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Simulation and RETScreen-Based Assessment of a Solar-Wind Hybrid System for an off-grid Facility

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Abstract

In regions such as South Africa, where electricity supply is often unstable, hybrid energy systems offer a way to ensure a continuous power supply while utilising abundant renewable resources. The key research question was defined as, "How can a hybrid energy system integrating wind, solar, and gas be designed and optimized to provide continuous, cost-effective power for small businesses in South Africa?" Research has mainly focused on optimising the balance between energy generation, storage, and consumption to improve efficiency and reliability. Small businesses, particularly restaurants, face operational disruptions and rising costs due to unreliable electricity. Although solar and wind energy are abundant, their intermittent nature limits standalone viability, while high investment costs and financial risks hinder adoption. The absence of an integrated hybrid solution combining wind, solar, and biogas further exacerbates these challenges. It should be noted that the initial design of this study incorporated biogas as a third energy source alongside solar PV and wind, with the intention of modelling a fully hybrid three-source system. During the feasibility assessment phase, however, it became evident that a single restaurant does not generate sufficient organic waste to make biogas production practically viable. This study investigates how a hybrid system integrating wind, solar, and gas can provide continuous, cost-effective power for an off-grid restaurant in Cape Town. Using MATLAB Simulink as a simulation tool and Renewable Energy Technology Screen, system performance, cost, and reliability were analysed under varying environmental conditions. Results show that no configuration fully met the daily demand of 336.24 kWh; the best scenario produced 290.18 kWh/day, indicating the need for additional supply or storage. The findings highlight the complexity of achieving energy security and provide a framework for resilient hybrid energy strategies.

Keywords
Hybrid energy systems; Off-grid power; Renewable integration; Simulation; Small business optimization, Energy security

1. Introduction
The growing demand for sustainable and reliable energy solutions has led to significant advances in hybrid energy systems. Globally, the integration of renewable energy sources - such as wind and solar power - into conventional systems has proven to be a crucial strategy to combat energy insecurity and reduce greenhouse gas emissions. In regions such as South Africa, where electricity supply is often unstable , hybrid energy systems offer a way to ensure a continuous power supply while utilising abundant renewable resources. Research in this area has mainly focused on optimising the balance between energy generation, storage and consumption to improve efficiency and reliability. Innovations in system integration, energy storage technologies and automatic control mechanisms are paving the way for robust and scalable solutions (Gous and van Niekerk 2020; Nigam and Sharma 2022; Kusakana et al. 2012). The premises of the Department of Industrial Engineering at the Cape Peninsula University of Technology are used to work together on such projects. In particular, the Product Lifecycle Management Competency Centre (PLMCC) research area. The PLMCC is a dedicated training facility for students, technicians, technologists, engineers, and industrial designers specializing in product design, product lifecycle management and systems engineering. The PLMCC engages in numerous projects, primarily focusing on design and simulation, while also encompassing project management, manufacturing simulation and behaviour modelling. This wide-ranging approach enables the PLMCC to manage projects of a multidisciplinary nature, providing comprehensive training that integrates various aspects of the product development process.

An outdated and unreliable electricity grid, which significantly impairs economic activity, especially for small businesses. The country has huge renewable energy potential, including high levels of solar radiation and wind energy, but this is still underutilised. An important study emphasises that the integration of renewable energy with effective storage solutions is crucial to cope with the frequent interruptions in electricity supply (Gous and van Niekerk 2020). In addition, the high costs associated with con1.1ventional backup systems such as diesel generators emphasise the need for cost-effective and sustainable alternatives. Hybrid systems tailored to South African conditions - incorporating storage technologies such as lead-acid batteries and utilising local solar and wind resources - offer a viable way to stabilise energy supply and reduce environmental impact. This context emphasises the need to develop region-specific hybrid energy solutions that meet both technical and economic challenges (Gous and van Niekerk 2020).

Small businesses in South Africa, particularly restaurants, face challenges due to an unreliable power supply, impacting operations and increasing cost. While solar and wind energy are abundant, their intermittent nature limits their standalone viability as a solution. Secondary to this there are significant investment costs and financial risks associated with implementing alternative and off grid power solutions for these small businesses. The absence of an integrated hybrid energy solution that combines wind, solar, and biogas further exacerbates these challenges. This gap leaves small businesses without a decision-making tool to cost-effectively and realistically create a dependable off grid energy strategy.

This paper is organized as follows: Project problem statement and its objectives. It then presents a Literature review of the related topics. It then presents the research methodology. The Findings and Discussions are then presented after which conclusions and recommendations are made, with further research recommendations being given.

1.1 Research Objectives
The main objective of this project is to simulate and analyse the performance of a solar-wind hybrid energy system for an off-grid restaurant in Cape Town. The study focuses on:

1) Assessing the feasibility of a hybrid solar-wind system to ensure a continuous and reliable energy supply, considering variations in solar radiation and wind speed.
2) Performing a cost analysis to determine the most economical configuration for renewable energy integration.
3) Evaluate the impact of energy storage solutions to balance power generation and demand fluctuations.
4) Analyse system performance under different environmental conditions to identify challenges and optimisation opportunities (Gous and van Niekerk 2020; Nigam and Sharma 2022; Kusakana et al. 2012).

The project was carried out using MATLAB Simulink to assess the reliability and efficiency of the system, focusing on cost analysis, performance optimisation and energy storage considerations rather than detailed system design (Nigam and Sharma 2022).

