Songklanakarin J. Sci. Technol.
43 (6), 1800-1806, Nov. - Dec. 2021

http://www.sjst.psu.ac.th

Original Article

A systematic decision-making approach for the assessment of hybrid renewable energy applications with techno-economic optimization: Application to the Rajamangala University of Technology Srivijaya (Trang Campus), Southern Thailand♣

Weerasak Chaichan[1*], Jompob Waewsak[2], and Yves Gagnon[3]

[1] *Faculty of Engineering, Thaksin University, Phatthalung Campus, Pa Phayom, Phatthalung, 93210 Thailand*

[2] *Research Center in Energy and Environment, Faculty of Science, Thaksin University, Phatthalung Campus, Pa Phayom, Phatthalung, 93210 Thailand*

[3] *Université de Moncton, Edmundston, New Brunswick, Canada*

Received: 21 December 2020; Revised: 28 June 2021; Accepted: 4 August 2021

Abstract

This paper proposes a systematic decision-making approach for the assessment of hybrid renewable energy applications with techno-economic optimization, with application to the Rajamangala University of Technology Srivijaya (Trang Campus) in southern Thailand. Using the hybrid optimization model for electric renewable (HOMER) Pro simulation tool, the techno-economic aspects of a grid-connected combined solar photovoltaics, wind turbine generator, and energy storage (Li-Ion battery), are optimized in order to minimize the net present cost (NPC) and the levelized cost of energy (LCOE). The model inputs are NASA-Surface Meteorology and Solar Energy and Modern-Era Retrospective analysis for Research and Applications databases, and monthly power loads of the campus analyzed. The results are compared and optimized amongst four combinations. It is found that the optimal hybrid renewable energy power system offers the lowest NPC and the lowest LCOE to satisfy the full load of the campus.

Keywords: hybrid renewable energy, optimization, net present cost, levelized cost of energy, energy storage

1. Introduction

In the last few years, as the use of fossil fueled is being questioned as a viable long term source of energy, renewable energy has come to play an important role in electricity portfolios (Hernandez, Alonso, Alvarez, & Carrillo, 2014; Singh, Singh, & Kaushik, 2016). In particular, solar and wind resources are generating electricity for large scale facilities and in rural remote areas (Zhou, Lou, Li, Lu, & Yang, 2010). Besides the large scale applications, solar power generation and energy storage systems have proven to be attractive energy sources not only for remote areas (Agarwal, Kumar, & Varun, 2013), but also for commercial buildings (Kazem, Khatib, & Sopian, 2013; Shaahid & Elhadidy, 2004). However, the disadvantage of solar and wind energy is their stochastic nature, thus affecting their reliability as an energy source for electricity generation.

Hybridization of both wind and solar energy was used to solve the problems mentioned above, followed by increases in the complexity of systems (Yang, Zhou, Lu, &

♣Peer-reviewed paper selected from The 9th International Conference on Engineering and Technology (ICET-2021)
*Corresponding author
Email address: sakchaichan@hotmail.com

Fang, 2008). In many countries, many rural areas are far away from transmission lines (Borhanazad, Mekhilef, Ganapathy, Modiri-Delshad, & Mirtaheri, 2014; Mbaka, Mucho, & Godpromesse, 2010). However, these areas can have important renewable energy potentials, such as solar and wind energy, and hybrid technology development can be the most appropriate approach. In the literature, hybrid solar/wind energy is often used in remote areas (Borhanazad *et al.*, 2014; Yong-jian, Da-wei, Hong-xun, & Ya-feng, 2009). It was found that a hybrid power generation system between solar and wind energy can reduce greenhouse gas (GHG) emissions and diesel consumption by up to 50% (Blechinger *et al.*, 2016).

The economic and environmental aspects of a stand-alone renewable power generation system were evaluated in Yemen (Ajlan, Tan, & Abdilahi, 2017). The optimization results based on the levelized cost of energy (LCOE) and using HOMER found that a hybrid solar/wind energy successfully reduced GHG emission by 30%. For its part, a study on the economic feasibility of LCOE by using HOMER to simulate an off-grid area in China showed that hybrid renewable energy systems can reduce GHG emissions by 40 to 70%, in comparison to conventional electricity generation (Ye *et al.*, 2017).

