24th International Conference on Renewable Energies and Power Quality (ICREPQ'26)
Santander (Spain), 10th to 12th June 2026
ISBN-13: 978-84-09-66511-2

Case Study 2: Payback Scenario of Solar, Wind and Hybrid Power System - Deployment at CPDAM Frostburg State University

Tariq **MASOOD**[1], Jamil **Abdo**[1], Kaimiao **Liu**[1], Shakil **M Rahman,** Iftikhar **Ul- Haq**

[1] Department of Engineering and Sustainable Technologies
Frostburg State University - 101 Braddock Road Frostburg, MD 21532 USA
TOPSOE Making Energy Transition**,** DK-2800 Kgs-Lyngby Denmark
e-mail: tmasood@frostburg.edu; jabdo@frostburg.edu; kliu@frostburg.edu; SRahman@frostburg.edu , ifha@topsoe.com

Abstract:

This case study presents the design, development, and implementation of a residential-scale hybrid solar and wind power generation system installed at the Center of Product Design and Advanced Manufacturing (CPDAM) at Frostburg State University (FSU). The "WISE" system integrates a 2-kW photovoltaic (PV) array and a 1.8 kW wind turbine mounted on a 45-ft monopole tower, jointly supplying a small residential-type building through a grid-tied configuration with net metering. Extensive resource assessment was conducted using three Davis Weather Pro® stations and long-term solar-insolation modeling. The hybrid system incorporates advanced inverter/charger technology, MPPT algorithms, remote monitoring, and automatic generator start capability, enabling reliable, scalable operation for both on-grid and backup modes. Real-time performance data collected throughout the year confirms stable output in varying weather conditions and validates the system's technical and educational value. The project demonstrates a viable residential renewable energy model, strengthens regional sustainability efforts, and provides experiential learning opportunities for engineering and technology students at FSU.

Performance data collected in real time over twelve months show that the hybrid system operates reliably, even in the highly variable weather conditions of the Appalachian region. The system achieved a combined annual energy production of approximately 2.9 MWh. The economic analysis reveals a levelized cost of energy (LCOE) of $0.56 per kilowatt-hour (kWh), with projected payback periods ranging from 12 to 25 years, depending on electricity price scenarios. Beyond technical validation, the system serves as a living laboratory, integrating operational data into undergraduate engineering curricula and supporting regional workforce development initiatives, thereby enhancing its educational and regional benefits. The primary contribution of this case study is the integration, deployment, and year-round analysis of a residential-scale hybrid PV–wind system, providing validated performance data from an Appalachian high-elevation environment. The work further contributes an educational model that links real system data with engineering coursework and hands-on learning at FSU.

Key words. Hybrid, photovoltaic, PV array, thermostat, auto generator, Solar charger

Abbreviation	:	Definitions
CPDAM	:	Center of product design and advance manufacturing
MPPT	:	Maximum Power production tracking
SCC	:	Solar charger control
PV	:	photovoltaic
FSU	:	Frostburg State University
MEA	:	Marland Energy Administration

1 Introduction

CPDAM is dedicated to creating a state-of-the-art equipment and testing laboratory that is accessible to the region's industry, community, FSU employees, and students. Our goal is to provide comprehensive services to businesses of all sizes small, medium, and large to support their growth and innovation. We are particularly focused on assisting startup companies in the region with product development, offering expertise and resources to help bring their ideas to life. Additionally, we offer training and workshops on the use of advanced equipment and software, benefiting the industry, community, and FSU members. We actively seek partnerships with local businesses, industry leaders, and community organizations to expand our impact and foster collaborative innovation. This center actively engages students in real-world, cutting-edge knowledge related to system and product design, as well as advanced manufacturing. We invite industry professionals, community members, and FSU partners to collaborate with our faculty, staff, and students to foster innovation and excellence in every project we undertake as shown in Figure 1 and 2 [1],[2].

While many hybrids renewable systems have been simulated extensively in the literature, there remains limited real-world performance data for small, residential-scale hybrid PV–wind systems deployed in high-elevation Appalachian regions. This project addresses that gap by presenting a full-scale installation, system integration, and a 12-month performance evaluation based on real operating data from CPDAM at Frostburg State University.