2. Literature Review

Overview of the Literature Landscape

Hybrid energy systems are increasingly recognised as a viable solution for overcoming the limitations of single renewable energy sources. Studies have shown that combining multiple energy sources - e.g. wind, solar and gas energy - into a single system increases reliability and efficiency by utilising the complementary characteristics of these sources (Gous and van Niekerk 2020). For example, solar energy is abundant during the day, while wind energy often peaks at night, and gas systems can fill gaps during periods of low renewable energy production. The literature also highlights the importance of understanding energy demand patterns in order to optimise system configurations and reduce operating costs (Gous and van Niekerk 2020).

Research by the National Renewable Energy Laboratory captures this momentum well, noting that the broader drive toward renewable energy has fuelled a marked rise in solar adoption, with the industry expanding by close to 50% over the previous decade on the back of supportive policy measures and growing commercial and industrial appetite for clean energy. As the sector continues to scale, this work serves as a useful reference for understanding the range of solar panel types now available, their relative strengths and weaknesses, and the specific applications each is best suited to (National Renewable Energy Laboratory 2023).

2.

Recent research emphasizes the role of energy storage systems in solar-wind hybrid configurations. According to Nayar et al. (2017), the integration of batteries and other storage technologies significantly enhances grid stability and ensures a continuous energy supply, especially in off-grid applications. Different storage methods, such as lithium-ion and lead-acid batteries, have been analysed in hybrid setups, revealing their impact on overall system efficiency and economic viability. The study further discusses the potential for hybrid energy storage solutions to mitigate power fluctuations caused by renewable intermittency, highlighting advancements in intelligent energy management systems (Nayar et al. 2017).

Further analysis from the International Energy Agency (2022) emphasizes the necessity of integrating solar and wind energy into modern power systems. The report discusses the challenges posed by variable renewable energy (VRE) sources and highlights the need for grid flexibility, forecasting models, and robust storage solutions to mitigate intermittency issues (International Energy Agency 2022).

Definition and significance of hybrid energy systems

Hybrid energy systems integrate several renewable and conventional energy sources to ensure a reliable and sustainable power supply. These systems usually combine photovoltaics (PV), wind power and storage solutions to balance out fluctuations and optimise electricity generation (International Energy Agency 2022). The main advantage of hybrid systems is their ability to increase energy security, improve efficiency and reduce dependence on fossil fuels.

Photovoltaic (PV) systems

Solar PV systems convert sunlight into electricity using semiconductor materials, usually silicon-based cells. The efficiency of PV systems depends on factors such as solar radiation, temperature and shading (International Energy Agency 2022; Kumar and Sudhakar 2021). Advances in bifacial PV modules and maximum power point tracking (MPPT) technology have significantly improved energy harvesting and system stability in hybrid applications (Sabo et al. 2023).

Wind energy systems

Wind turbines convert the kinetic energy of the wind into electricity through rotational movement. The performance of a wind system is influenced by the wind speed, the height of the turbine and the design of the rotor blades. Hybrid systems benefit from wind energy as it often complements solar power generation by producing electricity at night or when it is cloudy (International Energy Agency 2022).

Biogas energy systems

Biogas is an increasingly relevant component in hybrid energy systems, especially for off-grid applications that require a continuous availability of electricity. Biogas is produced by the anaerobic digestion of organic waste, producing methane-rich gas that can be used to generate electricity or for direct heating.

Advantages of biogas in hybrid systems:

- Continuous power generation: Unlike solar and wind energy, biogas can provide a stable and controllable energy supply, reducing reliance on battery storage.
- Waste management and sustainability: Biogas production utilises organic waste materials, contributes to circular economy models and reduces landfill waste.
- Hybrid integration potential: Biogas generators can be combined with battery storage and solar/wind power systems to increase system reliability.

Challenges include feedstock availability, digestion efficiency and infrastructure costs, which need to be assessed for specific project sites.

Battery storage technologies

Energy storage is essential for hybrid systems to balance supply and demand. The most used storage technologies include:

- Lithium-ion batteries: High efficiency, longer life, but expensive.
- Lead-acid batteries: Lower initial cost, but shorter lifespan.
- Redox flow batteries: Suitable for large-scale storage applications (Nayar et al. 2017).

The integration of storage systems improves grid stability, increases system reliability and enables off-grid applications (International Energy Agency 2022).

Energy management and control systems

Hybrid energy systems require intelligent control strategies to optimise energy distribution. Techniques such as:

- MPPT (Maximum Power Point Tracking): Maximises the power output of PV panels (Sabo et al. 2023).
- Load balancing and demand forecasting: Ensures the availability of energy at all times.
- Grid-connected vs. off-grid control strategies: Determines how hybrid systems interact with the supply grids (Rajasekaran and Karthikeyan 2024).

Modern hybrid systems integrate AI-driven forecasting models to improve real-time decision making and optimise energy use (International Energy Agency 2022).

Integration tools

The integration of hybrid energy systems requires a balance between technical feasibility and cost efficiency. MATLAB Simulink has established itself as a powerful tool for the simulation and optimisation of hybrid energy systems, enabling researchers to test dynamic interactions and refine system configurations (Nigam and Sharma 2022). Design principles focus on modularity and scalability to meet different energy requirements, with an emphasis on advanced control strategies to maximise efficiency and minimise costs (Nigam and Sharma 2022). The use of tools such as MPPT (Maximum Power Point Tracking) ensures optimal energy harvesting from renewable sources and significantly improves system performance under fluctuating conditions (Nigam and Sharma 2022).

Recent findings from Rajasekaran and Karthikeyan (2021) also underline the importance of integrating advanced inverter technologies such as multi-level inverters (MLI) and power balancing control (PBC). These mechanisms contribute to increasing the efficiency and stability of hybrid renewable energy systems, especially in on-grid and off-grid applications. Such strategies ensure a seamless combination of battery storage with generation technologies while maintaining voltage and frequency stability (Rajasekaran and Karthikeyan 2021).

