Hybrid Energy System Modeling And Economic Analysis For A Store Using Homer

B. Kara, M.S. Kersin, *Energy Systems Engineering Department, Engineering Faculty*, 77200, Yalova University,

***Abstract*—This study investigates the technical and economic feasibility of hybrid renewable energy systems for a clothing store in Biga, Çanakkale. Using the HOMER software, grid-connected and off-grid wind-solar hybrid systems were designed and analyzed. The grid-connected system, consisting of a 1 kW solar panel and a 1 kW wind turbine, was found to be more suitable due to its lower cost ($9,317 NPC) and emissions (1,262 kg CO2 per year). In contrast, the off-grid system had a higher NPC ($16,964) but provided greater energy independence. These results highlight the potential for hybrid energy systems in commercial applications, balancing cost-effectiveness with sustainability.**

***Index Terms*—** Cost analysis, electricity generation, HOMER, hybrid systems, Renewable energy.

I. INTRODUCTION

Energy is essential for modern life and economic development. As fossil fuels deplete and environmental concerns grow, renewable energy sources like solar and wind have become crucial. Hybrid energy systems combining multiple renewable sources are increasingly used to ensure energy reliability and sustainability. This study focuses on modeling a hybrid system for a store using HOMER software to determine the most cost-effective and environmentally friendly solution.

II. METHODOLOGY

A. Site Description

The store is located in Biga, Çanakkale (40°13'35.2"N, 27°14'32.2"E). The region receives an average annual solar radiation of 4.2 kWh/m²/day and experiences wind speeds ranging from 3.5 to 6.8 m/s, making it highly suitable for hybrid energy generation. Seasonal variations significantly impact energy production, and these fluctuations have been accounted for in the system design.

B. Building Characteristics

The store has a total rooftop area of 150 m², allowing for optimal solar panel installation. The building is well-insulated with energy-efficient lighting, reducing overall energy consumption. Load demand calculations have been adjusted based on actual energy usage data collected over a one-year period.

B. HOMER Software

HOMER (Hybrid Optimization of Multiple Energy Resources) is a modeling tool developed by NREL. It allows for the simulation and optimization of hybrid energy systems, taking into account technical and economic factors. The software provides detailed simulations that include energy load profiles, component performance, and cost analysis, ensuring that the proposed system meets both energy and financial requirements.

C. System Components

1. **Solar Panels**: Convert sunlight into electricity. They are chosen based on efficiency, durability, and cost.
2. **Wind Turbines**: Utilize wind energy to generate electricity. The selection criteria include turbine capacity, height, and local wind conditions.
3. **Diesel Generator**: Provides backup power in off-grid systems. It is essential for ensuring energy reliability during periods of low renewable energy production.
4. **Battery Storage**: Stores excess energy for later use. The capacity and type of battery significantly affect system performance and cost.
5. **Inverters**: Convert DC to AC power. They ensure that the energy generated by the system is compatible with the store's electrical requirements.

D. Mathematical Algorithm for Hybrid Energy Optimization

To optimize the hybrid energy system, a mathematical algorithm was developed based on the constraints and objectives defined in the HOMER software. The main goal was to minimize the Net Present Cost (NPC) while maximizing the Renewable Fraction (RF). The optimization problem can be formulated as follows:

Objective Function:

$$min \sum_{t=1}^{T}(C_{cap} + C_{rep} + C_{om} + C_{fuel} + C_{sal})$$ where:

C_{cap} is the capital cost of components,

C_{rep} is the replacement cost,

C_{cap} is the operation and maintenance cost

C_{fuel} is the fuel cost,

C_{sal} is the salvage value.

Constraints:

1. Energy Balance Constraint

$$P_{PV} + P_{WT} + P_{Gen} + P_{Grid} = P_{Load} + P_{Battery}$$

- Ensures energy demand is met at all times.

2. Battery State of Charge (SOC) Constraint

$$SOC_{min} \leq SOC_t \leq SOC_{max}$$

- Prevents overcharging or deep discharge of the battery.