While many studies have explored the performance of simulation-based hybrid photovoltaic (PV) and wind systems, there is a notable lack of experimental validation for small-scale residential hybrid systems in the high-elevation climates of the Appalachian region. This gap highlights the importance of this research work, making the researchers feel that their expertise is both relevant and necessary. This case study effectively addresses this shortcoming by providing concrete performance metrics, insightful economic outcomes, and significant educational impacts derived from the full-scale deployment of the hybrid system.

Fig.1 center of Product Design and Advance Manufacturing

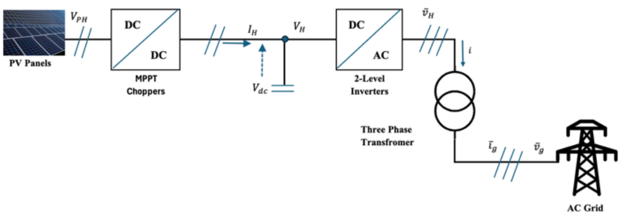


Fig.2 Solar system power generation schematic

A. *Hybrid System Design and Site Selection*

The initial requirements for the system have been clearly articulated in the interagency agreement between MEA and FSU. This agreement outlines the establishment of a grid-tied hybrid demonstration system featuring approximately 2 kW of photovoltaic (PV) energy and 1.8 kW of wind power to supply a small building effectively. With the size and configuration firmly established, the project's design phase has been streamlined to focus on selecting optimal locations and components, proposed location are described below in Figure 3. This project aims to showcase a compelling residential application, with four strategically chosen structures on the FSU campus equipped with a robust 120/240-volt distribution system [3].

To rigorously assess the wind and solar resources available at these sites, we have installed three state-of-the-art Davis Weather Pro® weather stations at locations 2, 3, and Tawes Hall. Given their proximity, Tawes Hall is assumed to experience weather conditions akin to those at locations 1 and 4, ensuring a comprehensive comparison. Each weather station is outfitted with an anemometer and a wind direction gauge, while the stations at Tawes Hall and Location 3 are further enhanced with solar radiation sensors. These stations seamlessly communicate with data loggers housed in a wireless console unit, which are configured to record all pertinent weather data synchronously every 5 minutes [4]. As illustrated in Figure 4, high-speed winds are observed more frequently at locations 1 and 4, a finding consistent with the higher elevation of these sites compared to locations 2 and 3. This vital data positions us to make informed decisions and optimize the hybrid system's efficacy, underscoring the project's potential impact. The choice of a 45-foot monopole tower represents a balance between better wind exposure and the specific zoning, structural, and aesthetic constraints of the site. Likewise, the selection of the 1.8-kW downwind turbine was based on its low cut-in speed, built-in inverter design, and its appropriateness for grid-connected residential use, rather than just its peak rated power.

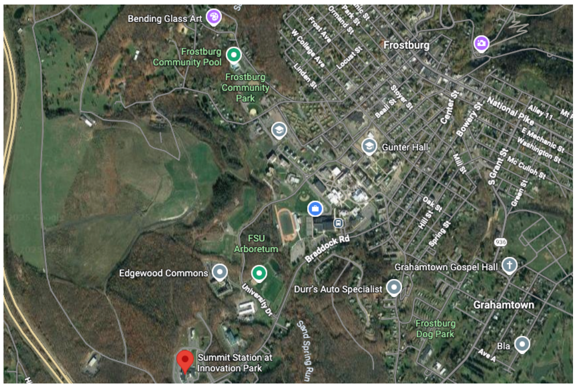
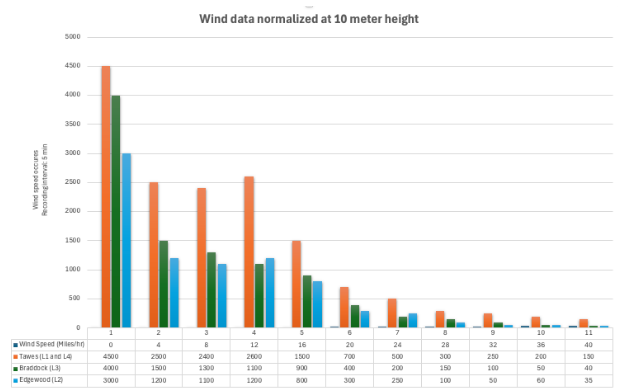