The study by Sabo et al. (2023) discusses the integration of solar and wind hybridization into multi-machine power systems. It highlights how advanced control strategies can ensure stable operation under variable renewable energy input, which is essential for real-world hybrid system implementations (Sabo et al. 2023).

Optimising costs and performance

Cost analysis and optimisation are crucial for the development of hybrid energy systems. In a South African study, linear programming was used to minimise the initial investment cost of a hybrid system while ensuring reliability and efficiency (Kusakana et al. 2012). Using the MATLAB optimisation toolbox, the study demonstrated the feasibility of precise component sizing and cost reduction through a balanced integration of photovoltaic modules, wind turbines and hydropower systems (Kusakana et al. 2012).

An important finding of Kusakana et al. (2012) is that the cost efficiency of hybrid systems can be improved by matching the system components to the specific energy profiles of the target region. For example, in regions with high wind speeds, wind turbines can be favoured over photovoltaic systems, thereby reducing the overall investment costs while covering the energy demand.
The additional perspective from Nayar et al. (2017) emphasizes the economic benefits of battery storage systems. Properly sized storage not only reduces reliance on fossil fuel-based backup systems but also ensures optimal utilization of renewable energy, which is particularly crucial in off-grid scenarios. The study further suggests that battery degradation rates must be considered in cost models to improve long-term economic efficiency (Nayar et al. 2017).

A recent study by Rajasekaran and Karthikeyan (2024) explores the implementation of firm-dispatchable generation in South Africa. The research discusses how renewable energy sources can be integrated into the country's existing power infrastructure while maintaining grid stability and addressing reliability concerns (Rajasekaran and Karthikeyan 2024).

Discussion of the literature review section
The literature reviewed in the preceding sections points to a clear and growing interest in hybrid renewable energy systems as practical solutions for sustainable off-grid power. Taken together, the studies provide a solid foundation, covering key aspects such as the operation of photovoltaic and wind energy systems, the role of battery storage in maintaining supply, and the use of energy management and control strategies. That said, a closer reading of the literature highlights several gaps that this study aims to address. One of the more noticeable limitations is the tendency for researchers to focus on single-source systems. Many studies examine either solar PV or wind energy in isolation, with less attention given to how these systems can complement each other in hybrid configurations. While the individual effectiveness of both technologies is well established, there is still limited exploration of how a combined solar-wind system performs under varying load conditions, particularly in suburban or commercial contexts.

Another issue that emerges is the lack of integration in modelling approaches. MATLAB Simulink is widely used for dynamic simulation, offering detailed insights into system behaviour, power flow, and component interaction over time. In contrast, RETScreen is often applied for techno-economic analysis, focusing on energy production, cost implications, and environmental impact. Although both tools are valuable, they are typically used separately, and there is relatively little evidence of studies that deliberately combine them within a single framework.

This separation is not insignificant. Relying only on dynamic simulation can overlook longer-term financial and environmental considerations, while techno-economic tools alone may not fully capture system performance under real operating conditions. For this reason, the dual-method approach adopted in this study—integrating MATLAB Simulink modelling with RETScreen analysis—offers a more comprehensive perspective. By considering both the technical performance and economic viability of a hybrid solar-wind system, and by applying this to an off-grid commercial restaurant setting, this study aims to provide a more balanced and practically relevant contribution to the existing body of research.

3. Economic Analysis
To ensure the long-term acceptance and practical implementation of a system, an economic analysis and evaluation is essential. Small businesses in particular, such as restaurants, often do not have the necessary financial resources and need to ensure that an investment is worthwhile.
This section takes a closer look at the financial aspects. The focus here is on the initial costs and the running costs of the system

Renewable Energy Technology Screen (RETScreen)
RETScreen is a software developed by Natural Resources Canada to analyse the financial and technical feasibility of energy projects. It is often used for cost-benefit analyses and performance evaluations. RETScreen stand for Renewable Energy Technology Screen, and is a Comprehensive financial modelling: Calculates capital costs, operating costs, ROI and payback period to assess project feasibility. Some of the benefits are listed below:

- Integrated energy and financial analysis: Combines energy production data with financial performance for more accurate predictions.
- Scenario and sensitivity testing: Analyses how fluctuations in costs, efficiency and energy prices affect the profitability.
- Industry standard tool: Used globally with benchmark data from real projects to ensure reliability.

RETScreen was selected to model the financial feasibility of the hybrid energy system and integrate data on costs, savings and efficiency. It helped to calculate key financial indicators and test different scenarios to ensure a realistic and data-driven investment analysis.

Comparison Of Grid-Connected And Off-Grid Hybrid Systems
Justification for off-grid systems
Given the frequent pow4er outages and instability of the South African electricity grid, off-grid hybrid systems offer a more reliable alternative for businesses such as restaurants in Cape Town. Grid-tied systems offer a flexible backup but are susceptible to load shedding and legal restrictions (Rajasekaran and Karthikeyan 2024).

Economic considerations
Off-grid systems require a higher initial investment due to battery storage and backup generation. However, they eliminate long-term grid dependency, electricity tariffs and potential regulatory fees (Sabo et al. 2023). In contrast, grid-connected systems are confronted with fluctuating feed-in tariffs and possible restrictions on energy exports (International Energy Agency 2022).

Energy storage and system independence
Off-grid systems require larger battery capacities to store surplus energy for the night and for times of low generation. Lithium-ion batteries are favoured due to their longer lifespan and efficiency despite higher costs (Nayar et al. 2017).

Case study: Restaurants in Cape Town
For small businesses, especially in Cape Town, an off-grid system offers the best long-term sustainability. The ability to control energy production, avoid power interruptions and reduce reliance on fossil fuel generators makes hybrid solar-wind-battery solutions an optimal choice (Rajasekaran and Karthikeyan 2024).