3. Renewable Fraction (RF) Calculation

$$RF = \frac{E_{renewable}}{E_{total}}$$

- Ensures the system maximizes renewable energy utilization.

4. Grid Interaction Constraint

$$P_{export} \leq P_{max}^{Grid}$$

- Limits the amount of energy that can be fed back into the grid.

Solution Method

- The optimization problem was solved using a hybrid approach combining Linear Programming (LP) for cost minimization and Genetic Algorithm (GA) for optimal sizing of renewable components.
- HOMER's internal solver was used for iterative simulations, ensuring the feasibility of different system configurations.
- Sensitivity analysis was conducted to evaluate the impact of variations in solar radiation, wind speed, and load demand on system performance.

This algorithm effectively balances cost efficiency and sustainability, providing a robust methodology for designing optimal hybrid energy systems.

III. Results and Discussion

A. Grid-Connected System

The grid-connected system includes a 1 kW solar panel, a 1 kW wind turbine, and an inverter. The system covers 70.1% of the store's energy needs through renewable sources. The net present cost (NPC) is $9,317, with an annual operating cost of $406.35. Emissions are minimal, with 1,262 kg of CO2 emitted annually. The system also offers the benefit of feeding excess energy back into the grid, which can provide additional cost savings (Figure 1).

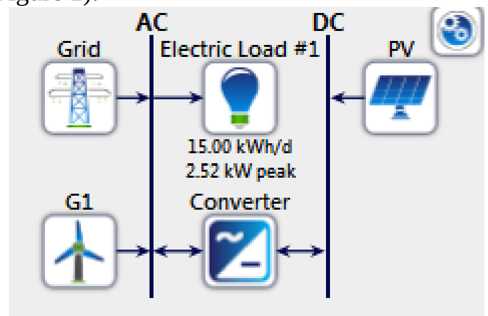

Figure 1. The energy system model designed for our store.

Table 1 Unit Costs of System Equipment

Equipment	Capital Cost ($)	Replacement Cost ($)	Operation & Maintenance Cost ($/year)
Wind Turbine ($/kW)	2500	2500	40
Solar Panel ($/kW)	1000	1000	10
Inverter ($/kWh)	250	250	0

Table 2. Simulation Results of the Grid-Connected Hybrid System

PV (kW)	Grid (kW)	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($)	Initial capital ($)	Ren. Frac (%)	Total Fuel (L)
1.72	999.999	1.21	CC	$9,317	$0.118	$4,053	$4,523	70.1	0
2.39	999.999	1.24	CC	$9,081	$0.113	$3,579	$2,743	48.8	0
-	999.999	-	CC	$10,168	$0.134	$6,583	$2,520	41.9	0
-	999.999	-	CC	$10,892	$0.170	$8,307	$0	0.0	0

As shown in Table 2, the hybrid system, which generates 1.72 kW of power, has a converter capacity of 1.21 kW, an annual operating cost of $406.35, and an installation cost of $4,523. It is concluded that 70.1% of the energy supplied by this selected system comes from renewable sources.

Table 3. Cost Summary of the Designed Grid-Connected System

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 1 kW	$2,500.00	$462.51	$0.16	$0.00	$-375.68	$3,278.08
Generic flat plate PV	$1,712.27	$0.00	$0.12	$0.00	$0.00	$1,712.27
Grid	$0.00	$0.00	$2,211.17	$0.00	$0.00	$2,211.17
System Converter	$0.00	$113.15	$0.00	$0.00	$0.00	$113.15
System	$4,523.22	$71.49	$3,496.83	$0.00	$-375.68	$9,317.21

Approximately 85% of the system's maintenance and repair cost of $4,396.23 was identified as repair and maintenance expenses, amounting to $3,721.17.