Figure 3 shows the possible location of the CPDAM (Google Earth)



	1	2	3	4	5	6	7	8	9	10	11
Wind Speed (Miles/hr)	0	4	8	12	16	20	24	28	32	36	40
Tawes (L1 and L4)	4500	2500	2400	2600	1500	700	500	300	250	200	150
Braddock (L3)	4000	1500	1300	1100	900	400	200	150	100	50	40
Edgewood (L2)	3000	1200	1100	1200	800	300	250	100	50	60	35

Figure 4 Wind data normalized at 10-meter height

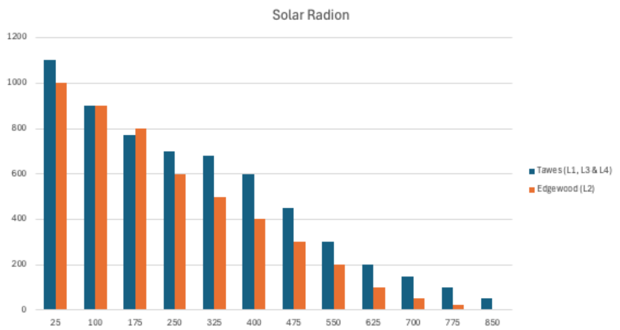


Figure 5 Solar Radiation at different location

The building's south-facing roof with a 45-degree tilt offers nearly optimal conditions for photovoltaic (PV) generation at this latitude. To evaluate the solar energy potential accurately, we utilized Asset® software, which analyzes the panoramic view for the solar array and incorporates a 30[3]-year solar insolation database from the PV Performance Calculator by the National Renewable Energy Laboratory, providing detailed technical insights for system design [5].

The site assessment findings, illustrated in Figure 5, provide significant insights into the building's solar potential. While the surrounding buildings and trees introduce an average shading of 14% throughout the year, the site still benefits from an impressive average of 3.61 hours of direct sunlight per day. The PV array consists of ten high-performance modules, as detailed in Table 1, mounted flush on the south-facing roof to maximize energy capture. The system's operation is managed by the HIP 200 BA3 control system, ensuring efficient and reliable performance, which underscores the system's design robustness and sustainability benefits. The electrical characteristics of the selected wind power turbine are shown in Table 2. The selected product has an inverter enclosed in the nacelle and provides a 12/240 60 Hz output for direct grid connection [6].

Table No.1 Electrical characteristics of PV Based

Rated Power	P_{MAX}	W	200
Maximum Power Delivery voltage	V_{PMX}	V	55.8
Maximum Power current flow	I_{PM}	A	3.59
Open circuit voltage	V_{OC}	V	68.7
Short circuit current	I_{SC}	A	3.83
Minimum Power	P_{MIN}	W	180
Maximum system voltage	V_{SYS}	V	600
Cell Efficiency		%	19.7
Module Efficiency		%	17
Power per square foot		W	15.8

Table No.2 Electrical characteristics of Wind Turbine

Rated Power	1.8 kW
Weight	154. | 70 Lbs/kg
Rotor Diameter	12 | 3.72 Ft/m
Swept Area	68.7 Ft^2/m^2
Type	Downwind rotor with stall regulation control
Direction of Rotation	Clockwise looking upwind
Blade material	Fiberglass reinforced composite
Number of Blades	3
Rated Speed	50-325 rpm
Tip Speed	66-213 f/s 9.7 63 m/s
Alternator	Spotless permanent magnet brushless
Ya control	Passive
Grid feeding	120/240 VAC 50-60 Hz inverter enclosed
Braking system	Electronic stall regulation w/ redundant relay switch
Cut in wind speed	8 mph | 3.5 m/s
Rated wind speed	20 mph | n9 m/s
Survival wind speed	140 mph | 63 m/s

2 Hybrid System Installation

A. System overview

This power system offers a versatile, adaptable solution, featuring devices, components, and optional accessories that can be tailored for any application—whether off-grid, grid-tied, or backup. It supports up to four inverters in parallel, enabling users to confidently scale to larger 120/240-volt, 3-wire, single-phase systems and ensuring reliable performance for diverse energy needs at CPDAM FSU. Figure 6 illustrates the configuration of the solar panel equipment, while Figure 7 depicts the wind power delivery equipment configuration [7].