Simulation and modelling techniques
MATLAB Simulink is widely used to simulate hybrid energy systems due to its robust modelling capabilities and dynamic simulation tools (Nigam and Sharma 2022). In recent studies, Simulink has been used to model Maximum Power Point Tracking (MPPT) techniques for solar and wind energy using methods such as Incremental Conductance (I&C) to optimise energy outputs (Nigam and Sharma 2022).

In addition, linear programming techniques in MATLAB were used to determine optimal system configurations. Kusakana et al. (2012) have shown that by formulating the cost optimisation problem as a linear minimisation task, researchers can produce faster and more reliable results compared to conventional numerical methods. This approach not only reduces computational complexity but also provides usable insights for system design and implementation (Kusakana et al. 2012).

The inclusion of DC-DC converters further stabilises the system and enhances its reliability and efficiency under variable conditions (Nigam and Sharma 2022). In addition, Rajasekaran and Karthikeyan (2021) discuss how smart control mechanisms for hybrid energy storage solutions contribute to improving overall system stability, especially in the case of unpredictable load demand or fluctuating renewable energy feed-in. These techniques form the foundation for the simulation approach in this project.

Challenges in hybrid energy systems
Hybrid energy systems face several technical and economic challenges. One of the main problems is the intermittency of renewable energy sources, which leads to voltage and frequency fluctuations. Research has shown that advanced control strategies, such as power balancing control (PBC), can mitigate these problems (Rajasekaran and Karthikeyan 2021).

Another challenge is the high initial cost of storage technologies. Although lithium-ion batteries offer higher efficiency and a longer service life, they require considerable initial investment. Although lead-acid batteries are cheaper, they deteriorate more quickly and need to be replaced more frequently (Nayar et al. 2017).

Regulatory barriers also pose a challenge, particularly in South Africa, where grid integration policies for hybrid energy systems remain inconsistent. Measures such as the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) have facilitated private sector participation, but further incentives are needed to make hybrid systems economically viable (Gous and van Niekerk 2020). More recently, fiscal measures such as the enhanced renewable energy tax incentive for businesses have begun to improve the economic case for adoption (National Treasury Republic of South Africa 2023).

Research Gaps and Future Work
Despite significant advancements in hybrid energy systems, several gaps remain in the existing research. Firstly, optimal system design remains a challenge due to the complexity of balancing multiple energy sources, especially in variable climatic conditions (Kusakana et al. 2012).

Secondly, long-term economic viability requires further study. Most research focuses on technical feasibility, while fewer studies analyse hybrid systems' financial sustainability over decades, considering maintenance and degradation costs (Nayar et al. 2017).

Lastly, site-specific solutions are underexplored. Many models use general assumptions, but localized studies, particularly for small businesses such as restaurants in Cape Town, are needed to refine hybrid energy models (Gous and van Niekerk 2020).

These gaps present opportunities for further research and optimization, ensuring that hybrid energy systems can provide reliable, cost-effective, and sustainable power solutions.

4. Research Methodology
This chapter describes the methodology for the design, modelling and simulation of a hybrid energy system consisting of solar and wind energy. The methodology follows a structured approach divided into four main phases. This is illustrated in the Figure 1: Project Methodology below. Each phase is explained in detail after the figure.

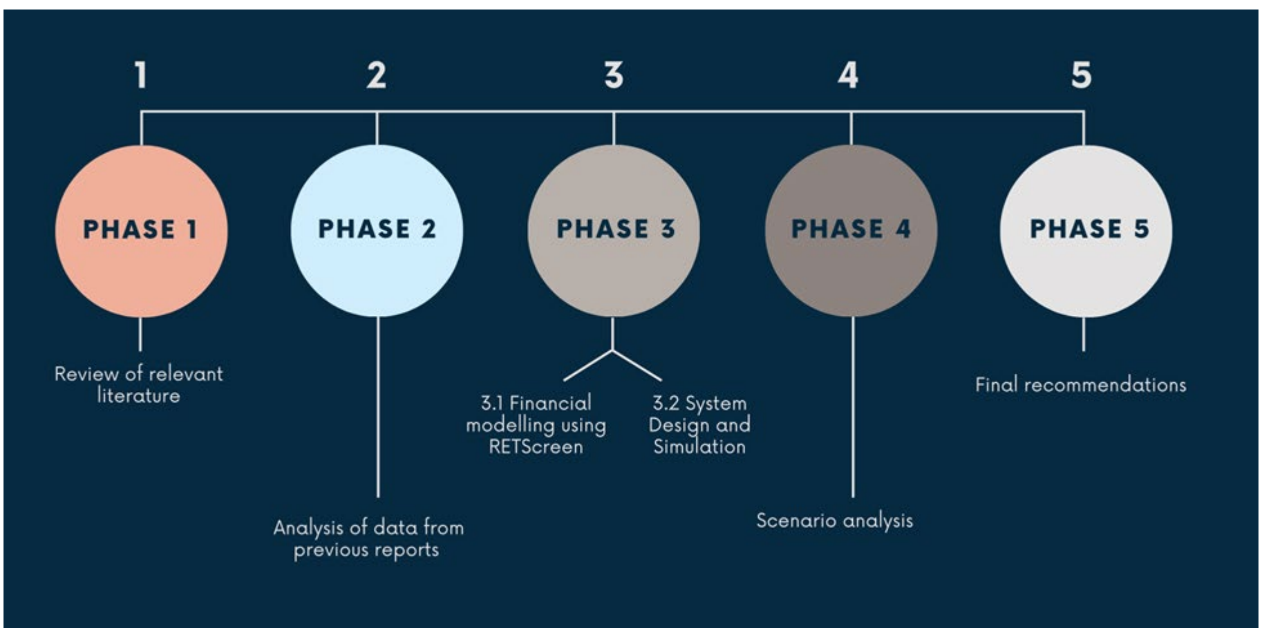

Figure 1: Project Methodology

- Phase 1: Review of relevant literature.

