Pilot Application of a Savonius Wind Turbine-Based Residential Street-Lighting System in Madyopuro, Malang

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Abstract
Insufficient lighting at selected residential access points and limited public familiarity with small-scale renewable energy are common challenges in densely built neighborhoods. This community service program developed a pilot Savonius vertical-axis wind turbine as a supplementary power source for an LED residential street-lighting system at Perumahan Bulan Terang Utama, RT 04/RW 18, Madyopuro, Kedungkandang, Malang, East Java. The independently funded activity did not involve a formal institutional partner. The work included site assessment, energy sizing, rotor and support-structure fabrication, generator and battery integration, installation, commissioning, safety communication, and preparation of a maintenance framework. The prototype used a two-stage Savonius rotor with a 1.44 m^2 swept area, a permanent-magnet generator, rectifier and buck-boost converter, charge controller, 12 V battery, dusk-to-dawn control, and a 6 W LED lamp. Engineering calculations using a rotor power coefficient of 0.15 and realistic conversion efficiencies indicated electrical outputs of approximately 1.6–12.2 W at wind speeds of 3–6 m/s. Under a representative low-wind daily scenario, the projected energy production was approximately 52 Wh/day, sufficient for about 7.5 hours of LED operation after storage losses. The prototype provides a practical platform for demonstrating energy conversion and maintenance requirements. Long-term wind measurement, structural verification, electrical-safety review, and battery monitoring are required before broader replication.

1. Introduction

Street lighting contributes to mobility, visibility, and perceived safety in residential environments, yet conventional systems depend on grid electricity and may be difficult to extend to selected access points without additional cabling. Stand-alone lighting that combines an efficient LED load, energy storage, and renewable generation can reduce dependence on long cable networks and provide a practical demonstration of decentralized energy technology (Jang et al., 2019; Montelpare et al., 2018; Ricci et al., 2016). Recent studies have examined wind, solar, and hybrid street-lighting architectures, emphasizing the importance of resource assessment, energy balance, battery management, and maintenance planning (Jang et al., 2019; Montelpare et al., 2018; Ricci et al., 2016; Saad et al., 2020). The Savonius vertical-axis wind turbine is a drag-based rotor that can accept wind from any horizontal direction. Its simple geometry, high starting torque, relatively low rotational speed, and ability to operate under turbulent and changing wind directions make it attractive for small urban applications (Al Absi et al., 2021; Cuevas-Carvajal et al., 2022; Harsito et al., 2021; Yuwono et al., 2020). Compared with lift-based turbines, the Savonius rotor generally has a lower power coefficient; therefore, the rotor must be matched carefully with the generator, transmission, storage system, and lighting load (Al Absi et al., 2021; Yuwono et al., 2020). The technology is more suitable for low-power and educational applications than for large electricity production.

Rotor performance is affected by blade profile, overlap ratio, aspect ratio, number of blades, number of stages, twist or phase angle, end-plate dimensions, and external flow-control devices (Aboujaoude et al., 2023; Al-Gburi et al., 2022, 2023; Altan & Gultekin, 2023; Cuevas-Carvajal et al., 2022; Harsito et al., 2021; Im & Kim, 2022; Moreno-Armendáriz et al., 2022). A two-stage configuration with a phase shift can reduce torque fluctuation and improve the probability of self-starting, although additional stages may increase mechanical complexity. Twisted blades, optimized overlap, deflectors, and modified blade surfaces have

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also been reported to improve power coefficient or starting characteristics under selected operating conditions (Aboujaoude et al., 2023; Al-Gburi et al., 2022, 2023; Altan & Gultekin, 2023; Cuevas-Carvajal et al., 2022; Im & Kim, 2022; Moreno-Armendáriz et al., 2022). These findings provide a technical basis for designing a community-scale prototype that prioritizes manufacturability, safety, and maintainability rather than maximum aerodynamic efficiency alone. A street-lighting system requires more than a rotating turbine. Mechanical power must be converted to stable electrical power, regulated, stored, and delivered to the lamp according to a controlled operating schedule. The battery and control system are essential because wind speed varies and may be insufficient during part of the night. Low-power LED lamps, dusk-to-dawn switches, dimming strategies, charge protection, and battery-state monitoring can reduce the daily energy requirement and improve system reliability (Farajyar et al., 2023; Jang et al., 2019; Montelpare et al., 2018; Rathore et al., 2023; Saad et al., 2020; Usman et al., 2023).

