



ENERGY PRODUCTION WITH HYBRID ENERGY SYSTEMS: CASE STUDY OF BATMAN

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ABSTRACT

Due to their pollution of the environment and the damage they cause to human health, renewable energy sources have emerged as a promising solution amid ongoing efforts to find alternatives to fossil fuels and nuclear energy. There are hybrid energy system applications consisting of two or more renewable energy sources. In this study, a hybrid power plant design utilizing solar and diesel energy was developed for Aksu Village, consisting of 36 households in the Hasankeyf district of Batman province, with the help of the HOMER Pro Program. A hybrid system connected to the electricity grid was considered, with solar energy panels to be used when needed. It was determined that the settlement would consume 450,000 kWh of electricity per year in 2023, which is an average of 37,500 kWh per month and 1,250 kWh per day. When the cost analysis of the hybrid system was performed, the lowest-cost system required an initial capital of 8,378,332 TL (\$288,908) and an annual operating and maintenance cost of 1,724,949 TL (\$59,481). Based on the electricity data used for the system, the cost per kW was found to be 5,104 TL (\$0.176).

1. INTRODUCTION

The growing energy needs of people have increased the demand for fossil fuels. Although nuclear power plants have begun to be used to generate energy as an alternative to fossil fuels, both fossil fuels and nuclear waste are harmful to our world and to humans. Carbon dioxide, one of the elements that causes environmental pollution, is released most during production in large facilities such as factories. The carbon dioxide released here has negative effects not only on environmental pollution but also on the world's ecosystem.

Societies require energy not only for production but also for basic needs such as shelter, heating, and cooking. While fossil fuels are used more in large facilities such as vehicles and factories, electrical energy is used for other needs. For example, in our country in 2023, electrical energy consumption was 335.2 terawatt-hours (TWh), while electrical production was 331.1 TWh [1]. In 2023, 36.2% of electricity production came from coal, 21% from natural gas, 19.3% from hydroelectric power, 10.3% from wind, 6.7% from solar, 3.4% from geothermal energy, and 3.2% from other sources. What is noteworthy here is the rapid upward trend in energy production from renewable energy sources [1]. The idea of renewable energy sources, which are energy sources that do not harm nature and living things, emerged both to meet energy needs and to prevent environmental pollution. Examples of renewable energy sources include wind, solar, hydro, geothermal, biomass, and wave energy. Our country is rich in renewable energy resources, and as a result, investments have begun to be made, albeit on a small scale, thanks to recent incentives. Among these investments, efforts to install solar panels for the purpose of generating electricity from solar energy have gained momentum in recent years. The total installed renewable energy capacity has reached 58,909 MW, with unlicensed solar installed capacity at 9,628 megawatts (MW), licensed solar installed capacity at 1,665 MW, and wind energy installed capacity at 11,697 MW [1].