For the financial analysis of solar, wind and gas energy systems, a variety of material was reviewed, including research articles, business publications and case studies. This review was important for understanding the cost components, the estimated lifetime of the systems and the methodologies used in the financial analysis of renewable energy projects.

In the first phase, an extensive literature review was conducted to understand the fundamentals of hybrid renewable energy systems. Various sources were analysed to identify best practices, system components and key performance indicators. This research provided insights into:

- The feasibility of integrating wind and solar energy in an off-grid system.
- The role of energy storage and power electronics in stabilising renewable energy yields.
- Economic and environmental considerations for hybrid energy systems.

The literature review served as a basis for the selection of suitable modelling techniques and the definition of key parameters for the simulation.

- Phase 2: Analysis of data from previous reports.

Report papers from previous projects were used to compile and analyse both the financial and technical data. This includes the estimated costs, the amount of energy generated, the maintenance costs incurred and the results of the technical feasibility studies. All calculations and results of the documents were analysed and prepared for financial modelling and checked for accuracy and validation.

To gain insight into energy system configurations, reports from previous student projects were reviewed. These reports included key data on solar, wind and biogas energy generation, system efficiency and cost structures. By consolidating these results, the financial and technical feasibility of hybrid configurations was assessed. The results were used to cross-validate the system design selected in the simulation model.

- Phase 3 - Concurrent steps in methodology
- Phase 3.1: RETScreen for financial modelling (Lene)

RETScreen enabled the project to be analysed by profiling the energy-related capital spent on the equipment. The focus was on a qualitative or quantitative analysis of the financial viability of the project, including ROI and break-even point calculations.

- Phase 3.2: System Design and Simulation

The hybrid energy system was designed and modelled in MATLAB Simulink. The system integrates photovoltaic (PV) panels and a wind turbine for power generation, using measured voltage and current outputs to calculate the power generation.

Photovoltaic (PV) system model

- Structure: The PV system consists of multiple modules arranged in parallel strings with multiple modules per string, allowing for flexible system configuration.
- Assumptions:
    - Constant cell temperature: The cell temperature is set to 25°C to simplify the model and isolate the effects of irradiation fluctuations.
    - Variable solar irradiation: The irradiation varies dynamically between 0 and 1000 W/m² to reflect realistic daily solar irradiation (6-8 hours of operation).
- Output measurement: The system outputs voltage and current values that are used to calculate the total PV power.

Wind energy system model

- Design: The wind system uses a permanent magnet synchronous machine (PMSM) as a generator.
- Assumptions:
    - Constant pitch angle: the pitch angle remains fixed to simplify the analysis and exclude active pitch control mechanisms.
    - Variable wind speed: The wind speed fluctuates randomly between 0 and 10 m/s, thus simulating the natural fluctuations in wind conditions.
- Output measurement: The generated AC voltage is converted into DC current and the system measures the corresponding current and voltage for power calculation.

Load and power balance considerations
The system compares the total power generated with a predefined load profile of the restaurant to assess energy utilisation. The difference between power generation and load demand is used to determine the need for battery storage or alternative backup solutions. Resistance loads are taken into account in individual subsystems to maintain system stability and avoid unrealistic voltage fluctuations.

4.1 Model Limitations and Assumption Boundaries
It is important to contextualise the simulation outputs against the assumptions that underpin the model. The PV subsystem was modelled at a constant cell temperature of 25°C throughout the simulation. This is a standard simplification in preliminary energy modelling, but it does introduce a degree of optimism into the solar output figures — in practice, cell temperatures in Cape Town regularly exceed 25°C, particularly during peak irradiance hours, and higher cell temperatures reduce conversion efficiency. The implication is that the simulated PV output likely represents a best-case performance scenario rather than a typical operating condition.

The wind subsystem carries a similar caveat. Wind speed was modelled as a random fluctuation between 0 and 10 m/s rather than being drawn from a statistically representative Cape Town wind profile, and the pitch angle was held constant throughout, removing the effect of active turbine control from the model entirely. These two simplifications together explain much of the erratic behaviour visible in the wind output signal and account for a meaningful portion of the gap between the theoretical sizing calculations and the simulation results. A system sized on the basis of expected average wind conditions will naturally appear to underperform when the simulation driving it does not accurately reproduce those conditions.

These are recognised limitations of the modelling approach adopted here, and they do not invalidate the comparative findings of the study — the relative performance differences between scenarios remain informative and directionally sound. What they do mean is that the absolute output figures, particularly for the wind scenarios, should be treated with some caution and interpreted as indicative rather than definitive. Addressing these assumptions through more representative input data and refined turbine modelling is a logical and necessary next step for any future work building on this study.

Biogas Parameter removed from study
It should be noted that the initial design of this study incorporated biogas as a third energy source alongside solar PV and wind, with the intention of modelling a fully hybrid three-source system. During the feasibility assessment phase, however, it became evident that a single restaurant does not generate sufficient organic waste to make biogas production practically viable. The additional infrastructure required to convert biogas into usable electricity further compounded this limitation, making it an unsuitable option for a facility of this size and operational scope. As a result, biogas was excluded from the simulation, and the study was refined to focus on solar and wind energy. While a biogas scenario is referenced in the findings for completeness, it could not be fully modelled, and its inclusion remains a recommendation for future research under more suitable conditions.