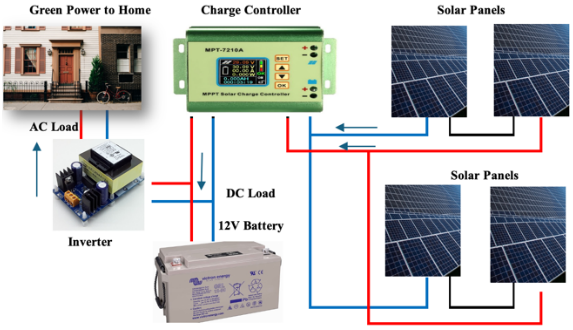


Figure 6: Power System Installation Diagram – Solar Power

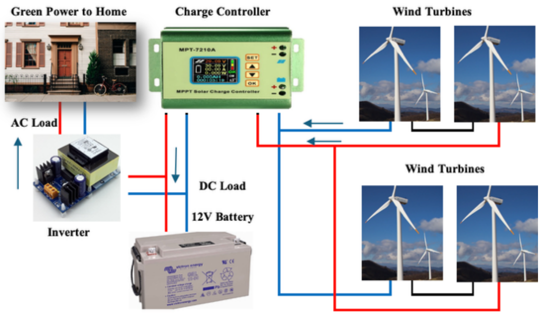


Figure 7: Power System Installation Diagram – Wind Power

B. System Modeling and Sizing Methodology

The hybrid system was sized based on a combination of measured resource availability, building load requirements, and regional solar–wind complementarity. Solar potential was evaluated using 30-year NREL insolation data combined with shading analysis, which indicated an average of 3.61 peak sun-hours per day and approximately 14% annual shading losses at the selected south-facing roof (45° tilt). Using these parameters, a 2-kW PV array was selected to achieve an expected monthly energy yield between 90–120 kWh, consistent with Appalachian solar resource levels. Wind resources were analyzed using three Davis Weather Pro® stations installed across campus, with normalized 10-m wind speeds consistently higher at elevated locations (Figure 4). The measured wind regime supported the selection of a 1.8-kW downwind turbine with a cut-in speed of 3.5 m/s and a rated output at 9 m/s. This configuration was projected to generate 60–140 kWh per month depending on seasonal wind variation.

The combined system was modeled to ensure complementary generation, where solar dominates during summer while wind compensates during winter months. Expected hybrid output was matched against the small building's load profile to ensure the system could offset a substantial portion of annual energy consumption while maintaining grid-interactive capability and net-metering compatibility. This modeling framework established the design envelope prior to installation and provided the baseline for later performance validation.

The energy outputs generated by the model were rigorously validated against actual production data, with deviations consistently confined to within ±10% on a seasonal basis. This impressive correlation not only underscores the reliability of the sizing methodology but also bolsters its applicability for similar residential hybrid systems in comparable climatic conditions.

3 Hybrid System Installation cost analysis

All cost calculations are based on constant real dollars, deliberately excluding financing costs and tax depreciation effects. Labor costs are allocated proportionally between the photovoltaic (PV) and wind subsystems, determined by their installation complexity. Furthermore, maintenance costs are excluded to ensure a clear focus on the effects of capital costs. This section presents cost analysis based on the initial cost of the Wise system cost of the grid energy. The actual expenditure for the equipment, delivery and installation Hybrid system components is presented in Table 2.

Table No.2. Equipment and installation cost.