Baghel and other academics studied an academic building using solar-biomass hybrid system providing sustainable energy transition. They used HOMER Pro for simulation, and the techno-environmental evaluation of the system is the main subject of analysis. At a peak load of 65 kW, HRES is intended to meet a daily energy consumption of 588 kWh. The system produces 3,76,780 kWh of electricity annually [2]. Hüner analyzed feasibility and environmental analysis of Hatay region in Türkiye biogas based HRES system. His study revealed that optimum HRES configuration was 200 kW PV, 100 kW biogas generator, 72 kW converter and 120 kW electrolyser, respectively. NPC and LCOE values for this study was found as \$1.92 M and \$0.2094 per kW, respectively [3]. Kaur and co-workers studied PV-biomass hybrid system using anaerobically treated crop residue in order to mitigate farmer's crop burns. They incorporated experimental data to HOMER Pro simulation environment to analyse HRES performance. Their results showed that bagasse-based biogas and PV system provide most optimum NPC and COE value which is \$394431 and 0.131\$/kW, respectively [4]. Modu et al. investigated HRES system using Levy flight-slack swarm algorithm (LF-SSA) to minimize annual system cost. LF-SSA offers the lowest LCOE \$0.933/kWh compared to SSA with \$0.947/kWh [5]. Winsly and other academics studied biomass solar wind and grid configuration considering South India region. They used eight different configuration and among these configurations, the optimum one was found 387 kW PV, 20 kW wind turbine, and 4 kW biomass gasifier generator. Cost of electricity of this system was calculated as \$0.096/kWh [6]. El Maaroufi and co-workers analyzed the techno-economic and environmental viability of an integrated renewable energy system designed for northern Morocco Their work's primary innovation is the combination of photovoltaics (PV), batteries, a biomass generator (BMG), a thermal load controller (TLC), and a boiler that runs on biodiesel ideal for applications requiring sustainable heating in remote highland areas. In comparison to diesel systems, they have a NPC of 16.476 billion dollars and have the potential to cut CO₂ emissions by 4,989,457 tons annually [7]. Makhough et. al. investigated the research gap on sustainable electricity in isolated mountainous regions of eastern Morocco by analyzing their unrealized energy potential. In order to accommodate local conditions, they suggested a hybrid energy system that combined solar, wind, and biomass energy with green hydrogen and batteries for storage, with the grid serving as a backup. The technology drastically lowers greenhouse gas emissions by more than 99% for CO₂ and 100% for SO₂, while achieving a levelized cost of energy of 0.024 \$/kWh [8]. A freestanding hybrid PV (photovoltaic)-WT (wind turbine)-BG (biogas generator) was presented by Jahangir and other academics in order to suggest an economically ideal plan for a rural area in Iran's southern region to be electrified. This study covered a wide range of topics, such as national regulations, agricultural waste, regional resources, modeling of every component, and system sensitivity to changes in biomass input, biofuel prices, and inflation rates. A 15% inflation rate was used for the first sensitivity model, while a 10% inflation rate was used for the second. The results showed that a 150 kW BG, an 80.7 kW PV, 27 batteries, and an inverter made up the ideal solution [9]. Aykut and co-workers looked into the viability of electrifying a 50,000-student university campus in Istanbul, Turkey, using a WT-PV-BG energy system. Introducing an economical and ecologically sustainable energy generation plan for the campus was the aim of this study. Using HOMER software, four distinct situations were examined in order to determine the system with the lowest COE and NPC. With an NPC and COE of 5621502\$ and 0.067 \$/kWh, respectively, the system with 1500 kW WT and 1000 kW BG was ultimately determined to be the best plan [10]. The goal of Li et al. [11] was to design the best stand-alone renewable energy plan for a remote Western Chinese town. Their study took biomass-related measures into consideration because of the region's abundance of agricultural waste. WT and PV were also taken into account because of the region's strong potential for these technologies. With a COE of 0.201\$/kWh, HOMER Pro's ideal design, which took into account the study's objectives of cost-effectiveness and sustainability, comprised three 10 kW WTs, 104 kW PV modules, 50 kW DG (diesel generator), 99 kW inverter, and 331 kWh batteries [11].

Our study focuses on meeting the electricity needs of Aksu village, a settlement of 36 households located in the Hasankeyf district of Batman, using renewable energy sources and, when necessary, grid electricity. A cost-benefit simulation for the hybrid system that will supply the village's electricity was performed using the HOMER (Hybrid Optimization of Multi-Electricity Renewable Energy) Program, developed by the US National Renewable Energy Laboratory (NREL), which enables the evaluation of designs for both off-grid and grid-connected power systems for various applications.

2. MATERIAL and METHOD

Batman, located in the north of the Southeastern Anatolia Region, was a district of Siirt Province until May 16, 1990, when it became Turkey's 72nd province. Until the 1940s, it was a small village, but with the discovery of oil in the Raman Mountain to its south, it began to develop rapidly and has reached a population of 647,205 as of 2023. The province has an area of 4,964 km², most of which is covered by mountains, and its elevation above sea level is 570 m. Located between 41°10' and 41°40' east longitude and 38°40' and 37°50' north latitude, Batman has a continental climate with very hot and dry summers and cold and snowy winters. From 1959 to 2023, the annual average temperature was 16 °C, the average maximum temperature was 23.8 °C, the average minimum temperature is 8.9 °C, the highest temperature is 48.8 °C, the lowest temperature is -24 °C, the average number of rainy days is 80.7, and the average rainfall is 489 mm. Our study focuses on meeting the electricity needs of Aksu village, a settlement of 36 households located in the Hasankeyf district of Batman, using renewable energy sources and, when necessary, grid electricity. A cost-benefit simulation for the hybrid system that will supply the village's electricity was performed using the HOMER (Hybrid Optimization of Multi-Electricity Renewable Energy) Program, developed by the US NREL, which enables the evaluation of designs for both off-grid and grid-connected power systems for various applications.