- Phase 4: Scenario analysis

Multiple scenarios were simulated to analyse the impact of different energy configurations, including solar-only, wind-only, and hybrid setups. Each scenario was evaluated in terms of finical feasibility and cost savings.
In the final phase, various system configurations were analysed in terms of their feasibility for covering the restaurant's energy requirements. Various scenarios were considered, including

- **Hybrid solar-wind system**: Evaluation of the benefits of combining solar and wind energy to improve reliability and efficiency. This configuration represents the main scenario for this study as it balances energy availability by utilising solar energy during daytime hours and wind energy as a supplemental source. The analysis focuses on determining the required system configuration to effectively meet the restaurant's energy needs.
- **100% solar energy supply**: Evaluating whether an entirely solar-powered system could meet the energy needs and determining the number of solar panels required.
- **100% wind energy supply**: Investigating the feasibility of a wind-only system and analysing the power generation potential in different wind conditions.

- Hybrid system **with biogas integration**: Consideration of the inclusion of biogas as an additional renewable energy source to supplement wind and solar energy.

While the theoretical biogas scenario was defined to investigate the economic feasibility, the practical implementation was not pursued further. Future research should consider alternative energy sources.
The other scenarios were analysed on the basis of energy production, system reliability and practical feasibility. The results were used to compare possible configurations and identify areas requiring further optimisation.
This structured methodology ensures a comprehensive approach to modelling and evaluating the hybrid energy system. The following chapter presents and discusses the simulation results and analyses their impact on practical feasibility.

- Phase 5: Final recommendations

Based on the financial results and the sensitivity analysis, recommendations were made for the most cost-effective configuration of the hybrid system. The focus was on optimising the investment costs while maximising the long-term financial benefits. Possible financial benefits that could improve the economic viability of the project were also considered.

5. Findings and Discussion

This chapter presents the findings from the simulation of the hybrid energy system. The results focus on the energy generation potential of solar and wind power, the overall system performance, and an evaluation of different supply scenarios. The discussion also includes an assessment of the energy balance and potential system limitations. Figure 2 Below presents the complete MATLAB Simulink model developed for this study, illustrating how the solar PV and wind energy subsystems are structured and integrated into a single hybrid simulation environment. The upper portion of the model represents the solar PV subsystem, where solar irradiance and cell temperature serve as the primary inputs, feeding into a 63-module PV array configuration. This subsystem outputs voltage and current signals that are processed to produce the total solar power output. The lower portion of the model represents the wind energy subsystem, built around a Permanent Magnet Synchronous Machine. Wind speed data is used as the input, with generator speed, pitch angle, and wind data informing turbine behaviour. The alternating current output of the wind turbine is converted to direct current through an AC to DC converter before being fed into the combined system. On the right-hand side of the model, the outputs of both subsystems are aggregated to produce a combined solar-wind power signal, which is then measured against a repeating load profile representing the restaurant's energy demand. A battery backup block is included to capture surplus and deficit behaviour, and the necessary total output is recorded as the final simulation output. Together, the subsystems reflect the component-level modelling approach adopted in this study, allowing dynamic interaction between the two energy sources to be observed under variable input conditions.

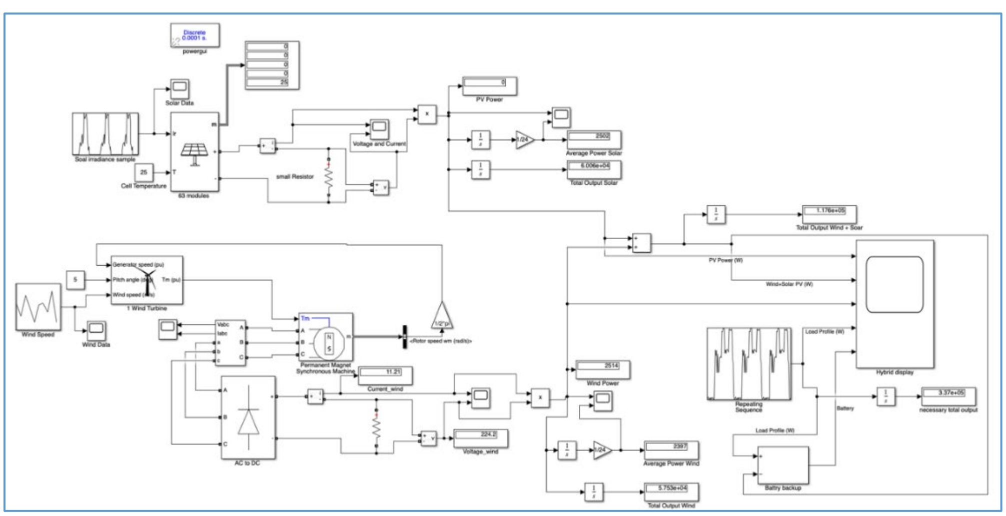

Figure 2: MATLAB Simulink model architecture of the hybrid solar-wind system.

General Findings
Figure 3 presents the load profile used as the demand baseline for evaluating the energy requirements of the restaurant case study over a 24-hour simulation period. The profile reflects realistic power consumption patterns typical of a small commercial restaurant in Cape Town, characterised by peak demand of approximately 25–30 kW during midday and evening hours, coinciding with meal preparation and peak service periods, and a significant reduction in consumption to below 5 kW during late night and early morning hours when the facility is largely inactive. This variation in demand across the day is an important feature of the simulation, as it creates periods of both surplus and deficit generation depending on the output of the solar and wind subsystems at any given hour. The load profile therefore serves a dual purpose in this study — it grounds the simulation in a practically relevant demand scenario, and it provides the benchmark against which the performance of each modelled energy configuration is measured and compared

Analysis of the scenarios
A hybrid system offers a sustainable way of covering a restaurant's entire energy A hybrid system offers a sustainable way to cover the entire energy needs of a restaurant. However, its cost-effectiveness depends on a number of factors, such as site conditions, investment costs, operating costs and the energy generated. To make sure that the system is not only practical but also cost-effective, these factors need to be carefully analysed. In this section, scenarios are analysed that include different combinations of energy sources and site-specific conditions.