Hybrid energy systems analysis is quite complex. Therefore, it is necessary to design software tools. Previously, the nineteen software tools were compared (Sinha, & Chandel, 2014). HOMER was found to be the most widely used tools due to it has the maximum combination of renewable energy systems. In addition, HOMER performs the optimization and sensitivity analysis. Thus, the evaluation of many possible system configurations can easier and faster.

In 2019, Thailand's electricity generation portfolio was comprised of natural gas (59.5%), coal and lignite (16.5%), fuel oil and diesel (0.1%), and renewable energy (23.9%) (Department of Alternative Energy Development and Efficiency, 2020). From the national policy, the Thai government is encouraging large investments in clean energy through the PDP 2018 policy, where investments in renewable energy are planned, focusing on solar and wind power (Ministry of Energy (Thailand), 2018).

Aligned with the Thai government's objective of reducing the usage of fossil fuel for electricity generation, this paper proposes a systematic decision-making approach for the assessment of hybrid renewable energy applications with a techno-economic optimization using the HOMER Pro computer simulation toolkit, with application to the Rajamangala University of Technology Srivijaya (Trang Campus) in southern Thailand. Hybrid renewable energy-based power applications, consisting of combined solar photovoltaics (PV), wind turbine generator (WTG), and energy storage (Li-Ion battery), are analyzed for better system reliability than without energy storage (Agarwal *et al.*, 2013), as well as a grid connection for power backup. The results can provide a systematic decision-making approach for renewable energy investments for the campus.

2. Methodology

In order to assess the most suitable hybrid power generation technology for the location analyzed, this paper applied the HOMER Pro computer simulation toolkit as a research tool for the analysis, planning and design optimization, as shown in Figure 1. The input parameters of potential optimal system configurations with an objective function are related to technical aspects and cost characteristics (e.g., solar PV, wind turbine, power converter, battery, grid connection, and economics). The optimization constraints are load demand, resources, technical aspects, reliability, and GHG emissions. The output results of the optimal hybrid renewable energy configurations are optimized for equipment sizes, costs data, energy generation and consumption, and total GHG emissions.

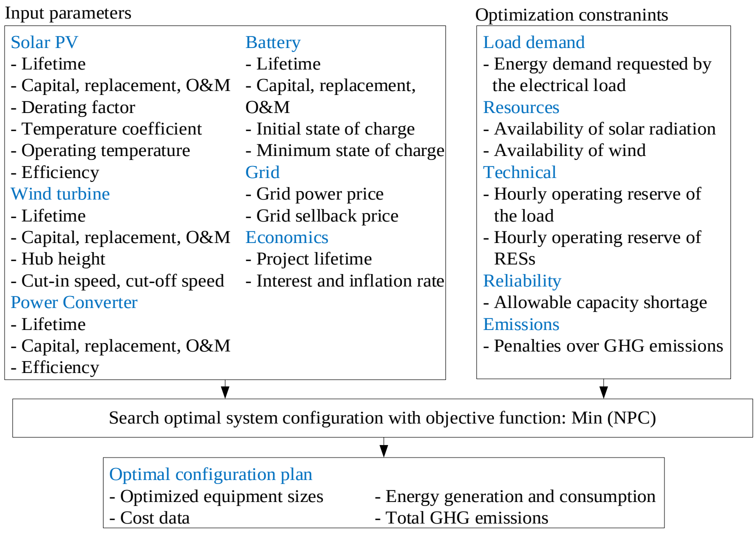


Figure 1. Methodology for the hybrid renewable energy planning and design optimization. The input parameters of potential optimal system configurations with an objective function are related to technical aspects and cost characteristics (e.g., solar PV, wind turbine, power converter, battery, grid connection, and economics). The optimization constraints are load demand, resources, technical aspects, reliability, and GHG emissions. The output results of the optimal hybrid renewable energy configurations are optimized for equipment sizes, costs data, energy generation and consumption, and total GHG emissions.