Homer Pro performs energy balance calculations for each system configuration, taking into account system cost calculations, capital, replacement, operating and maintenance, fuel, and interest costs. It determines whether this configuration is feasible, i.e., whether it can meet the electricity demand under the specified conditions, and estimates the system's installation and operating costs over the project's lifetime [12].

2.1. Load and Solar Data

It has been determined that in 2023, the villagers consumed 450,000 kW of electricity, which corresponds to 37,500 kW per month and an average of 1,250 kW per day. According to the data obtained, the data in Figure 1 was obtained by evaluating the average electricity used per day by the villagers in 2023 according to hourly intervals. The figure below includes load values for electricity used in agriculture and livestock farming.

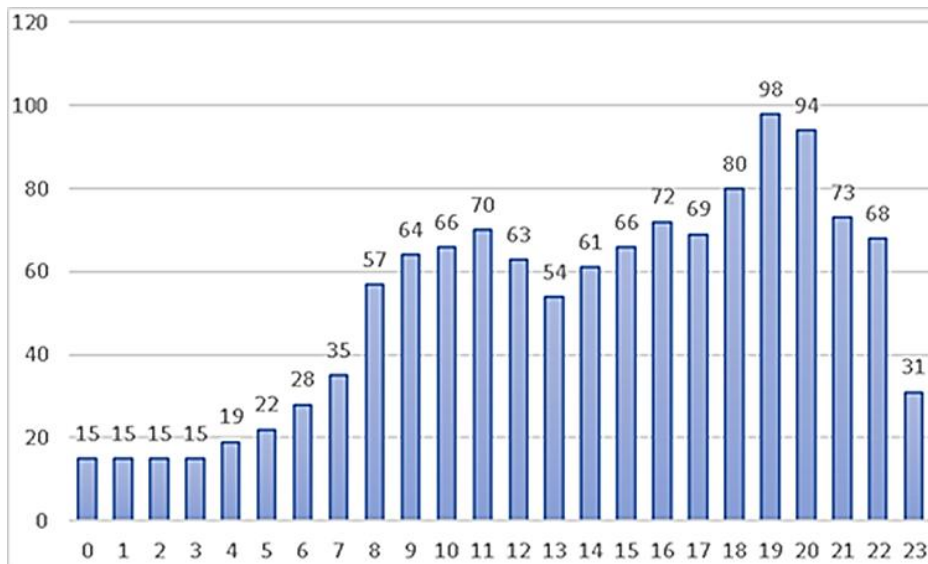


Figure 1. Aksu Village Daily Electricity Consumption.

According to the Solar Energy Potential Atlas (Figure 2) obtained from the General Directorate of Electrical Works of Batman Province, it has been observed that Aksu Village, located between Hasankeyf and Gercüş Districts, has a solar radiation potential higher than the average of Batman Province, which has a high potential [13]. Hasankeyf global radiation values are obtained from General Directorate of Electrical Works of the Ministry of Energy and Natural Resources, illustrated in Figure 3.

Figure 4 shows that the maximum sunshine duration in the district of Hasankeyf was 12.28 hours in July, while the lowest values were around 4 hours in December and January. Due to the insufficient sunshine duration in the winter months, we need to add electricity supply from the grid to the system we will prepare. According to the Ministry of Energy and Natural Resources' regulation on license-free electricity production, if electricity is used from the grid, the amount of electricity consumed must be equal to the amount of electricity that is not consumed and is to be sent to the grid [14]. This will ensure that the settlement is made.