Item Description	Amount paid ($)
Wind turbine including inverter	4.024
Tower for wind Turbine	3,300
PV, panels, mounting racks, mechanical supply and inverters	13,730
Labor (PV and Windmill) Installation	11,403
PV cost (Assuming 1/3 of labor)	17,531
Windmill cost (Assuming 2/3 of labor)	14,926
Hybrid Generation System Cost	32, 457

The manufacturer's warranty covers the PV panel for 25 years and the Slipstream 3.7 windmill for 5 years. The electrotechnical components included in the wind turbine and blades have a service life of over 20 years. However, due to moving parts, the system will require maintenance and some replacements. The expected service life of components such as the mechanical fixtures, wind turbine tower, inverters, and switches typically exceeds 20 years. The unit energy cost (in $/kWh), shown in Table No. 3, is calculated based on an assumed 20-year service life for the hybrid system. Manufacturer costs have been excluded from this calculation. Total lifetime generation is estimated based on 8 months of actual generation data, including projected generation from May through September. A more accurate estimate can be obtained after at least 1 year of data collection.

Table No.3 Cost per unit power and Energy

	PV	Wind	Hybrid
Cost	17,531	14926	32457
kWh/yr	2162	722	2884
Lifetime generation (kWh)	43240	14440	57680
$/W	8.77	8.29	8.54
$/kWh	0.41	1.03	0.56

Above table indicates that the cost per installed unit of power ($/kW) for photovoltaic (PV) systems and wind turbines is comparable. However, the cost of energy produced per unit ($/kWh) over the 20-year lifetime of the systems is $0.41 for PV and $1.03 for wind. The higher energy cost for wind is primarily due to the specific wind conditions at the Hybrid site and the tower height of 45 feet.

[1] https://www.eia.gov/electricity/monthly/

Improved wind exposure could lead to a decrease in the energy production cost from the wind turbine. The PV array installed on the roof of Fuller House experiences 14% shading, which significantly affects energy generation, especially during winter. Enhancing the capture of available solar radiation would lower the cost per kilowatt-hour (kWh). To better estimate the cost of grid energy over the next twenty years, we consider the trend in electricity prices from 2015 to 2024. Energy data from the Energy Information Agency's Electric Power Monthly website is used to analyze these price trends. Figure 8 and 9 displays the yearly fluctuation and monthly average price from 2022-2025.

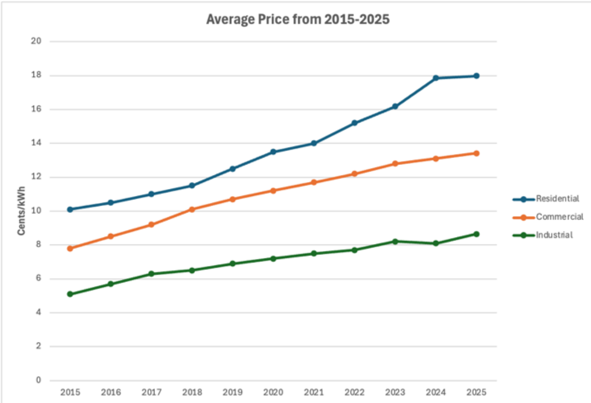


Figure 8[1]: shows the yearly fluctuation of the electricity price for each sector

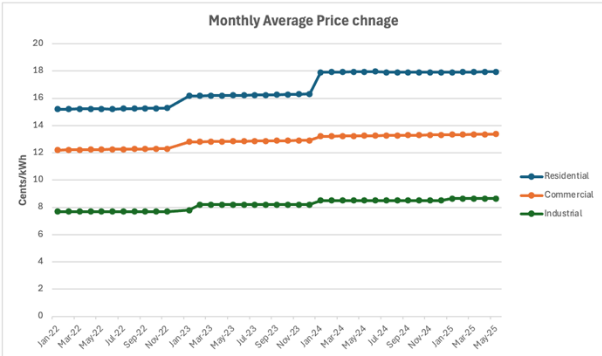


Figure 9[2]: shows the monthly average price of electricity for end users

The average residential electricity price per kWh in Maryland is projected to rise from 12.11 cents in 2020 to 17.98 cents by 2025. This represents a 34% increase, considerably higher than the national average. To estimate the payback period for residential energy generation systems in Maryland, three scenarios were analyzed. Scenario 1 assumes a constant annual increase in energy prices of 5% over the next 20 years. Scenario 2 assumes an 8% yearly price increase, slightly above the national average. Scenario 3 anticipates a 10% annual price increase over the same period. Figures 11, 12, and 13 illustrate the payback scenarios for photovoltaic (PV), wind, and hybrid generation systems. In all calculations, the average residential electricity price in Maryland for 2024-2025 (17.98 cents per kWh) has been used. The PV payback plots include scenarios both with and without a