2.1 Mathematical modeling and cost specifications of hybrid renewable energy systems

2.1.1 Mathematical modeling of the photovoltaics

Photovoltaics converts solar irradiance into electricity. In this simulation, the Canadian Solar Max Power CS6X-325P PV panel model is used with a rated capacity of 325 W and an efficiency of 16.94%. The lifetime is assumed as the same as the project lifetime (25 years). The operating temperature is 45 °C, the derating factor is set as 12%/year, the capital and replacement costs are 700 $/kW and the O&M costs per year are 14 $/kW (Duman & Güler, 2018). The power of the PV output in time (P_{PV}(t)) is calculated using Equation (1) (Bagheri, Shirzadi, Bazdar, & Kennedy, 2018; Mills & Al-Hallaj, 2004),

$$P_{PV}(t) = P_{PV,r} \cdot f_{PV} \cdot \left(\frac{G_T(t)}{G_T STC}\right) \cdot \left[1 + C_P\left(T_{cell}(t) - 25\right)\right] \qquad (1)$$

where $P_{PV,\,r}$ is the capacity of the PV array under standard test conditions in kW, f_{PV} is the derating factor, G_T and $G_T STC$ are the actual conditions and standard conditions of solar radiation, respectively, on the PV panel in kW/m^2, and C_p is the temperature coefficient power (%/°C).

For its part, the real-time temperatures of the PV panels ($T_{cell}(t)$) were expressed by Equation (2) (Akhtari & Baneshi, 2019),

$$T_{cell}(t) = T_\alpha(t) + \left(T_{cell,NOTC} - T_{\alpha,NOTC}\right) \cdot \left(\frac{G_T(t)}{G_{T,NOTC}}\right) \cdot \left[1 - \frac{\eta_c}{\alpha.\tau}\right] \qquad (2)$$

where T_a is the ambient air temperature in °C, $T_{cell,\,NOTC}$ and $T_{a,\,NOTC}$ are the nominal operating temperature of the PV and the temperature of the ambient air, respectively, in °C, h_c is the PV array efficiency (%) of the electrical conversion, while a and t are the PV solar absorbance (%) and solar transmittance, respectively, of the shield above the surface of the PV array (%).

2.1.2 Mathematical modeling of the WTG

For the simulation, the 3-blade 10 kW Eocycle E010 WTG model is used and connected to the hybrid renewable power system at the AC bus. The lifetime of the WTG is 20 years, the hub height is 16 m, the cut-in and cut-out wind speed is 2.75 m/s and 20 m/s respectively, the capital and replacement costs are 20,000 $ (Abo-elyousr & Elnozahy, 2018), and the costs of O&M is 150 $/year (Dawoud *et al.*, 2015). The wind speeds at the hub height (v_w) are obtained using Equation (3),

$$v_w(t) = v_{anem}(t) \cdot \left[\frac{\ln\left(\frac{H_{hub}}{H_0}\right)}{\ln\left(\frac{H_{anem}}{H_0}\right)}\right] \qquad (3)$$

where v_{anem} is the speeds at the height of the anemometer in m/s, H_{hub} and H_{anem} are the heights of the hub and the anemometer, respectively, in m, and H_0 is the surface roughness length in m.

The output power from the WTG under standard conditions of temperature and pressure at each wind speed is calculated by determining the wind speed at the hub high using Equation (4) (Dahiru & Tan, 2020),

$$P_{w,STP}(t) = \begin{cases} 0 & v_w(t) < v_i \\ P_{w,r} \cdot \left[\dfrac{v_w^3(t) - v_i^3}{v_r^3 - v_i^3}\right] & v_i \le v_w(t) \le v_r \\ P_{w,r} & v_r < v_w(t) \le v_o \\ 0 & v_w(t) > v_o \end{cases} \qquad (4)$$

where $P_{w,r}$ is the wind turbine generator power output at rated wind speed, v_r is the rated wind speed, v_i and v_0 are the cut-in and cut-out wind speeds, respectively, of the WTG.

The output value to actual conditions is calculated by the actual air density value using Equation (5) (Bagheri, Delbari, Pakzadmanesh, & Kennedy, 2019; HOMER, 2016),

$$P_w(t) = P_{w,STP}(t) \cdot \left(\frac{\rho(t)}{\rho_o}\right) \qquad (5)$$

where r and r_0 are the real air density in kg/m^3 and the air density at standard pressure and temperature (1.225 kg/m^3), respectively.

2.1.3 Mathematical modeling of the power converter

DC/AC and AC/DC power converters are required for the hybrid system, which is integrating DC power sources, such as PV, while the demand is an AC load. In this study, a power converter model System Converter is used. The lifetime of the power converter is 15 years, the capital and replacement costs of the power converter are 750 $/kW, while the costs of O&M are 15 $/kW/year (Duman & Güler, 2018), with an efficiency of 95%.