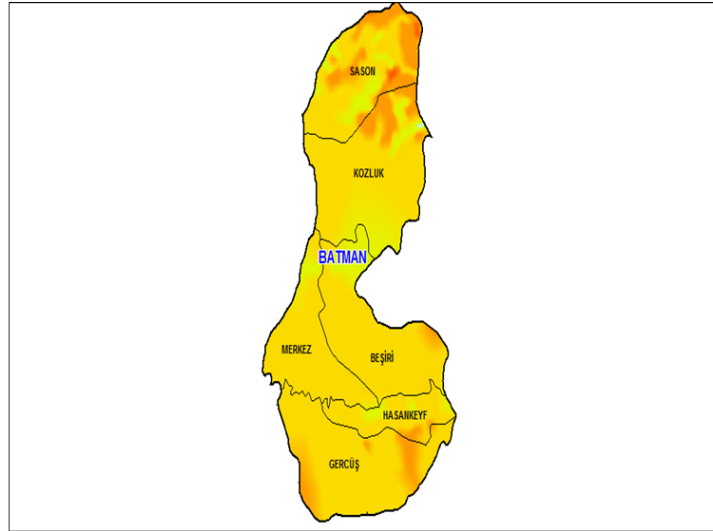


Figure 2. Batman Solar Energy Potential Atlas.

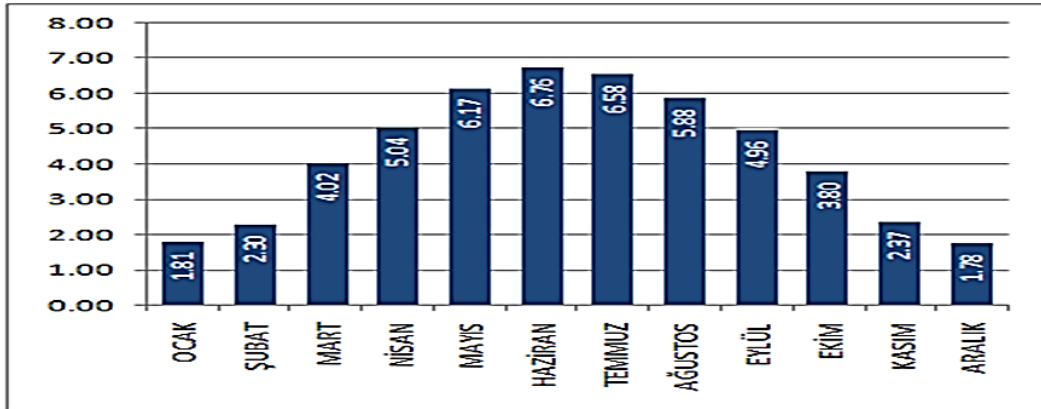


Figure 3. Hasankeyf Global Radiation Values (kWh/m²-day).

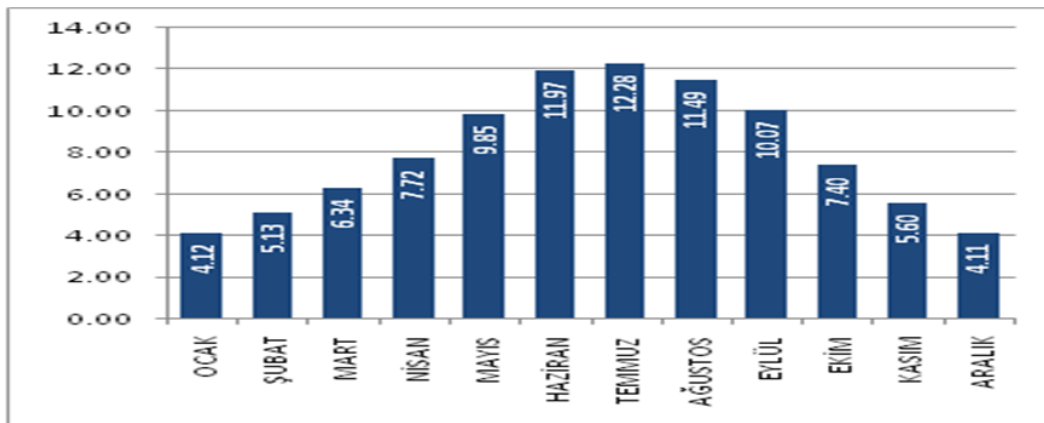


Figure 4. Hasankeyf Sunshine Duration (Hours).