The goal of the analysis is to test real-world conditions and show how changes, e.g. in energy composition or site conditions, affect the profitability.

The focus is on identifying the combination that meets both the financial and practical requirements of the restaurant.
To do this, calculations on energy production, cost distribution and space requirements are calculated for each scenario. In addition, key figures such as break-even point, ROI and life cycle costs are calculated to identify long-term efficiency, following established approaches to return-on-investment calculation (Kenton 2023). This analysis not only shows the financial benefits of the different combinations, but also provides a recommendation for the realisation of the project.
Standardised formulas are used to calculate the individual energy sources. These form the basis and are explained below so that they can then be applied to the individual scenarios.

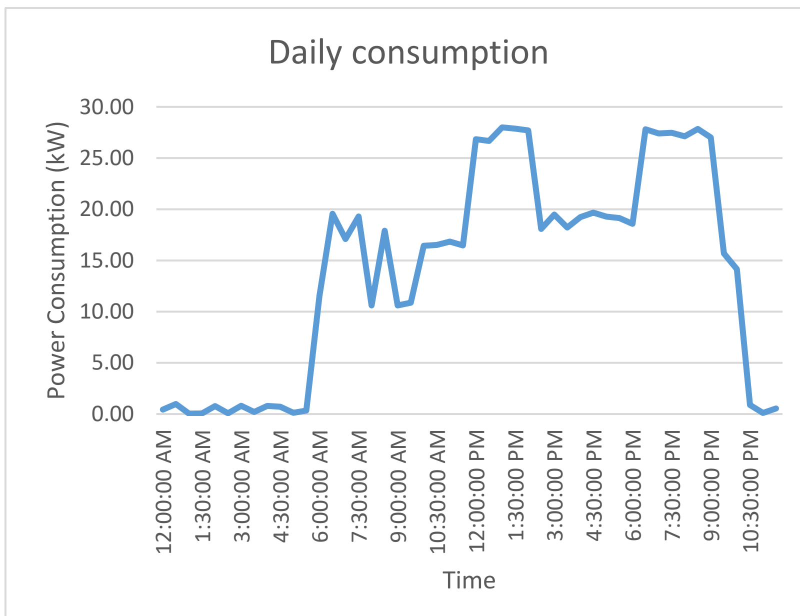

Figure 3: Suggested load profile for a restaurant in Cape Town

Scenario 1 – Solar & Wind
In this scenario, the restaurant's total daily energy demand of 336.24 kWh is split evenly between solar and wind energy, with each source covering 168.12 kWh/day. This scenario is especially relevant for locations where both solar and wind energy are available, allowing for a more stable and more diversified energy supply.

Calculation of the number required per source

- Solar energy

To cover 168.12 kWh per day, the required number of solar modules is calculated on the basis of average solar radiation of 8 hours per day, an efficiency of 85% and a module output of 400 W. Based on the method, **63 solar modules** are required.

- Wind energy

Wind energy also covers 168.12 kWh of the total requirement. With a rated output of 7.5 W, a capacity factor of 30 % and an operating time of 24 hours/day, one turbine generates 54 kWh per day. According to the method, **4 wind turbines** are required to meet the energy demand.

- Battery

Since the lithium-ion battery has a lifespan of only 10–15 years and the system runs for 25 years, two batteries are required over the project lifetime. Therefore, the total battery cost includes **two units**.

Simulation Findings

Solar Output: The PV array includes 63 modules and generates a total output of **60.02 kWh per day**, with an average power output of **2.502 kW**. The maximum power output occurs during peak sunlight hours. The yellow curve in the PV Power graph represents actual power output, while the blue curve indicates the average power over the simulation period.

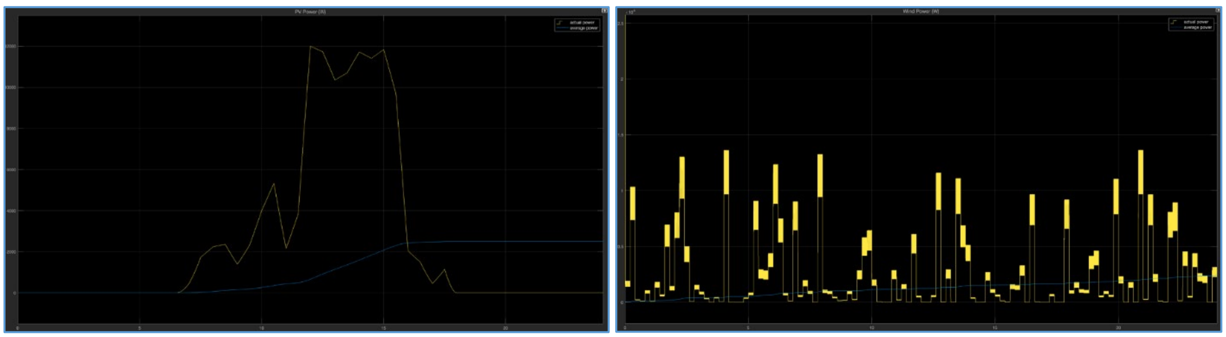

Figure 4. Simulated PV and wind power output (kW) over a 24-hour period.

Figure 4 presents the simulated power output of both the solar PV and wind energy subsystems over the 24-hour simulation period, expressed in kilowatts (kW), alongside key performance metrics derived from the simulation. The PV subsystem produced a total daily output of 60.06 kWh, closely mirroring the solar irradiance pattern established in Figure 3 — rising through the morning, peaking around midday, and tapering into the evening. This predictable generation profile confirms that the PV subsystem behaves as expected within the Simulink model and represents the more stable of the two energy sources modelled.