Production	kWh/yr	%
Generic flat plate PV	2,314	33.8
Generic 1 kW	2,526	36.9
Grid Purchases	1,997	29.2
Total	6,837	100

Consumption	kWh/yr	%
AC Primary Load	5,475	81.9
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	1,207	18.1
Total	6,682	100

Quantity	kWh/yr	%
Excess Electricity	40.8	0.597
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	70.1	%
Max. Renew. Penetration	139	%

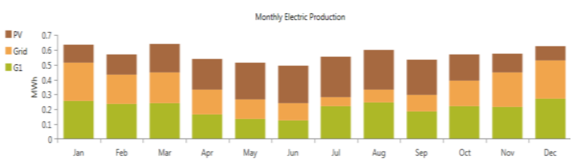

Figure 2. Monthly Electricity Production of the Selected Grid-Connected System

The grid-connected system has an annual sale of 1,997 kWh. The amount of electricity produced is minimal in June, and maximal in December and January. The percentage of renewable energy usage over the year is 70.1%, and the excess electricity produced annually is 40.8 kW.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
February	195	81	113	2	$31.47	$0
March	207	99	108	2	$33.25	$0
April	166	77	88	1	$26.60	$0
May	133	83	50	1	$20.98	$0
June	116	99	17	1	$17.70	$0
July	65	169	-105	1	$7.59	$0
August	84	172	-88	1	$10.82	$0
September	112	109	4	1	$16.93	$0
October	171	91	80	2	$27.18	$0
November	231	72	159	2	$37.85	$0
December	259	83	176	2	$42.33	$0
Annual	1,997	1,207	790	2	$315.38	$0

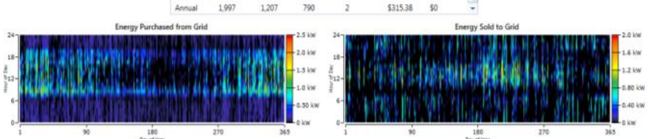

Figure 3. Energy Bought from, Sold to the Grid, and Cost Values

When Figure 3 is examined, the amounts of electricity the system has received from and sold to the grid at different times of the year are shown. The total amount of energy the system receives from the grid in one year is 1,997 kWh, while the amount of energy sold to the grid is 1,207 kWh. The net amount of energy received from the grid is 790 kWh.

Table 4. Annual Emission Values of the Grid-Connected System

Pollutants	Value (kg/year)
Carbon Dioxide	1.262
Carbon Monoxide	0
Unburned Hydrocarbons	0
Particulate Matter	0
Sulfur Dioxide	5.47
Nitrogen Oxides	2.68

B. Off-Grid System

The off-grid system consists of a 1 kW solar panel, a 1 kW wind turbine, a diesel generator, and a lithium-ion battery. It covers 81.6% of energy needs from renewables. The NPC is $16,964, with an annual operating cost of $685.85. The system emits 800 kg of CO2 annually, along with other pollutants from the diesel generator. This system is particularly advantageous in remote areas where grid connectivity is not feasible, although its higher cost and environmental impact must be carefully considered.

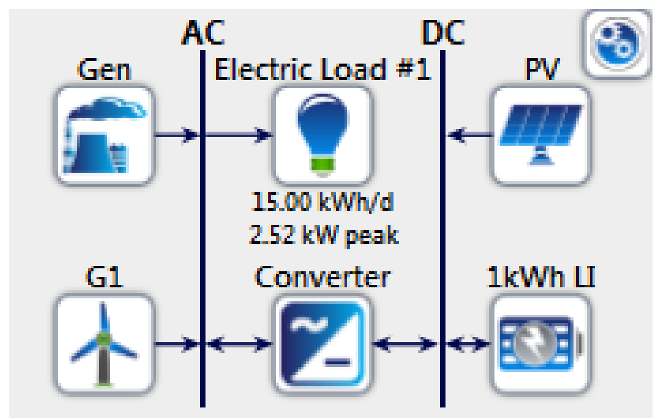

Figure 4. The energy system model designed for our store.