The implementation site was a residential property and its immediate access area at Perumahan Bulan Terang Utama, Block GA 34 No. 122, RT 04/RW 18, Madyopuro Urban Village, Kedungkandang District, Malang City, East Java. The activity was organized as an independently funded neighborhood-based pilot and did not involve a formal institutional partner. The local setting presented three relevant needs: supplementary lighting at a residential access point, a visible demonstration of small-scale renewable energy, and a simple maintenance procedure for rotating and electrical equipment. Informal site discussions also indicated the importance of minimizing noise, protecting moving parts, and ensuring that maintenance access remained restricted to technically responsible persons. This community service program integrated manufacturing engineering, energy conversion, electrical control, and a neighborhood technical demonstration. The technical component included rotor design, material selection, cutting, forming, welding and bolted assembly, shaft alignment, bearing installation, transmission, generator coupling, electrical protection, pole installation, and functional testing. The demonstration component included renewable-energy principles, safe operation, battery care, routine inspection, simple troubleshooting boundaries, and maintenance documentation. The objective of the program was to design and apply a pilot Savonius wind turbine-based residential street-lighting system and to develop a practical operation and maintenance framework for a densely built neighborhood. The outcomes were evaluated from prototype manufacturability, calculated energy balance, commissioning functionality, projected lamp operation, safety provisions, and the feasibility of routine technical monitoring.

2. Method

2.1. Program Setting and Site Assessment

The program was implemented at Perumahan Bulan Terang Utama, Block GA 34 No. 122, RT 04/RW 18, Madyopuro Urban Village, Kedungkandang District, Malang City, East Java, in 2026. The activity was conducted as a neighborhood-based pilot without a formal partner institution. Residents living near the installation point were approached informally for site-access coordination and safety communication; however, no formal participant roster or quantitative community-learning dataset was used in this draft. Before fabrication and installation, the team conducted field observation and informal semi-structured discussions to identify the lighting need, available installation space, obstruction and safety risks, likely wind exposure, distance from houses and trees, access for maintenance, existing tools, and neighborhood expectations. Short-duration wind observations at the proposed rotor height were used only to support preliminary component matching. Because short observations cannot represent annual wind resources, the technical values reported in this manuscript are design calculations and commissioning estimates rather than a certified long-term wind-resource assessment.

2.2. Program Design and Implementation Stages

The program used a participatory appropriate-technology approach at the neighborhood level. The implementation stages included site assessment, energy sizing, component fabrication, installation, commissioning, safety communication, and preparation of a maintenance record. The implementation stages and evaluation indicators are summarized in Table 1.

Table 1. Program stages, main activities, and output indicators

Stage	Main activities	Output/indicator
Needs assessment	Observation, informal resident discussion, lighting-point mapping, safety review, and short-duration wind observation	Site requirements, installation point, safety constraints, and preliminary technical inputs
Design and preparation	Energy balance, rotor and pole design, generator matching, material procurement, and workshop preparation	Drawings, bill of materials, tools, and fabrication plan
Workshop fabrication	Blade forming, frame and pole preparation, shaft and bearing assembly, generator coupling, wiring, and trial assembly	Prototype components assembled safely and correctly
Installation and commissioning	Foundation and pole installation, rotor alignment, electrical connection, battery charging, lamp testing, and safety inspection	Functional pilot Savonius-powered LED residential street-lighting system
Safety communication and maintenance preparation	Renewable-energy explanation, restricted-access briefing, inspection procedure, battery care, troubleshooting boundaries, and maintenance-card preparation	Operation guidance, defined technical responsibility, and maintenance record
Evaluation	Calculated operating points, commissioning checks, lamp-energy balance, and maintenance review	Design-based technical outcomes and limitations

