta \right]$$

(5)
The annual energy and total power that the turbine will deliver considering its $V_{cut-in}$ and $V_{cut-out}$ velocity, therefore, are given by equations (6)-(8) respectively [18]:

$$E_{WT} = Total \ P_{WT} \cdot 8760 \text{hr/yr}$$  

$$Total \ P_{WT} = \sum_{cut-out} \ P_v \ f(v)$$  

$$f(v) = \frac{k}{c} \left( \frac{v}{V_m} \right)^{k-1} \cdot e^{-\frac{v^k}{c^k}}$$  

The Windographer software used in this study uses 50m as reference height, the value of $f(v)$ at the turbine hub height $H$ was determined using resolve values of $k$ and $c$ using equations (9) and (10) given in [19] expressed as

$$k = \left( \frac{\sigma_v}{V_m} \right)^{-1.090}$$  

$$c = \frac{0.184 + 0.816 k^{2.7385}}{V_m}$$  

where $\sigma_v$ is the standard deviation of velocities, $V_m$ is the mean velocity (m/s). The $\sigma_v$ and $V_m$ values at the turbine hub height were computed using equation (11)

$$\frac{V_m}{(V_m)_{H_0}} = \left( \frac{H}{H_0} \right)^{\alpha} = \frac{\sigma_v}{(\sigma_v)_{H_0}}$$  

where $\alpha$ is the friction coefficient, sometimes called Hellman exponent or shear exponent, equal to 0.15 for tall grass on level ground [18]. The hub height $H$ of the turbines considered is 12m while the reference height $H$ is 50m. After solving for wind turbine and solar PV power outputs, the energy system configuration was done, using only the available components from HOMER Pro’s library, as shown in Figure 1.

![Figure 1. Renewable energy system components model in HOMER.](image)

### 2.3. Simulation using HOMER Pro and What’sBest!

After configuring the system, simulations were performed using HOMER Pro student version and What’sBest!. The HOMER Pro ‘Setup Assistant’ was used as a basis for creating and simulating the energy system under study. For What’sBest! optimization process, the net present cost (NPC) formula was set up within the Microsoft Excel as it is what to minimize. The formula used to minimize NPC is given by equation (12)

$$\sum_{all \ components} \left[ C_{0i} + \sum_{n=1}^{t} \frac{C_{n,i}}{(1 + r)^n} \right]$$  

where $C_{0i}$ is the capital cost of the component $i$ at year 0. The annual net cash flow $C_{n,i}$ includes the annual cost (O&M, replacement, and cost of buying electricity from the grid) of the components minus the revenue generated (e.g. salvage value and grid sale). The cost of buying electricity from the grid was P 12.87 per kWh ($0.2475/kWh) which is based on the statement of account issued by the distribution
unit to San Isidro campus from July 2018-June 2019 while the selling price of excess energy is based on Energy Regulation Commission (ERC) rules on net-metering [20], which was assumed half of the grid purchase, of Php 6.435/kWh. The components of the grid-connected renewable energy system of the present study considered are wind turbine, solar PV, grid, and converter. The discount rate $r$ used in the present study is 10% [21].

3. Discussion of Results
The results of this study are divided into four sections, presented as follows:

3.1. **TSU San Isidro Campus educational buildings energy consumption and electric load**
The energy consumption of San Isidro campus is shown in figure 2 with the highest energy consumption at the month of September.

![Figure 2. Monthly energy Consumption.](image)

![Figure 3. Solar resource assessment using HOMER.](image)

3.2. **TSU San Isidro campus solar and wind resource assessments result using HOMER and Windographer**
The result of solar resource assessment of the study is shown in see figure 3. It can be observed that the highest daily radiation is in April and the lowest one is in December. Meanwhile, using Windographer, the monthly average wind speed and direction frequency at 50 m reference height $H_0$ are shown in figure 4. The value of the Weibull scale parameter $c_{H_0} = 4.38$ m/s and shape factor $k_{H_0} = 1.94$, the mean velocity of $(V_m)_{H_0} = 3.886$ m/s, and a standard deviation of $(\sigma_v)_{H_0} = 2.019$ at 50 m reference height $H_0$.
These results indicate that the site is only good for small-scale wind turbines. Thus, considering the small-scale wind turbines of the same brand inside HOMER Pro library, Aeolos and AWS wind turbines of 10m and 12m hub heights, respectively, were considered. The power curves of each turbine were redrawn as shown in figure 5. To estimate the wind turbine power output at 10m and 12m hub heights, the probability density functions were solved and is shown in figure 6.