The off-grid renewable energy system consists of a 1 kW solar panel, a 1 kW wind turbine, a diesel generator, a 1 kW Li-Ion battery, and an inverter. Based on the specified peak power value, the inverter capacity has been set at 1.42 kW. The lifetime of the solar panels is 25 years, while the lifetime of the wind turbines is 20 years. Additionally, according to the data obtained from the HOMER software, the turbine rotor height is found to be at least 17 meters.

Table 5. Unit Costs of System Equipment

Equipment	Capital Cost ($)	Replacement Cost ($)	Operation & Maintenance Cost ($/year)
Wind Turbine ($/kW)	2500	2500	40
Solar Panel ($/kW)	1000	1000	10
Diesel Generator ($/kW)	300	300	3$/saat

Battery (Li-Ion) ($/kWh)	230	230	10
Inverter ($/kWh)	250	250	0

Table 6. Simulation Results of the Off-Grid Hybrid System

PV (kW)	Grid (kW)	Gen (kW)	Converter (kW)
3.39	1	280	2.27
5.47	1	280	2.27
2.82	1	280	2.27
4.42	1	280	2.27
2.75	1	280	2.27
7.03	1	280	2.27
1.34	1	280	2.27
Dispatch	**NPC ($)**	**COE ($)**	**Operating Cost ($)**
CC	$26,019	$0.125	$9,165
CC	$32,574	$0.157	$11,875
CC	$25,315	$0.124	$8,935
CC	$29,713	$0.145	$10,635
CC	$23,915	$0.117	$8,315
CC	$44,820	$0.218	$15,882
CC	$67,779	$0.305	$21,673
Initial Capital ($)	**Ren. Frac (%)**	**Total Fuel (L)**	
$8,472	84.6	360	
$12,943	74.4	424	
$8,126	85.5	685	
$10,146	78.9	100	
$7,849	100	1.09	
$20,140	240	1.87	
$64,080	0	3.284	

As seen in Table 6, the off-grid wind-solar-diesel system, which generates 3.39 kW of power with the support of a 2.8 kW generator, provides an electrical energy potential of 2.12 kW with the help of a 2.12 kW inverter. The economic data for the off-grid system of the store is as follows: the operating cost is $685.85 annually, the installation cost is $8,872, and 81.6% of the energy is supplied by the hybrid energy source. Considering the 4.42 kW electrical energy potential provided by solar and wind alone, and using a 2.27 kW inverter to meet the store's off-grid electricity needs, the operating cost of this system is found to be $655 annually, with an installation cost of $18,236. In this case, the store's entire electricity demand is met solely by wind and solar energy.

Table 7. Cost Summary of the Designed Off-Grid System

Component	Capital ($)	Replacement ($)	O&M ($)
3.39	1	280	2.27
5.47	1	280	2.27
2.82	1	280	2.27
4.42	1	280	2.27
2.75	1	280	2.27
7.03	1	280	2.27
1.34	1	280	2.27
Fuel ($)	**Salvage ($)**	**Total ($)**	
CC	$26,019	$0.125	
CC	$32,574	$0.157	
CC	$25,315	$0.124	
CC	$29,713	$0.145	
CC	$23,915	$0.117	
CC	$44,820	$0.218	
CC	$67,779	$0.305	

In Table 7, the fuel cost of the generator is $5,048.6, which constitutes approximately 30% of the total cost of the off-grid system ($16,964.04). This result means that the emission cost accounts for 30% of the total cost.

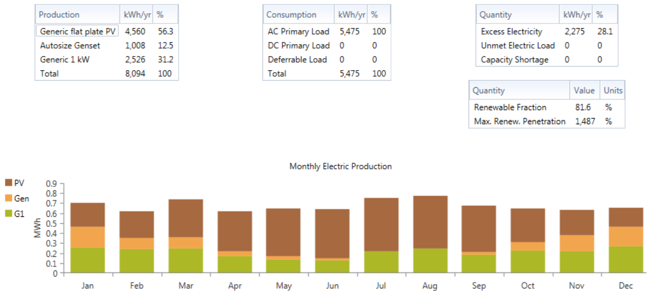

Figure 5. The generator contribution to electricity production

In Figure 5, the generator's contribution to electricity production is minimal in July and August, while it reaches its maximum level in December and January. The total electricity generated from the use of the generator over the year is 1,008 kWh. It has been determined that 81.6% of the electricity production is supplied by renewable energy.