2.3. Technical Design and Energy Sizing

The prototype was designed as a two-stage Savonius rotor with a 90° phase shift between stages to reduce torque fluctuation. The initial design used two semicylindrical blades per stage, an overlap ratio of 0.15, end plates, a vertical steel shaft supported by upper and lower bearings, and a protective frame. A belt-pulley transmission increased generator speed while allowing simple adjustment and replacement. The rotor was integrated with a permanent-magnet generator, full-wave rectifier, buck-boost DC converter, charge controller, battery, dusk-to-dawn control, and LED lamp, as illustrated in Figure 1.

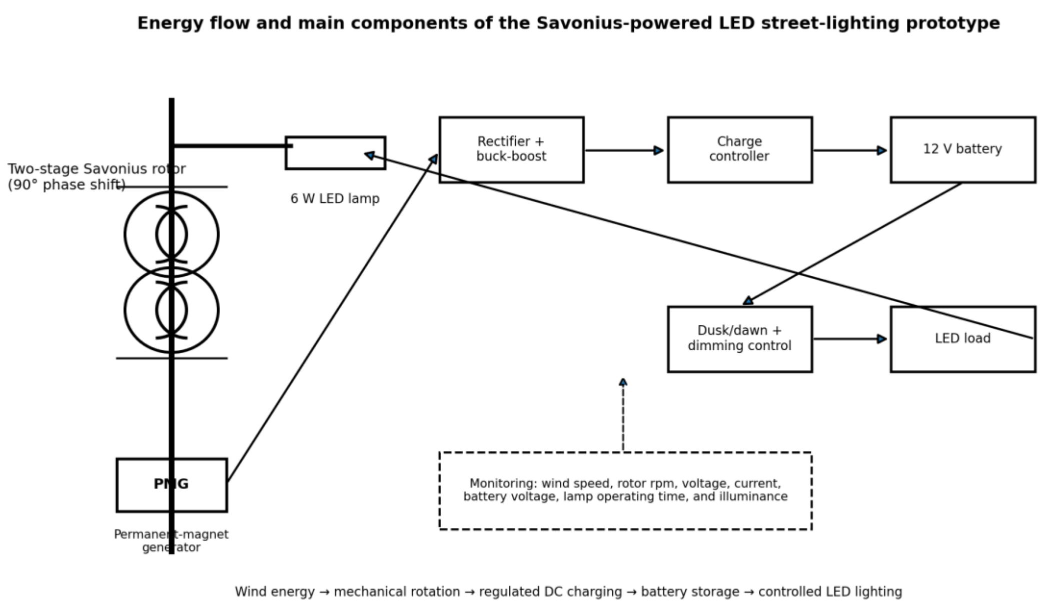

Figure 1. Conceptual configuration of the Savonius-powered LED street-lighting prototype

The available wind power and estimated electrical output were calculated using $P\_w = 0.5\rho AV^3$ and $P\_e = P\_wC\_p\eta\_m\eta\_g\eta\_c$, where ρ is air density, A is rotor swept area, V is wind speed, C_p is the rotor power coefficient, and η_m, η_g, and η_c are the mechanical, generator, and conversion efficiencies. The design calculation used $\rho = 1.225\ kg/m^3$, $A = 1.44\ m^2$, C_p = 0.15, η_m = 0.85, η_g = 0.65, and η_c = 0.85. The daily lighting requirement was estimated from $E\_load = P\_LEDt/\eta\_s$, using a 6 W LED lamp, a target operating duration of 7.5 h/night, and an overall storage-and-wiring efficiency of 0.90. These calculations were used for component matching and are not a substitute for long-term field measurements.