![Figure 4. Monthly average wind speed gathered using Windographer.](image)

![Figure 5. Wind turbines power curve.](image)

![Figure 6. Probability density function at different height.](image)

![Figure 7. Renewable energy system components model and load profiles sample in HOMER Pro.](image)

3.3. The design, simulation and optimization of the grid-connected renewable energy system using HOMER Pro and Microsoft Excel spreadsheet

The components considered and the electric load profile of San Isidro campus grid-connected renewable energy system design are illustrated in figure 7.
3.4. Comparison of HOMER simulation and spreadsheet iteration result

Results were compared based on the optimum number of components, NPC, and energy produced, considering the net-metering. Emission reduction is also presented in the following.

3.4.1. Optimization result for the system with net-metering. For systems with net-metering (limited to 100kW capacity), HOMER Pro simulation result showed 100 kW rated capacity solar PV system, equivalent to 303 units, with an inverter capacity of 89.6 kW and zero turbines. This component’s combination has the least NPC of $449,781 (Php 23,388,612). See figure 8. In terms of energy production, solar PV has 170,939 kWh/yr while the grid purchase is 129,386 kWh/yr.

[Figure 8. HOMER Pro optimization result with net-metering.]

On the other hand, What’sBest! iteration result showed an NPC of $437,875 (Php 22,769,478) as shown in WB!Status sheet of figure 9. Three hundred three (303) units of solar PV was found to be the optimum number of solar PV, equivalent to 100 kW rated power, the number of wind turbine is equal to zero, and the converter capacity is 84.53 kW. In terms of energy production, the solar PV system produced 189,454 kWh/yr while the grid energy purchase is 110,894 kWh/yr. Comparison of
optimization results of both HOMER and What’sBest! for Microsoft excel spreadsheet, with net-metering, is summarized in table 1. The simple payback period was computed by dividing the initial investment by the annual savings.

**Table 1. Summary of comparison between HOMER Pro and What’sBest! for excel with net-metering**

| Parameter                  | HOMER Pro | What’sBest! | Unit |
|----------------------------|-----------|-------------|------|
| NPC                        | 449,780.92 (23, 388, 612) | 437,875 (Php 22, 769, 478) | $(Php) |
| No. of solar PV            | 303       | 303         |      |
| No. of wind turbine        | 0         | 0           |      |
| PV system rated capacity   | 100       | 100         | kW   |
| Annual $E_{PV}$            | 170,939   | 189,454     | kWh/yr |
| Excess Electricity         | 492       | 0           | kWh/yr |
| Investment                 | 190,167 (9, 888, 684) | 189,744 (9, 866, 688) | $(Php) |
| Simple Payback Period      | 5.02      | 4.85        | yr   |

3.4.2. **Optimization result for the system without net-metering.** For systems without net-metering (no grid sales), HOMER Pro simulation result gave 379 units of solar PV and zero turbines which has an NPC of $ 603, 518 (Php 31, 382, 936). Meanwhile, What’sBest! iteration result without net-metering showed the least NPC of Php 24, 386, 651.83 with the number of solar PV of approximately 308 units with equivalent NPC of $ 468, 975 (Php 24, 386, 691).

3.4.3. **Emission and cost comparison based on the optimum result.** The amount of emission can be found by simply multiplying the energy purchased from the grid by the kilograms of emission per kWh ($CO_2 = 0.632, SO_2 = 0.00274, NO_2 = 0.00134$). The amount of emissions can be reduced by up to 51%. See table 2 for the summary of emission comparison and annual costs in table 3.

**Table 2. Emissions comparison of the optimum result.**

| Quantity                     | Grid Only | HOMER Pro | What’sBest! | Unit |
|------------------------------|-----------|-----------|-------------|------|
| Carbon Dioxide ($CO_2$)      | 169, 780  | 81,772    | 70,085      | kg/yr |
| Sulfur Dioxide ($SO_2$)      | 736       | 355       | 304         | kg/yr |
| Nitrogen Dioxide ($NO_2$)    | 360       | 173       | 149         | kg/yr |

**Table 3. Annual cost comparison of the optimum result.**

|                      | Grid Only | HOMER Pro | What’sBest! | Unit |
|----------------------|-----------|-----------|-------------|------|
|                      | 3,457,396.86 | 1,487,252 | 1,421,475.54 | Php/yr |