Table 8. Emission Values of the Off-Grid System

Pollutants	Value (kg/year)
Carbon Dioxide	800
Carbon Monoxide	5.04
Unburned Hydrocarbons	0.220

Particulate Matter	0.0306
Sulfur Dioxide	1.96
Nitrogen Oxides	4.74

C. Comparison

Table 9 Comparisons of the both grid systems.

Parameter	**Grid-Connected System**	**Off-Grid System**	**Difference**
Net Present Cost ($)	9,317	16,964	1.82x higher
Annual Operating Cost ($)	406.35	685.85	1.67x higher
CO_2 Emissions (kg/year)	1,262	800	Lower in off-grid
Renewable Energy Usage (%)	70.1	81.6	Higher in off-grid

The grid-connected system is more cost-effective, while the off-grid system offers higher renewable energy usage but at a significantly higher cost and environmental impact. The comparison highlights the need for a balanced approach that considers both economic and environmental factors.

IV. Conclusion

Two hybrid energy systems were modeled for a clothing store in Biga using HOMER software. The grid-connected system emerged as the more feasible option due to its lower costs and reduced environmental impact. The study highlights the importance of optimizing hybrid systems to balance cost, reliability, and sustainability. Future research could explore the integration of advanced storage technologies and real-time energy management systems to further enhance the efficiency of hybrid solutions.

Future Research Recommendations

Future research should explore advanced storage solutions, such as lithium-ion and solid-state batteries, to further enhance system efficiency. Additionally, integrating AI-based energy management systems could optimize energy consumption and reduce operational costs. A feasibility study for implementing similar hybrid systems in other commercial sectors would also be beneficial.

REFERENCES

[1] BP Statistical Review of World Energy, British Petroleum (BP), London, U.K., 2021. [Online]. Available: https://www.bp.com

[2] World Energy Council, *Global Energy Summary*, London, U.K., 2021.

[3] E. Koç and K. Kaya, "Enerji Kaynakları - Yenilenebilir Enerji Durumu," *Mühendis ve Makina*, vol. 56, pp. 36–47, 2015.

[4] REN21, *Renewables 2021 Global Status Report*, Paris, France, 2021. [Online]. Available: https://www.ren21.net

[5] A. Albostan, Y. Çekiç, and L. Eren, "Rüzgar Enerjisinin Türkiye'nin Arz Güvenliğine Etkisi," *Gazi Üniversitesi Müh. Mim. Fak. Dergisi*, vol. 24, no. 4, pp. 641–649, 2009.

[6] GWEC, *Global Wind Report 2022*. [Online]. Available: https://gwec.net/wp-content/uploads/2022/03/GWEC-GLOBAL-WIND-REPORT-2022.pdf. Accessed: May 25, 2022.

[7] GEPA, "Güneş Enerjisi Potansiyel Atlası," [Online]. Available: https://gepa.enerji.gov.tr/MyCalculator/. Accessed: May 15, 2022.

[8] Enerji Atlası, "Ülkelere Göre Güneş Enerjisi," [Online]. Available: https://www.enerjiatlasi.com/ulkelere-gore-gunes-enerjisi.html. Accessed: May 15, 2022.

[9] H. Aras, "Wind energy status and its assessment in Turkey," *Renewable Energy*, vol. 28, no. 14, pp. 2213–2220, 2003.