2.2. HRES Configuration

The system model designed in the Homer Pro program based on the data entered for Aksu village is shown in Figure 5. Since the EPDK updated prices four times a year for our village, which uses low voltage and a single-term tariff of 8 kWh/day and below, at three-month intervals, the average price of electricity purchased from the grid in 2023 was entered as 2.215 TL, and the price of electricity to be sold to the grid by us was entered as 0.694 TL [15]. In 2023, the average exchange rate was 1 USD = 29 TL [16]. The cost of electricity purchased from the grid was calculated as 0.076 USD, and the cost of electricity produced and sold to the grid was calculated as 0.024 USD.

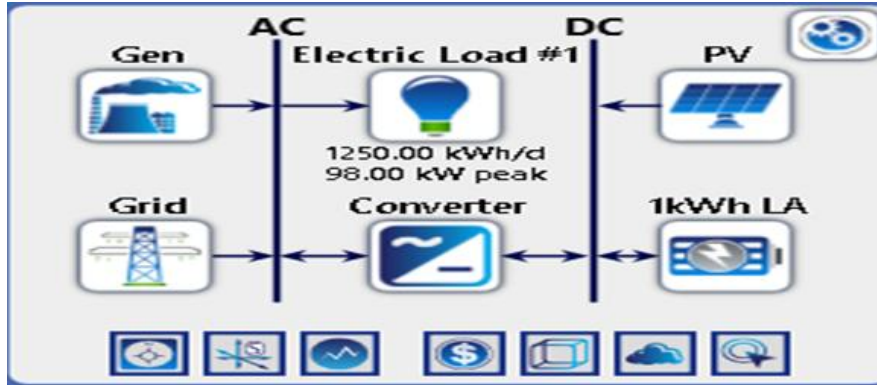


Figure 5. Homer Pro Design Model.

2.3. Economic Formula

The formulas used in cost calculations to perform an economic evaluation for our project are listed below [12].

Real interest rate:

$$i = \frac{i' - f}{1 + f} \quad (1)$$

i = real interest rate

i' = nominal interest rate

f = yearly inflation rate

Net Present Cost:

$$\sum_{t=0}^n \frac{B_t}{(1+i)^t} - \sum_{t=0}^n \frac{C_t}{(1+i)^t} \quad (2)$$

B_t = cash inflow in year t

C_t = cash outflow in year t

n = year

Cost of energy:

$$\frac{C_{tot}}{E_{tot}} \quad (3)$$

C_{tot} = The total cost of annual system, including all components

E_{tot} = Annual energy production

3. RESULTS AND DISCUSSION

When examining our Cost Table, the Lowest Cost System requires an initial capital of 8,378,332 TL (\$288,908) and annual operating and maintenance costs of 1,724,949 TL (\$59,481). Looking at the electricity data used for the system, the cost per kW is found to be 5,104 TL (\$0.176).

Table 1. HRES configuration cost summary.

	Base case	Lowest cost system
NPC	2,95 M \$ (85,55 M TL)	1,12 M \$ (32,48 M TL)
Initial investment	55.000 \$ (1.595.000 TL)	288.908 \$ (8.378.332 TL)
O&M cost	206.362 \$/yr (5.989.498 TL/yr)	59.481 \$/yr (1.724.949 TL/yr)
COE	0,461\$/kWh (13,369 TL/kWh)	0,176 \$/kWh (5,104 TL/kWh)

The interest rate applied by the Central Bank for loans granted to banks is 15.58% [17], and the inflation rate is 10.02% [18] on average. The project life is set at 25 years based on the data entered. When economic criteria are evaluated, the system is easily repaid within 3.6 years. This shows that the system pays for itself in less than two years and begins to generate profit. The investment/cost return, which is the ratio between net income and investment showing that the investment gain is positive relative to the cost, was found to be 59%. The internal rate of return (IRR), which is the discount rate that expresses the rate at which investments will provide added value, i.e., the series of added values to be obtained in a certain period equal to the investment amount, was found to be 62%.

The prices obtained from the data entered into the Homer Program are given in US Dollars, and when the dollar is calculated as an average of 29 Turkish Liras in 2023, the data obtained is as follows. The net present cost of the system, obtained by subtracting the present value of investment expenses from the present value of the return, was calculated as \$1,825,144 (52,929,176 TL), and the annual return of the project was calculated as \$130,195 (3,775,655 TL).