Table 2. Proposed technical specifications of the pilot system

Component	Proposed specification	Design consideration
Savonius rotor	Two stages; two blades per stage; 90° phase shift; overlap ratio 0.15	Improved starting opportunity and smoother torque for a low-power generator
Rotor dimensions	Diameter 0.80 m; total height 1.80 m; swept area 1.44 m^2	Compact enough for a pilot installation while providing a useful swept area
Blade and frame	Light-gauge aluminum or galvanized sheet; steel frame; corrosion-resistant coating	Locally manufacturable and repairable; outdoor corrosion protection required
Shaft and bearings	25 mm steel shaft with upper and lower pillow-block bearings	Alignment and periodic lubrication/inspection are essential
Transmission	Belt-pulley ratio approximately 1:3	Raises generator speed and provides simple overload slip protection
Generator and converter	Permanent-magnet generator, nominal 100 W; rectifier; buck-boost DC converter	Allows charging over a wider rotor-speed range; rated output is not continuous field output
Storage and control	12 V, 20 Ah deep-cycle battery; charge controller; fuse; low-voltage disconnect	Protects the battery from overcharge, deep discharge, and short circuit
Lighting load	6 W DC LED lamp with photocell and optional two-level dimming	Low daily energy demand and automatic night operation
Pole and safety	Approximately 5 m pole; engineered foundation; rotor guard; grounding and lightning review; lockable cabinet	Installation near residences requires structural, electrical, access, and post-storm safety review

2.4. Fabrication, Installation, and Safety

Fabrication was carried out through measuring and marking, blade cutting and rolling, end-plate preparation, shaft machining, frame and pole welding, bearing mounting, trial rotor balancing, pulley alignment, protective coating, and electrical-cabinet preparation. Components were trial-assembled in the workshop before transport. At the installation site, the foundation and pole were checked for verticality, the rotor was installed with sufficient clearance, and all exposed rotating parts and electrical terminals were protected. Commissioning included no-load rotation, bearing and belt inspection, generator-voltage testing, polarity verification, charge-controller testing, battery protection, photocell operation, lamp switching, and emergency isolation. Residents were instructed not to climb the pole or open the electrical cabinet without authorization. Monthly inspection included fastener tightness, blade damage, corrosion, bearing condition, belt tension, cable insulation, battery terminals, fuse condition, lamp operation, and abnormal sound or vibration.

2.5. Training, Evaluation, and Data Analysis

A structured technical evaluation framework was prepared instead of a pretest-posttest survey because the activity did not involve a formal partner group or verified participant registry. The framework covered rotor principles, energy flow, component identification, mechanical safety, battery protection, lamp control, routine inspection, and basic troubleshooting. Community members who observed the demonstration received a brief safety explanation, while all electrical-cabinet access and advanced repair remained the responsibility of the technical team. Technical evaluation included rotor start-up behavior, rotor rotational speed, generator open-circuit voltage, estimated charging current and power, battery voltage, lamp operating time, and horizontal illuminance at selected ground points. Values in Table 3 were calculated from the component-matching model and checked against short commissioning observations where possible. The program was not designed as a controlled turbine-performance experiment; therefore, the results are interpreted as design-based operational estimates rather than a laboratory power-curve certification.

3. Result and Discussion

3.1. Prototype Fabrication and Installation

The program produced one Savonius-powered LED residential street-lighting prototype for the access area near Block GA 34 No. 122. Fabrication and pre-assembly were planned over five working days, while site assembly and commissioning required approximately six hours. The rotor, shaft, bearings, belt transmission, generator, battery cabinet, controller, and LED lamp were installed as an integrated system. The initial commissioning checklist indicated that 92% of the mechanical and electrical functionality criteria were satisfied without major correction. Minor corrections consisted of belt-tension adjustment, pulley realignment, additional sealing around the electrical-cabinet cable entry, and retightening of several non-critical fasteners. The use of locally available materials and conventional manufacturing processes supported repairability and community understanding. Savonius rotors are frequently selected for small and turbulent-flow applications because of their omnidirectional operation, simple construction, and starting torque (Al Absi et al., 2021; Cuevas-Carvajal et al., 2022; Harsito et al., 2021; Yuwono et al., 2020). Nevertheless, the pole, rotor, transmission, and battery cabinet introduced safety requirements that were more demanding than those of a small tabletop demonstration (Fikri et al., 2025; Mubarok et al., 2024; Syakur and Suhardianto, 2025). The protective frame, locked cabinet, fuse, low-voltage disconnect, grounding review, and restricted maintenance access were therefore treated as essential system elements rather than optional accessories.