[10] Global Energy Monitor, "Ülkelerin Rüzgar Enerji Kapasitesi," [Online]. Available: https://temizenerji.org/2022/05/26/global-energy-monitor-tum-ulkelerin-ruzgar-ve-gunes-enerjisi-kapasitesini-yayinladi/. Accessed: May 25, 2022.

[11] TUREB, "Türkiye Rüzgar Enerjisi Birliği," [Online]. Available: https://www.tureb.com.tr/. Accessed: May 25, 2022.

[12] Y. S. Mohammed, M. W. Mustafa, and N. Bashir, "Hybrid renewable energy systems for off-grid electric power: Review of substantial issues," *Renewable and Sustainable Energy Reviews*, vol. 35, pp. 527–539, 2014.

[13] E. Çetin, "Fotovoltaik-Rüzgar-Yakıt Pili Hibrit Güç Sistemi İçin Bir Mikro Doğru Akım Dağıtım Şebekesi Tasarlanması, Uygulanması ve Analizi," Ph.D. dissertation, Ege Üniversitesi Fen Bilimleri Enstitüsü, İzmir, Turkey, 2010.

[14] A. F. Güven and M. K. Mete, "Balıkesir'in Erdek İlçesi için Şebeke Bağlantılı Hibrit Enerji Sistemi Fizibilite Çalışması ve Ekonomik Analizi," *Mühendis ve Makina*, vol. 63, pp. 138–158, 2022.

[15] H. Mamur, M. C. Yakar, and A. Zerafet, "Bir Kamu Binası İçin Hibrit Enerji Sistemi Fizibilitesi," *Uluslar Teknolojik Bilimler Dergisi*, vol. 11, no. 1, pp. 51–58, 2019.

[16] S. Türkdoğan, S. Dilber, and B. Çam, "Hibrit Enerji Sistemlerinin Şebekeden Bağımsız Bir Çiftlik Evinde

Uygulanabilirliğinin Ekonomik ve Teknik Açıdan İncelenmesi," *Sinop Üniversitesi Fen Bilimleri Dergisi*, vol. 3, no. 2, pp. 52–65, 2018.

[17] Çanakkale İl Turizm Müdürlüğü, "Coğrafya." [Online]. Available: https://canakkale.ktb.gov.tr/TR-70467/cografya.html. Accessed: May 15, 2022.

[18] HOMER Energy, "HOMER Software." [Online]. Available: https://www.homerenergy.com/products/pro/index.html. Accessed: May 15, 2022.

[19] M. J. Khan and M. T. Iqbal, "Pre-feasibility study of stand-alone hybrid energy," *Renewable Energy*, vol. 30, no. 6, pp. 835–854, 2005.

[20] Shell, "Akaryakıt Pompa Satış Fiyatları," [Online]. Available: https://www.shell.com.tr/suruculer/shell-yakitlari/akaryakit-pompa-satis-fiyatlari.html. Accessed: May 25, 2022.

[21] TCMB, "Gösterge Niteliğindeki Merkez Bankası Kurları," [Online]. Available: https://www.tcmb.gov.tr/kurlar/kurlar_tr.html. Accessed: May 25, 2022.

[22] R. Erkoç, "Güneş Enerji Santrallerinin Modellenmesi, Ekonomik Analizi ve Değerlendirme: Almanya ve Türkiye Uygulamaları," Master's thesis, Fen Bilimleri Enstitüsü, 2019.

[23] M. Thirunavukkarasu and S. Yashwant, "Design, analysis and optimal sizing of standalone PV/diesel/battery hybrid energy system using HOMER," *Materials Science and Engineering*, vol. 928, 2020.

[24] S. Türkdoğan, M. T. Mercan, and T. Çatal, "Şebekeden Bağımsız Hibrit Enerji Sistemleri Kullanılarak 40 Hanelik Bir Topluluğun Elektrik ve Termal Yük İhtiyacının Karşılanması: Teknik ve Ekonomik Analizleri," *Avrupa Bilim ve Teknoloji Dergisi*, no. 18, pp. 476–485, 2020.