Table 2. Electricity production and consumption data.

		kWh/yr	%
Production	PV	114.617	24,1
	Automatic generator	59.042	12,4
	Grid (Purchase) Acquisitions	301.795	63,5
	Total	475.454	100
Consumption	Alternative current (AC) Primary load	456.250	100
	Direct current (DC) Primary load	0	0
	Deferrable load	0	0
	Total	456.250	100

When examining the electricity data in Table 2, it is seen that 475,454 kWh of electricity was generated annually, 456,250 kWh of electricity was consumed, and the surplus electricity amount was calculated as 5,145 kWh. For the fuel data used as diesel for the system, the average daily fuel consumption was 50.9 L, the average hourly fuel consumption was 2.12 L, and the total fuel consumption was calculated as 18,590 L. The emission data to be obtained when the project is implemented is shown in Table 3.

Table 3. Emission values.

Quantity	Value (kg/yr)
CO ₂	239.395
CO	307
Free Hydrocarbons	13,4
Particulate Matter	1,86
Sulfur Oxide	946
Nitrogen oxides	693

4. CONCLUSIONS

In our study, the Homer Pro program was used to perform cost and other analyses of the electricity that would be generated by installing solar panels in Aksu Village, located in the Hasankeyf district of Batman Province in the Southeastern Anatolia Region, where the duration of sunshine is high. The lowest-cost system requires an initial capital of 8,378,332 TL (\$288,908) and annual operating and maintenance costs of 1,724,949 TL (\$59,481). Based on the electricity data used for the system, the cost per kW was found to be 5.104 TL (\$0.176). The net present cost of the system is calculated as \$1,825,144 (52,929,176 TL), and the annual return on the project is calculated as \$130,195 (3,775,655 TL). Thus, the system pays for itself in less than two years by also using grid electricity and begins to generate profit.

The use of photovoltaic panels to generate electricity from solar energy, a renewable energy source, is a new and rapidly developing technology. Looking at our country's solar energy potential, it is observed that while some parts of the Black Sea, Marmara Region, and Central Anatolia Region have low sunshine durations, this ratio is very high in other regions. It seems very logical to turn to this energy source, which is both cleaner and could end our dependence on foreign energy, in regions where sunshine duration is high and there is a need for energy. As it is a new technology, there has not been much research on whether photovoltaic panels pose a threat to human or animal health or have negative effects on the environment. However, considering the chemical substances such as lead contained in the panels, research should be conducted on whether they are harmful to the environment.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

This manuscript was entirely written, edited, analyzed, and prepared without the assistance of any artificial intelligence (AI) tools. All content, including text, data analysis, and figures, was solely generated by the authors.

Contributions of the Authors

Özcan BAŞARAN: Resources, software, writing original draft, writing-review and editing.

Yavuz KIRIM: Resources, supervision, methodology, software, writing-review and editing.

REFERENCES

- [1] Enerji ve Tabii Kaynaklar Bakanlığı. "2023 Yılı Türkiye'de Enerji Üretim ve Tüketim Değerleri." Enerji.gov.tr. Accessed: Jun. 12, 2024. [Online.] Available: <https://enerji.gov.tr/bilgi-merkezi-enerji-elektrik#:~:text=T%C3%BCrkiye>
- [2] N. Baghel, K. Manjunath, and A. Kumar, "Assessment of solar-biomass hybrid power system for decarbonizing and sustainable energy transition for academic building," *Proc. Saf. Environ. Prot.*, vol. 187, pp. 1201–1212, 2024.
- [3] B. Hüner, "Feasibility and environmental analysis of biogas-based hybrid energy system using HOMER pro software: A case study for Hatay," *Energy Convers. Manag.*, vol. 326, pp. 119480, 2025.
- [4] M. Kaur, S. Dhundhara, Y. P. Verma, S. Chauhan, and Y. Arya, "Impact of anaerobically digested pretreated crop residue on performance and economics of solar photovoltaic-biomass microgrid system," *Sustain Energy Technol. Assessments*, vol. 76, pp. 104280, 2025.
- [5] B. Modu, M. P. Abdullah, A. L. Bukar, M. F. Hamza, and M. S. Adewolu, "Operational strategy and capacity optimization of standalone solar-wind-biomass-fuel cell energy system using hybrid LF-SSA algorithms," *Int. J. Hydrogen Energy*, vol. 50, pp. 92–106, 2024.
- [6] B. W. Winsly, V. K. Ramalingam, J. S. Santhappan, A. J. Maria, M. P. Chokkalingam, and V. Rajendran, "Optimal sizing and techno-economic-environmental evaluation of biomass-solar-wind-grid hybrid energy system: A case study of an institute in South India," *Energy Convers. Manag.*, vol. 325, pp. 119352, 2025.