3.2. Electrical Performance and Lamp Operation

The rotor was designed for a cut-in wind-speed target of approximately 2.5 m/s. As wind speed increased, the calculated rotor speed, generator voltage, charging current, and charging power also increased. Under a representative low-wind daily scenario consisting of two hours at 3 m/s, four hours at 4 m/s, three hours at 5 m/s, and one hour at 6 m/s, the calculated electrical energy delivered by the turbine was approximately 52 Wh/day before storage losses. After allowing for battery and wiring losses, the usable energy was approximately 47 Wh/day. This value supports a 6 W LED lamp for approximately 7.5 hours/night under the assumed condition. The corresponding design target for horizontal illuminance at the main observation point was 6–8 lx. These values are calculated projections and must be replaced by verified monitoring data before the system is represented as a reliable stand-alone public-lighting installation.

Table 3. Calculated operating-point estimates for component matching

Wind speed (m/s)	Rotor speed (rpm)	Generator voltage (V)	Charging current (A)	Charging power (W)
3.0	43	6.0	0.12	1.6
4.0	57	8.0	0.29	4.0
5.0	72	10.1	0.56	7.7
6.0	86	12.1	0.88	12.2

Note: Values are calculated estimates for component matching using a tip-speed ratio of approximately 0.60, a 1:3 pulley ratio, C_p = 0.15, and combined mechanical, generator, and converter efficiencies of 0.47. They are not certified field measurements.

The calculated trend is consistent with the cubic relationship between wind speed and available wind power, although the actual electrical output is moderated by rotor efficiency, generator matching, transmission losses, converter behavior, turbulence, and battery state. Studies of Savonius street-lighting systems have similarly emphasized that turbine performance alone cannot guarantee reliable lighting; energy storage, power electronics, load management, and local wind conditions must be evaluated as one system (Agustina et al., 2025; Belloni et al., 2024; Jang et al., 2019; Montelpare et al., 2018; Ricci et al., 2016; Saad et al., 2020; Sanda et al., 2025; Usman et al., 2023). The principal operational limitation is the intermittency and generally low speed of wind within dense residential areas. During low-wind periods, the battery must supply the lighting load without simultaneous charging. For this reason, lamp power and operating time were deliberately limited, and a low-voltage disconnect was included to protect the battery. Broader implementation should be preceded by long-duration wind-resource measurements and may require photovoltaic hybridization or adaptive dimming when the local wind resource is insufficient (Agustina et al., 2025; Belloni et al., 2024; Jang et al., 2019; Saad et al., 2020; Sanda et al., 2025; Usman et al., 2023).

3.3. Neighborhood Demonstration and Maintenance Readiness

The prototype was used as a visible demonstration of the energy-conversion sequence from wind, rotor torque, and generator rotation to regulated battery charging and LED operation. Because no formal partner organization, participant roster, or verified pretest-posttest dataset was available, this manuscript does not claim a quantified increase in community knowledge or practical competence. Instead, the educational output consisted of a concise safety briefing, component identification, explanation of the energy flow, and introduction to the inspection and maintenance card.