2.1.4 Mathematical modeling of the Li-Ion battery

The battery is the energy storage in the hybrid renewable energy power system that provides a more reliable power source, while being able to cover sudden increases in the load demand. Therefore, it contributes in improving the system stability and reliability. The Trojan SSIG 06 255 model is used in this study. The lifetime cycle of the battery is 914.3 kWh, the capital and replacement costs of the battery are 167 $/unit, the O&M costs are 8 $/unit/year, a nominal capacity of 1.52 kWh, a nominal voltage of 6 V, a round trip efficiency of 80% , and maximum charge and discharge currents of 45 A and 300 A, respectively. The minimum state of charge (SOC) is set to 30 % (Duman & Güler, 2018). The storage capacity of the considered batteries is given by Equation (6) (Baek *et al.*, 2016),

$$C_{wh} = E_L . AD . h_{Conv} . h_{BAT} . DOD \qquad (6)$$

where E_L is the total load in kWh/day, *AD* is the daily autonomy, *DOD* is the depth of discharge of the battery, while h_{Conv} and h_{BAT} are the converter and battery efficiencies, respectively.

2.1.5. Economic model

As mentioned above, in this study, the total net present cost (NPC) and the levelized cost of energy (LCOE) are used as the main indicators to compare the economic feasibility of the various scenarios studied. The objective function is to minimize the total NPC of the hybrid renewable energy system, which can be calculated using Equation (7) (HOMER, 2016; Acuña *et al.*, 2018),

$$Objective\ function = min\ \ NPC\ = min\left(\frac{TAC}{DF\ \ i, n_{proj}}\right) \qquad (7)$$

where *TAC* is the total annualized cost ($/year), $DF(i,\ n_{proj})$ is the discount factor based on the interest rate.

The LCOE is calculated to compare the different hybridization scenarios. The LCOE is the cost per unit of useful electrical energy produced by the hybrid renewable energy system, and it is expressed as in Equation (8) (HOMER, 2016),

$$LCOE = \frac{TAC}{E_{load}} \qquad (8)$$

where E_{load} is the total electrical load (kWh/year) of the hybrid renewable energy system.

The renewable fraction (RF) is the fraction of the energy delivered to the total load from renewable power sources, which is calculated by determining the wind speed at the hub height using Equation (9) (HOMER, 2016),

$$RF = 1\text{-}\left(E_{g,non\text{-}\ ren} / E_{load}\right) \qquad (9)$$

where, $E_{g,non\text{-}\ ren}$ is the nonrenewable electrical production (kWh/year).

2.2 Mathematical modeling of the air pollution

Power generation from fossil fuels affects air pollution by releasing carbon dioxide (CO_2) to the atmosphere. Therefore, in this study, the total CO_2 emissions are calculated from the hybrid renewable energy system. It is related to the rate of fuel consumption (Halabi & Mekhilef, 2018) as given in Equation (10):

$$TCE_{comp} = 3.667 . m_f . LHV_{fuel} . CEF_f . X_c \qquad (10)$$

where, TCE_{comp} is the total amount of CO_2 emissions by component, m_f is the amount of diesel fuel (liters), LHV_{fuel} is the lower fuel heating value (MJ/L), CEF_f and X_c are the carbon emission factor (ton carbon/TJ) and the oxidized fraction of carbon, respectively, where each 3.667 g of CO_2 include a quantity of 1 g of carbon.

3. Case Study

In the proposed study, a systematic decision-making approach for the assessment of hybrid renewable energy applications with techno-economic optimization, with application to the Rajamangala University of Technology Srivijaya (Trang campus), is proposed. The area is located at $7°34.4'N$ and $99°21'E$, and it has an annual average temperature of 26.54 °C. The HOMER Pro computer simulation software is used to analyze and evaluate the techno-economic performance parameters of NPC, LCOE, RF, and GHG emissions. Figure 2 shows the schematic diagram of the hybrid renewable energy system, consisting of combined solar PV, WTG, and energy storage (Li-Ion battery), as well as a grid connection for power backup. The average annual consumption of electrical energy for the winter and summer seasons are each given at 6791.43 kWh/day. Further, the monthly electrical load profiles are illustrated in Figure 3. It can be seen that the electrical load demand has low values outside of academic semesters (March-June, November) while the load demand increases when the academic semesters are on-going.