- [7] A. El-Maaroufi, M. Daoudi, and R. A. Laamara, "Optimization of hybrid solar/wind/biomass systems for sustainable heating in isolated mountainous areas of northern Morocco," *Sol. Energy*, vol. 299, pp. 113683, Oct. 2025.
- [8] A. Makhoukh, A. Redouane, N. Oubouch, and A. El Hasnaoui, "Optimizing off-grid energy solutions: a hybrid approach leveraging solar, wind, and biomass for sustainable development," *Global Energy Interconnect.*, vol. 8, pp. 858-873, 2025.
- [9] M. H. Jahangir and R. Cheraghi, "Economic and environmental assessment of solar-wind-biomass hybrid renewable energy system supplying rural settlement load," *Sustain. Energy Technol. Assessments*, vol. 42, pp. 100895, 2020.
- [10] E. Aykut, and Ü. K. Terzi, "Techno-economic and environmental analysis of grid connected hybrid wind/photovoltaic/biomass system for Marmara University Goztepe campus," *Int. J. Green Energy*, vol. 17, pp. 1036–1043, 2020.
- [11] J. Li, P. Liu, and Z. Li, "Optimal design and techno-economic analysis of a solar-wind-biomass off-grid hybrid power system for remote rural electrification: A case study of West China," *Energy (Oxf.)*, vol. 208, pp. 118387, 2020.
- [12] HOMER Pro User Manual, "HOMER Pro-3.14." Accessed: Aug. 25, 2020. [Online]. Available: <https://www.homerenergy.com/products/pro/docs/latest/index.html>
- [13] Enerji ve Tabii Kaynaklar Bakanlığı. "Enerji ve Tabii Kaynaklar Bakanlığı Elektrik İşleri İdaresi Genel Müdürlüğü." enerji.gov.tr. Accessed: Feb. 5, 2025 [Online]. Available: <https://gepa.enerji.gov.tr/pages/72.aspx>
- [14] Enerji ve Tabii Kaynaklar Bakanlığı. "Enerji ve Tabii Kaynaklar Bakanlığı Elektrik Piyasasında Elektrik Üretim Yönetmeliği." enerji.gov.tr. Accessed: April. 9, 2025 [Online]. Available: <https://www.mevzuat.gov.tr/File/GeneratePdf?mevzuatNo=31502&mevzuatTur=KurumVeKurulYonetmeli&mevzuatTertip=5>
- [15] Enerji Piyasası Düzenleme Kurumu. "EPDK Güncel Enerji Fiyatları." epdk.gov.tr. Accessed: March. 12, 2025 [Online]. Available: <https://www.epdk.gov.tr/Detay/Icerik/3-1327/elektrik-faturalarina-esas-tarife-tablolari>
- [16] Türkiye Cumhuriyeti Merkez Bankası. "Döviz Kurları." tomb.gov.tr. Accessed: May. 2, 2024 [Online]. Available: https://www.tomb.gov.tr/kurlar/202301/Jan_tr.html
- [17] Türkiye Cumhuriyeti Merkez Bankası. "Para Politikası." tomb.gov.tr. Accessed: May. 5, 2024 [Online]. Available: <https://www.tomb.gov.tr/wps/wcm/connect/TR/TCMB+TR/Main+Menu/Temel+Faaliyetler/Para+Politikasi/PPK/2023>
- [18] Türkiye Cumhuriyeti Merkez Bankası. "Tüketici Fiyatları." tomb.gov.tr. Accessed: May. 5, 2024 [Online]. Available: <https://www.tomb.gov.tr/wps/wcm/connect/TR/TCMB+TR/Main+Menu/Istatistikler/Enflasyon+Verileri/Tuketici+Fiyatlari>