[2] https://www.eia.gov/electricity/monthly/

$3,000 state incentive for residential users. This incentive can reduce the payback period by 2 to 3 years, depending on the rate of increase in electricity prices.

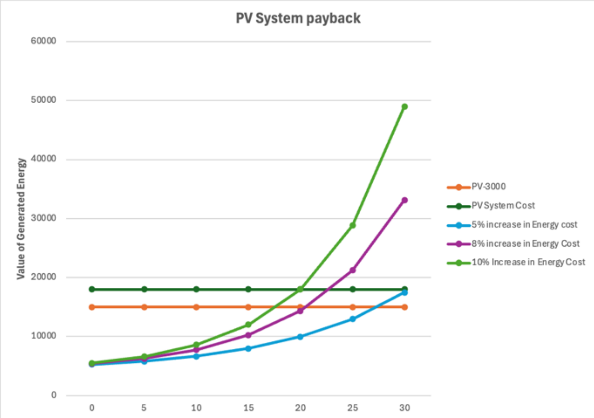


Figure 11 PV system payback scenarios

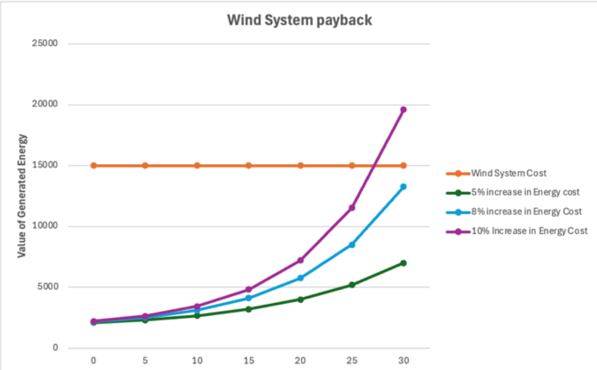


Figure 12 Wind system payback scenarios

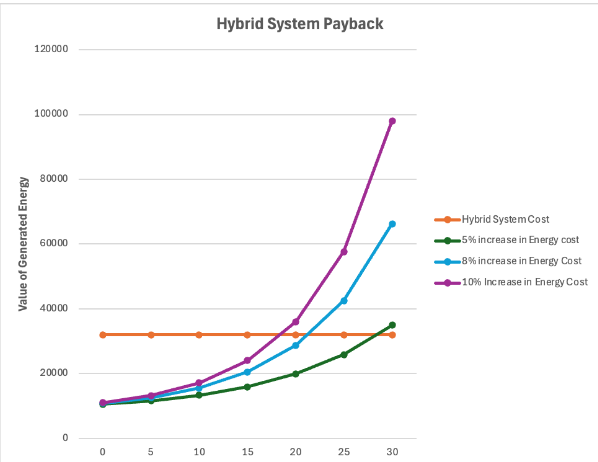


Figure 13 Hybrid system payback scenarios

The findings indicate that photovoltaic systems are generally more economically advantageous than small wind systems under the prevailing conditions in Maryland. Nonetheless, a hybrid configuration offers enhanced resilience to seasonal variability and protects against future price fluctuations. This implies that the hybrid system should be regarded as a solution focused on reliability, rather than solely a means of minimizing costs.

4 Education outcomes of the project

The hybrid renewable energy installation serves as a pedagogical testbed, facilitating data-driven instruction in energy systems modeling, techno-economic analysis, and sustainability assessment. Students directly engage with operational datasets, strengthening the connection between theoretical coursework and real-world system behavior.