The power potential of renewable energy resources for the Rajamangala University of Technology Srivijaya (Trang campus) are presented in Figure 4. The model inputs are renewable energy resource databases, i.e., NASA-SSE for solar energy (NASA Surface meteorology and Solar Energy service, 2020), MERRA for wind energy (NASA Global Modeling and Assimilation Office, 2020), where the mean monthly average solar radiation (ASR) and the mean monthly average wind speed (AWS) are 5.17 kWh/m^2/day and 3.64 m/s, respectively. According to this figure, the monthly ASR was highest in February (6.24 kWh/m^2/day) and lowest in November (4.49 kWh/m^2/day) due to the rainy season, as seen in Figure 4a. For its part, the monthly AWS profile is illustrated in Figure 4b, with the highest and lowest monthly average wind speeds in December (4.98 m/s) and April (2.5 m/s), respectively.

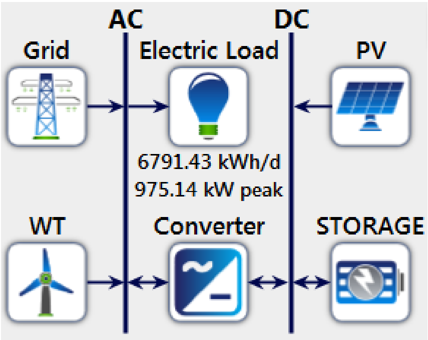


Figure 2. Modeling of a grid connected hybrid renewable energy system. Figure shows the schematic diagram of the hybrid renewable energy system, consisting of combined solar PV, WTG, and energy storage (Li-Ion battery), as well as a grid connection for power backup. The average annual consumption of electrical energy for the winter and summer seasons are each given as 6791.43 kWh/day.

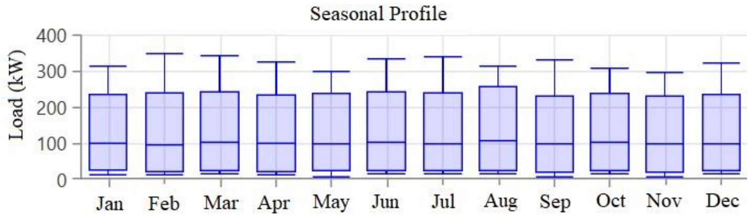
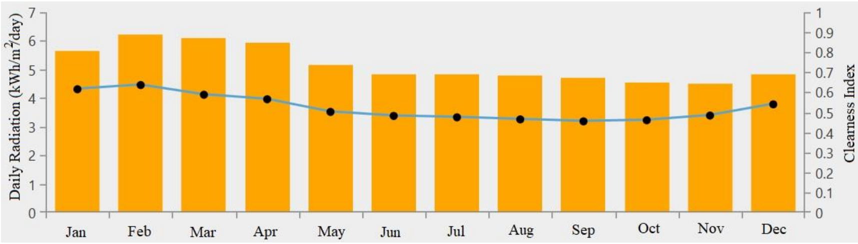
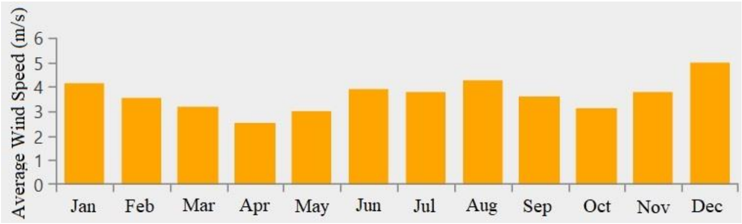


Figure 3. Seasonal profiles of the electrical load. The electrical load demand has low values outside of academic semesters (March-June, November) while the load demand increases when the academic semesters are on-going.



a) Monthly ASR profile



b) Monthly AWS profile

Figure 4. Potential of a) solar and b) wind energy resources at the Rajamangala University of Technology Srivijaya (Trang campus). Monthly ASR was highest in February (6.24 kWh/m2/day) and lowest in November (4.49 kWh/m2/day) due to the rainy season, as seen in Figure 4a. For its part, the monthly AWS profile is illustrated in Figure 4b, with the highest and lowest monthly average wind speeds in December (4.98 m/s) and April (2.5 m/s), respectively.