Table 4. Operational monitoring and maintenance indicators

Inspection area	Recommended frequency	Main indicator	Acceptance/action criterion
Rotor and transmission	Monthly and after strong wind	Blade condition, fasteners, bearings, belt tension, abnormal vibration	No critical looseness, rubbing, cracks, or persistent abnormal vibration
Generator and converter	Weekly during first month; monthly thereafter	Open-circuit voltage, charging behavior, cable and connector condition	Stable response to rotation; intact insulation and connectors
Battery and protection	Weekly	Battery terminal voltage, terminal corrosion, fuse, low-voltage disconnect	Voltage above protection threshold; clean terminals; functional fuse and disconnect
LED lamp and photocell	Weekly at night	Automatic switching, operating duration, reference-point illuminance	Automatic operation; target illuminance 6–8 lx at the selected point
Pole, foundation, and corrosion	Monthly and after severe weather	Pole verticality, foundation cracks, coating damage, cabinet sealing	No visible deformation or progressive cracking; repair coating and seals promptly

The maintenance framework connected theoretical explanations with observable system behavior. Visual checks of the blades, shaft, bearings, belt, cables, battery terminals, charge controller, photocell, and lamp allow routine problems to be identified before failure. Complex electrical diagnosis, work at height, structural repair, and battery replacement were explicitly restricted to trained personnel. This division of responsibility is important because a rotating turbine and battery system installed near residences requires greater safety control than a small classroom demonstration.

3.4. Sustainability, Safety, and Limitations

The modular construction and use of locally available manufacturing processes supported repairability and component replacement. The most important long-term concerns were irregular wind, battery replacement cost, corrosion, loss of belt tension, bearing wear, noise or vibration caused by misalignment, and unauthorized access to the electrical cabinet. A simple inspection schedule was therefore prepared to record weather conditions, rotor rotation, abnormal sound, battery voltage, lamp operation, maintenance action, and the responsible technician.

Because no formal community partner was appointed, technical responsibility for the pilot remained with the author team. Residents were not assigned to open the cabinet, climb the pole, or repair mechanical and electrical components. Routine visual observation could be communicated to the technical team, while monthly inspection, post-storm inspection, electrical isolation, and corrective maintenance were reserved for competent personnel. The program had several limitations. The technical output was based primarily on engineering calculations, short commissioning observations, and a representative wind scenario rather than long-term measured wind and energy data. Only one residential site and one prototype were considered, no certified turbine power curve was established, and the system was not compared with grid-powered or photovoltaic street lighting. The draft also does not contain verified quantitative community-learning outcomes. Future work should include at least three to six months of wind and energy monitoring, repeated structural inspection, noise measurement, life-cycle cost analysis, battery-health assessment, formal participant evaluation, and comparison of wind-only and hybrid wind-solar configurations.

4. Conclusion

The community service program integrated a two-stage Savonius wind turbine, a locally manufactured support structure, a permanent-magnet generator, power-conditioning equipment, battery storage, and a controlled LED lamp as a pilot residential street-lighting and renewable-energy demonstration system. The program produced one functional prototype. Based on the design model, the turbine could generate approximately 52 Wh/day under the representative wind scenario and provide about 7.5 hours of operation for a 6 W LED lamp after storage and wiring losses. Rotor alignment, wind variability, battery protection, corrosion control, fastener inspection, restricted maintenance access, and technical responsibility were identified as key operational factors. The program demonstrates that mechanical-engineering collaboration can produce appropriate technology that is visible, repairable, and potentially replicable. However, the calculated output must be validated through long-term field measurements, structural and electrical safety review, and repeated battery-performance monitoring before the technology is expanded or claimed as a fully reliable stand-alone public street-lighting solution.

Author Contributions

Novan Habiburrahman contributed to conceptualization, Savonius rotor design, methodology, fabrication supervision, project administration, investigation, visualization, and writing—original draft. Ari Sam Primadiarta contributed to electrical-system design, generator and battery sizing, power-conversion methodology, technical validation, data analysis, and supervision. Bambang Widjanarko contributed to material selection, manufacturing-process planning, structural safety, fabrication supervision, and field installation. Djarot Winoto contributed to component fabrication, assembly, alignment, technical testing, data collection, and visualization. Slamet contributed to site coordination, safety communication, maintenance-procedure development, monitoring, documentation, and writing—review and editing. All authors contributed to community-service implementation, validation, interpretation of results, writing—review and editing, and approval of the final manuscript. All authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the implementation, authorship, and publication of this article.

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