Students will develop essential skills to critically evaluate the technical and practical feasibility of hybrid renewable energy systems by analyzing data from an innovative real-world installation featuring a 2-kW solar photovoltaic array and a 1.8-kW wind turbine. Through this compelling case study, they will explore energy production trends, assess the reliability of the system, and understand how grid-connected net metering supports self-sustaining energy operations. This project has sparked significant interest in wind and solar energy at Frostburg State University. Faculty members from various disciplines, such as sociology, English, geography, and interdisciplinary studies, have assigned term projects and discussions related to wind and solar energy, including:

- *ENES320: Wind/Solar-Powered Generation System Design*
- *ENES401: Fundamentals of Energy Engineering*
- *ENGL338: Technical Writing*

Additionally, students will enhance their ability to compare cutting-edge renewable energy technologies, calculate the balance between energy demand and generation, and identify key factors influencing system performance, such as environmental conditions, equipment configuration, and load characteristics. By the end of this module, students will be empowered to apply sustainability principles to engineering design decisions and propose strategic solutions for optimizing small-scale hybrid energy systems tailored for educational, residential, or community use

5 Results and Discussion

Figures 13 and 14 vividly illustrate the monthly and annual fluctuations in wholesale electricity prices, meticulously categorized by region and peak demand levels. Between October 2024 and October 2025, we predict substantial price hikes that will affect consumers across various sectors:

Residential electricity rates are set to experience a notable increase of 5.2%, rising from 17.02 to 17.98 cents per kilowatt-hour (kWh). This shift will likely prompt households to reconsider their energy consumption habits and budgeting strategies.

Commercial rates are expected to escalate by 4.0%, moving from 12.89 to 13.41 cents per kWh. As businesses face rising operational costs, they may need to explore energy efficiency solutions to offset these increases.

Industrial rates could surge significantly by 6.7%, advancing from 8.11 to 8.65 cents per kWh. Recognizing this change can help industrial entities prepare effectively, reducing uncertainty and fostering confidence in their planning processes.

These projected increases in electricity prices highlight the necessity for all consumers to stay informed and to actively plan and manage their energy use wisely in the coming months, empowering them to control their costs.

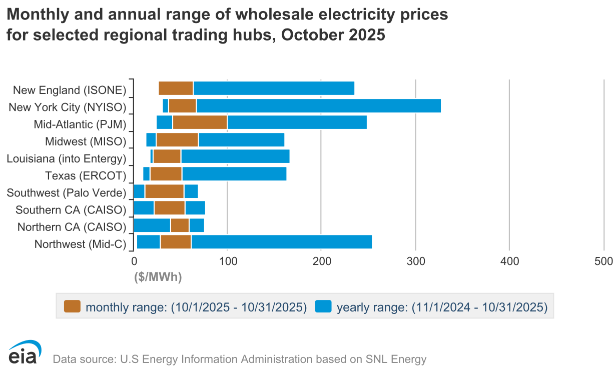


Figure 13: Power Delivery in the Month of January

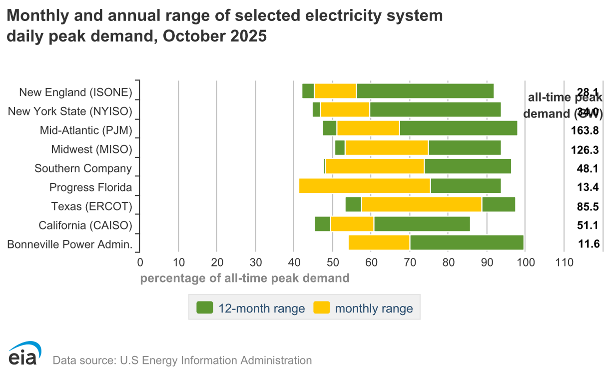


Figure 14: Power Delivery in the Month of January

6 Conclusion

The FSU Hybrid Power Generation System has convincingly demonstrated the effectiveness of residential wind and solar energy solutions in Western Maryland. Despite some challenges regarding wind availability and shading, this system represents a strong investment opportunity for homeowners eager to embrace sustainable energy. The photovoltaic (PV) component has delivered impressive results, with a payback period ranging from 12 to 25 years, influenced by rising electricity prices and favorable state incentives. The growing PV market offers homeowners benefits such as straightforward installation, low maintenance requirements, a robust 25-year warranty, and minimal visual impact. These qualities make solar energy an attractive option for residential power generation in the region.