4. Results and Discussion

In the scenarios studied, the project lifetime is 20 years, the maximum annual capacity shortage is 5%, the nominal discount rate is 6%, and the expected inflation rate is 2%. The details of the optimization results for four combinations are shown in Tables 1 and 2.

According to the results in Table 1, it is found that a hybrid renewable energy system, incorporating PV, WTG, battery, converter, and grid connection (Scenario 1), is the optimal application as it offers the lowest NPC (3,696,697 $/project lifetime) and the lowest LCOE (0.1090 $) to satisfy the full load. On the GHG emissions point of view, the optimal hybrid renewable energy system emits 715,281 kg/year of GHG. The fraction of the energy delivered to the total load from renewable power sources of 54.3 %.

Based on the results presented in Table 2 for load demand of 6791.43 kWh/day, the best hybrid renewable energy system (Scenario 1) composed of a hybridized solar PV with a capacity of 1,020 kW, 9 sets of WTG with a total of 90 kW capacity, 72 Li-Ion batteries of 1.52 kWh each, and a power converter of 490 kW.

The power balance and the battery SOC for one week of May are shown, as an example, in Figure 5 in order to understand the power exchange between the components (PV and WTG) of the hybrid renewable energy system. The battery SOC can be charged continuously during the operation of the system. In summary, the hybrid power generation system is stability and could provide a low cost of energy.

Currently, Rajamangala University of Technology Srivijaya has considered investment in renewable energy power project on other campuses. The Trang campus is in the process of the appropriate energy potential analysis. Therefore, an appropriate system of economic feasibility analysis and system component sizing from Tables 1 and 2, respectively, can be used as a reference in the proposed budgeting system for further renewable energy investment.

5. Conclusions

A systematic decision-making approach for the assessment of hybrid renewable energy applications with techno-economic optimization, with application to the Rajamangala University of Technology Srivijaya (Trang Campus) in southern Thailand, is proposed. Using the HOMER Pro computer simulation tool-kit, the techno-economic aspects of hybrid renewable energy-based power applications, with grid connection for power backup, are

Table 1. Model optimization results of the hybrid renewable energy power generation ranked by LCOE

Rank	Sr.	Hybrid renewable energy configuration	NPC ($)	LCOE ($/kWh)	R.F. (%)	GHG (kg/yr.)
1	1	PV/WTG/battery/converter/grid	3,696,697	0.1090	54.3	715,281
2	3	PV/battery/converter/grid	3,720,762	0.1097	51.2	764,647
3	2	WTG/battery/converter/grid	4,281,447	0.1262	21.7	1,226,914
4	4	Grid (base case)	4,410,102	0.1300	0	1,566,647

Table 2. Optimized system component sizing and associated cost with each hybrid renewable energy configuration.

Sr.	Equipment Size					Cost	
	PV (kW)	WT (Qty.)	Battery (Qty.)	Converter (kW)	Grid	O&M costs ($/yr)	Capital costs ($)
1	1,020	9	72	490	Yes	170,686	1,273,513
2	-	37	8	8.85	Yes	258,118	747,974
3	1,081	-	72	516	Yes	180,727	1,155,331
4	-	-	-	-	Yes	322,253	0

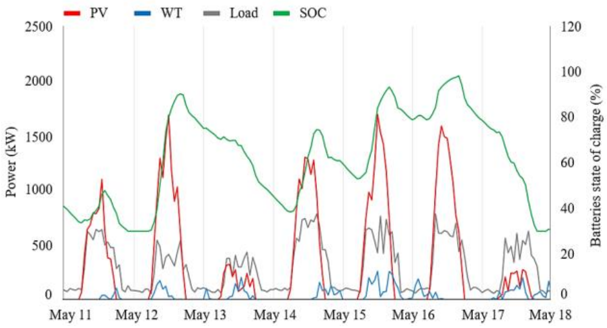


Figure 5. Power production, load and battery SOC for a typical weekly operation in May. The battery SOC can be charged continuously during the operation of the system. In summary, the hybrid power generation system is stability and could provide a low cost of energy.

optimized in order to minimize the net present cost (NPC) and the levelized cost of energy (LCOE). Four combinations are compared, namely 1) PV-WTG-battery-converter-grid, 2) WTG-battery-converter-grid, 3) PV-battery-converter-grid and 4) grid connection only (base case). It is found that the hybrid renewable energy system incorporating PV-WTG-battery-converter-grid (Scenario 1) is the optimal application as it offers the lowest NPC (3,696,697 $/project lifetime) and the lowest LCOE (0.1090 $). The optimal hybrid renewable energy system emits 715,281 kg/year of GHG on an annual basis, while the battery SOC can be charged continuously during the operation of the system.