4. **Conclusion**

The energy consumption, electric load, and hourly load of Tarlac State University San Isidro campus were determined and generate the hourly load profile. Meanwhile, solar and wind resource assessments in the San Isidro campus were successfully conducted using HOMER Pro and Windographer software, respectively. Wind resource assessment showed that an average of 3.886 m/s wind speed prevails on the campus at 50 m height. Using these values, HOMER Pro then was used to simulate and analyzed the renewable energy system design, which yields a purely solar PV system as the best optimization results in terms of NPC. Similarly, the What’sBest! optimization tool was used to minimize the NPC, but results
showed that there is a significant difference between that of the HOMER Pro. HOMER Pro gave a higher NPC of Php 23,388,612 compared to What’s Best! in the spreadsheet of Php 22,769,478 but with the same 100 kW rated solar PV power and no wind turbines. Since NPC is lower when net-metering is considered, therefore, 303 units of solar PV and no wind turbine are the optimum numbers of components. With these numbers of components, a reduction of carbon dioxide, sulfur dioxide, and nitrogen oxides of up to 51% are feasible. Moreover, a financial saving of at least Php 1,970,145 per year can be achieved.

5. **Recommendations**

The researcher of the study would like to recommend the application of net-metering if the installation of solar PV in the university studied will push thru. The optimum size of solar PV and converter may not be available in the market, and it is therefore recommended to use the nearest (higher) standard sizes. To further improve the study: (1) hourly load profile from distribution companies might be better to use for a more accurate result; (2) the use of other different mathematical models/techniques for solving solar PV energy and other variables; and (3) use of other optimization tools is recommended to have a comparison of wind and solar energy estimation.

**References**

[1] Letcher T M 2017 *Wind Energy Engineering: A Handbook for Onshore and Offshore Wind Turbines* (London EC2Y 5AS: Academic Press) ed Lisa Reading pp 26-31

[2] Lal D K, Dashand B B and Akella A K 2011 *Int. J. Electr. Eng. Informatics* 3 3 pp 307–25

[3] Sinha S and Chandel S S 2015 *Renew. Sustain. Energy Rev.* 50 755–69

[4] Liu Y, Luand Z and Yang F 2018 The investigation of solar PV models *IEEE Power Energy Soc. Innov. Smart Grid Technol. Conf. ISGT* pp 1–5

[5] Diaf S, Notton G, Belhamel M, Haddadi M and Louche A 2008 *Appl. Energy* 85 10 pp 968–987

[6] Iqbal M 1983 *An Introduction to Solar Radiation* 53 9 (Ontario M3C 2A1: Academic Press, Inc.) pp 321-49

[7] Spencer J 1971 Fourier series representation of the position of the Sun *Search* 2 5 p 172

[8] Maleki S A M, Hizam H and Gomes C 2017 *Energies* 10 1 p 134

[9] Duffie J, Beckman W and McGowan J 2013 *Solar Engineering of Thermal Processes* (New Jersey: John Wiley & Sons, Inc.) pp 43-91

[10] Kuo C W, Chang W C and Chang K C 2014 *Renew. Energy* 66 pp 56–61

[11] Gorjian S, Hashjin T and Ghobadian B 2012 *2nd Iran. Conf. Renew. Energy Distrib. Gener. ICREDG* pp 172–177

[12] Chapman R 1990 *IEEE Conf. Photovolt. Spec.* pp 965–70

[13] Liu B and Jordan R 1960 *Sol. Energy* 4 3 pp 1–19

[14] Kalogirou S 2014 *Solar Energy Engineering Processes and Systems* (Oxford OX 5 1GB: Academic Press) pp 75-105

[15] Guemyard C 2009 *Sol. Energy* 83 3 pp 432–44

[16] Malicdem E 2015 Optimal tilt of solar panels in the Philippines

[17] Khoo Y S, Nobre A, Malhotra R, Yang D, Ruther R, Reindland T and Aberle A G 2013 *IEEE J. Photovoltaics* 4 2 pp 647–53

[18] Masters G 2013 *Renewable and Efficient Electric Power Systems* (New Jersey: John Wiley & Sons, Inc.) pp 430-63

[19] Mathew S 2006 *Wind Energy Fundamentals, Resource Analysis and Economics* (Berlin Heidelberg: Springer Science & Business Media) pp 75-76

[20] Energy Regulation Commission 2013 Rule Enabling the Net-Metering Program for Renewable Energy

[21] National Economic Development Authority 2016 Revisions on ICC Guidelines and Procedures