On the other hand, the wind turbine has not met initial efficiency expectations due to its location, where nearby buildings and trees restrict optimal wind flow. Nevertheless, the small wind turbine market is expanding rapidly, with innovative models like the Skystream 3.7 providing easy installation and plug-and-play convenience, even if they lack the versatility of PV systems.

Leveraging both wind and PV power generation presents an excellent strategy to maximize energy output throughout the year. During the winter months, when solar energy production dips, the wind turbine can significantly enhance energy generation. While wind energy is consistently available during the day, solar energy generation stops at night. By adopting a well-balanced mix of wind and PV systems tailored to their residential energy needs, homeowners can effectively lower their cost per kilowatt-hour and secure a sustainable energy future—truly a win-win for their wallets and the environment.

References

[1]. Jamil Abdo & Tariq Masood "New Technique to develop Intelligent, highly reliable & Efficient Unmanned Power Generation Modular" 22nd International Conference on Renewable Energies and Power Quality (ICREPQ'24) Bilbao (Spain), 26th to 28th June 2024

[2]. Devan P. K., Bibin C., Krrishana A. G., et al., "A comprehensive review on solar tricycles," Materials Today: Proceedings, 2020. https://doi.org/10.1016/j.matpr.2020.03.826

[3]. Masud M. H., Akhter M. S., Islam S., et al., "Design, Construction and Performance Study of a Solar Assisted Tri-cycle," Periodica Polytechnica Mechanical Engineering, 61(3), 234–241 (2017). https://doi.org/10.3311/PPme.10240

[4]. Sharma P., Mishra R. K., "Comprehensive study on photovoltaic cell's generation and factors affecting its performance: A Review," Materials for Renewable and Sustainable Energy, 14(1) (2025). https://doi.org/10.1007/s40243-024-00292-5

[5]. Strojny P., "Study on the efficiency of small-scale wind turbine with rotor adapted for low wind speeds," Bulletin of the Polish Academy of Sciences: Technical Sciences, 72(6) (2024). https://doi.org/10.24425/bpasts.2024.151954

[6]. Ahmad M., Shahzad A., Shah S. I. A., "Experimental investigation and analysis of proposed hybrid vertical axis wind turbine design," Energy & Environment, 36(2) (2025). https://doi.org/10.1177/0958305X231181675

[7]. Kening Fu;Yanbing Jia;Xiaoqing Han "Study on Wind Power Consumption Capacity of Power Grid Considering Risk and Unit Commitment published in 2018 IEEE Power & Energy Society General Meeting (PESGM)

[8]. Fei Cao;Jialing Qiu;Zixu Jing "Performance simulation and distribution strategy of solar and wind coupled power generation systems in Northwest China Published 2020 12th IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)

[9]. Shi Xuewei;Shi Xuefang;Dong Wenqi "Research on Energy Storage Configuration Method Based on Wind and Solar Volatility" Published in 2020 10th International Conference on Power and Energy Systems (ICPES)

[10]. Homod M. Ghazal;Khalid A. Khan;Fahad Alismail; Maximizing Capacity Credit in Generation Expansion Planning for Wind Power Generation and Compressed Air Energy Storage System published in 2021 IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe)

[11]. Jamil Abdo & Tariq Masood "Techno Economics Analysis to Reshape Global Clean and Green Energy" 22nd

International Conference on Renewable Energies and Power Quality (ICREPQ'24) Bilbao (Spain), June 2024

[12]. Tariq Masood & Jamil Abdo "New Technique to Enhance Hybrid Renewable Energy Resources' Operational Flexibility and Reliability" 22nd International Conference on Renewable Energies and Power Quality (ICREPQ'24) Bilbao (Spain), June 2024

[13]. Ma S., Li J., Li G., et al., "Design of optimal controller for photovoltaic maximum power point tracking applications," Energy Sources, Part A: Recovery, Utilization, and Environmental Effects (2022). https://doi.org/10.1080/15567036.2022.2028937