From the results, the cost of energy is lower compared to the present (0.0210 $). If another renewable energy were used, such as community waste or agricultural waste, it is expected to significantly increase the fraction of electricity generated from renewable energy, thus reducing the LCOE and the GHG emissions.

References

Abo-Elyousr, F. K., & Elnozahy, A. (2018). Bi-objective economic feasibility of hybrid micro-grid systems with multiple fuel options for islanded areas in Egypt. *Renewable Energy*, *128*, 37–56. doi:10.1016/j.renene.2018.05.066

Acuña, L. G., Lake, M., Padilla, R. V., Lim, Y. Y., Ponzón, E. G., & Soo Too, Y. C. (2018). Modelling auto nomous hybrid photovoltaic-wind energy systems under a new reliability approach. *Energy Conversion and Management*, *172*, 357–369. doi:10.1016/j.enconman.2018.07.025

Agarwal, N., Kumar, A., & Varun. (2013). Optimization of grid independent hybrid PV–diesel–battery system for power generation in remote villages of Uttar Pradesh, India. *Energy for Sustainable Development*, *17*(3), 210–219. doi:10.1016/j.esd.2013.02.002

Ajlan, A., Tan, C. W., & Abdilahi, A. M. (2017). Assessment of environmental and economic perspectives for renewable-based hybrid power system in Yemen. *Renewable and Sustainable Energy Reviews*, *75*, 559–570. doi:10.1016/j.rser.2016.11.024

Akhtari, M. R., & Baneshi, M. (2019). Techno-economic assessment and optimization of a hybrid renewable co-supply of electricity, heat and hydrogen system to enhance performance by recovering excess electricity for a large energy consumer. *Energy Conversion and Management*, *188*, 131-141. doi:10.1016/j.enconman.2019.03.067

Baek, S., Park, E., Kim, M.-G., Kwon, S. J., Kim, K. J., Ohm, J. Y., & del Pobil, A. P. (2016). Optimal renewable power generation systems for Busan metropolitan city in South Korea. *Renewable Energy*, *88*, 517–525. doi:10.1016/j.renene.2015.11.058

Bagheri, M., Delbari, S. H., Pakzadmanesh, M., & Kennedy, C. A. (2019). City-integrated renewable energy design for low-carbon and climate-resilient communities. *Applied Energy*, *239*, 1212–1225. doi:10.1016/j.apenergy.2019.02.031

Bagheri, M., Shirzadi, N., Bazdar, E., & Kennedy, C. A. (2018). Optimal planning of hybrid renewable energy infrastructure for urban sustainability: Green Vancouver. *Renewable and Sustainable Energy Reviews*, *95*, 254–264. doi:10.1016/j.rser.2018.07.037

Blechinger, P., Cader, C., Bertheau, P., Huyskens, H., Seguin, R., & Breyer, C. (2016). Global analysis of the techno-economic potential of renewable energy hybrid systems on small islands. *Energy Policy*, *98*, 674–687. doi:10.1016/j.enpol.2016.03.043

Borhanazad, H., Mekhilef, S., Gounder Ganapathy, V., Modiri-Delshad, M., & Mirtaheri, A. (2014). Optimization of micro-grid system using MOPSO. *Renewable Energy*, *71*, 295–306. doi:10.1016/ j.renene.2014.05.006

Dahiru, A. T., & Tan, C. W. (2019). Optimal sizing and techno-economic analysis of grid-connected nanogrid for tropical climates of the Savannah. *Sustainable Cities and Society*, 101824. doi:10. 1016/j.scs.2019.101824

Dawoud, S. M., Lin, X. N., Sun, J. W., Okba, M. I., Khalid, M. S., & Waqar, A. (2015). Feasibility Study of Isolated PV-Wind Hybrid System in Egypt. *Advanced Materials Research*, 1092-1093, 145–151. doi:10.4028/www.scientific.net/amr.1092-1903

Department of Alternative Energy Development and Efficiency. (2020, November 5). Energy Situation January - December 2019. Retrieved from htt ps://www.dede.go.th/ewt_news.php?nid=52877

Duman, A. C., & Güler, Ö. (2018). Techno-economic analysis of off-grid PV/wind/fuel cell hybrid system combinations with a comparison of regularly and seasonally occupied households. *Sustainable Cities and Society*, *42*, 107–126. doi:10.1016/j.scs.2018. 06.029

Halabi, L. M., & Mekhilef, S. (2018). Flexible hybrid renewable energy system design for a typical remote village located in tropical climate. *Journal of Cleaner Production*, *177*, 908–924. doi:10.1016/ j.jclepro.2017.12.248

HOMER. (2020, November 2). HOMER ® pro version 3.7 user manual © all rights reserved. Retrieved from https://www.homerenergy.com

Kazem, H. A., Khatib, T., & Sopian, K. (2013). Sizing of a standalone photovoltaic/battery system at minimum cost for remote housing electrification in Sohar, Oman. *Energy and Buildings*, *61*, 108–115. doi:10.1016/j.enbuild.2013.02.011

Mbaka, N. E., Mucho, N. J., & Godpromesse, K. (2010). Economic evaluation of small-scale photovoltaic hybrid systems for mini-grid applications in far north Cameroon. *Renewable Energy*, *35*(10), 2391–2398. doi:10.1016/j.renene.2010.03.005

Mills, A., & Al-Hallaj, S. (2004). Simulation of hydrogen-based hybrid systems using Hybrid2. *International Journal of Hydrogen Energy*, *29*(10), 991–999. doi:10.1016/j.ijhydene.2004.01.004

Ministry of Energy (Thailand). (2020, November 5). Thailand Power Development Plan 2018. Retrieved from http://www.eppo.go.th/index.php/th/plan-policy/tieb /pdp

Mundo-Hernández, J., de Celis Alonso, B., Hernández-Álvarez, J., & de Celis-Carrillo, B. (2014). An overview of solar photovoltaic energy in Mexico and Germany. *Renewable and Sustainable Energy Reviews*, *31*, 639–649. doi:10.1016/j.rser.2013.12. 029

NASA Global Modeling and Assimilation Office. (2020, November 7). Modern-Era Retrospective analysis for Research and Applications (MERRA). Retrieved from https://gmao.gsfc.nasa.gov/reanalysis/MERRA

NASA Surface meteorology and Solar Energy service. (2020, November 7). Solar radiation data. Retrieved from http://www.soda-pro.com/web-services/radiation/ nasa-sse

Shaahid, S. M., & Elhadidy, M. A., (2004). Prospects of autonomous/stand-alone hybrid (photo-voltaic plus diesel plus battery) power systems in commercial applications in hot regions. *Renewable Energy*, *29*(2), 165-177. doi:10.1016/S0960-1481(03)00194-0

Sinha, S., & Chandel, S. S. (2014). Review of software tools for hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews*, 32, 192–205. doi:10.1016/j.rser.2014.01.035

Singh, S., Singh, M., & Kaushik, S. C. (2016). Feasibility study of an islanded microgrid in rural area consisting of PV, wind, biomass and battery energy storage system. *Energy Conversion and Management*, *128*, 178–190. doi:10.1016/j.encon man.2016.09.046

Yang, H., Zhou, W., Lu, L., & Fang, Z. (2008). Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm. *Solar Energy*, *82*(4), 354–367. doi:10. 1016/j.solener.2007.08.005

Ye, B., Yang, P., Jiang, J., Miao, L., Shen, B., & Li, J. (2017). Feasibility and economic analysis of a renewable energy powered special town in China. Resources, *Conservation and Recycling*, *121*, 40–50. doi:10. 1016/j.resconrec.2016.03.003

Yong-jian, L., Da-wei, Y., Hong-xun, L. & Ya-feng, L. (2009). Wind-solar complementary power inverter based on intelligent control. *Proceedings of 4th IEEE Conference on Industrial Electronics and Applications*, 3635-3638. doi: 10.1109/ICIEA.2009. 5138884

Zhou, W., Lou, C., Li, Z., Lu, L., & Yang, H. (2010). Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems. *Applied Energy*, *87*(2), 380–389. doi:10.1016/j. apenergy.2009.08.01