The wind subsystem, by contrast, produced a total output of 57.53 kWh per day from a single turbine, with an average power of 2.397 kW, scaling to a combined output of 230.12 kWh per day across four turbines. However, the wind power profile is characterised by significant fluctuations driven by varying wind speed inputs, reflected in the sharp spikes visible in the output signal. The average power curve plotted alongside the instantaneous output highlights the gap between theoretical mean generation and actual moment-to-moment behaviour, and illustrates why wind energy alone presents reliability challenges as a standalone supply source. It should be noted that while the main scenario models four wind turbines, only a single turbine output is shown in the combined display for clarity — direct extrapolation to a four-turbine configuration carries inherent uncertainty given the instability observed in the individual turbine model.

When the two sources are considered in isolation, their individual shortcomings are clear — the PV system is time-constrained by daylight availability, and the wind system introduces unpredictable variability that undermines supply consistency. What remains to be seen is whether combining them within a single hybrid configuration is sufficient to close the gap between generation and demand. This is the central question that Figure 5 addresses. The combined hybrid output of 290.18 kWh per day already signals that the deficit is not fully resolved, but the degree to which hybridisation improves upon either source operating independently, and the role of battery interaction in managing the remaining shortfall, is best understood through the hybrid display presented in Figure 5.

The battery signal visible in the current figure offers an early indication of this dynamic — instances of both charging and discharging throughout the day highlight periods where generated power exceeds demand and where it falls below it. These gaps between supply and demand reinforce a central finding of this study, that solar and wind generation alone are insufficient to guarantee continuous supply, and that battery storage or an additional backup source is necessary to bridge the deficit. Mitigating the wind variability observed here would require either an increased turbine count or a more sophisticated energy management approach such as Maximum Power Point Tracking, both of which are identified as priorities for future work and discussed further in the recommendations.

Before presenting the simulation results, it is necessary to establish the input conditions and demand assumptions that underpin the model. Figures 3, 4, and 5 collectively define the operating environment of the simulation — the environmental resource data driving each subsystem, and the demand profile against which their outputs are evaluated. Together they provide the contextual foundation for interpreting the hybrid system performance presented in Figure 5.

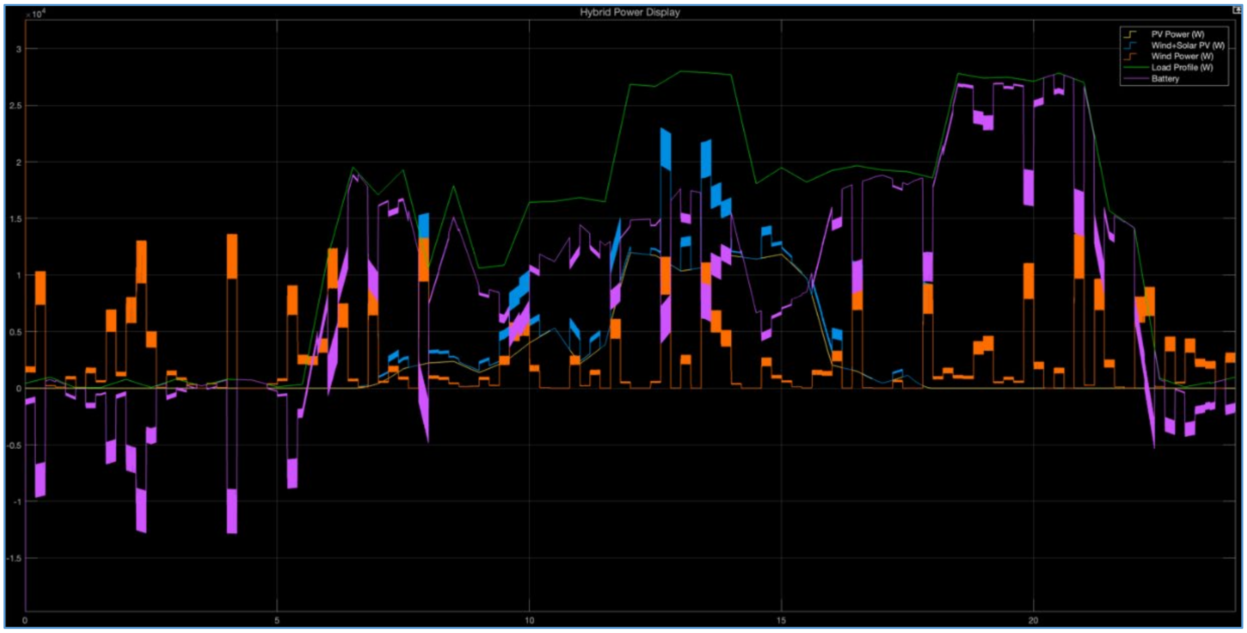

Figure 5: Simulated hybrid power output relative to restaurant load demand over a 24-hour period

Figure 5 presents the simulated power output of the hybrid solar-wind system over a 24-hour period, with all values expressed in watts (×10^5) on the vertical axis and simulation time in hours on the horizontal axis. The orange signal represents solar PV output, the blue signal reflects wind turbine generation, and the green signal shows the combined hybrid output of both sources. The white signal represents the restaurant's actual load profile, serving as the demand benchmark against which generation is measured. The purple signal depicts battery power behaviour, where positive values indicate discharging and negative values indicate that the battery is in a charging state. The figure illustrates the inherent variability of each individual source and demonstrates that the hybrid configuration produces a more consistent generation profile than either solar or wind operating independently. Despite this, the combined output does not uniformly meet the load demand across all hours, which reinforces the need for battery storage as a supplementary measure.

<u>Economic analysis</u>
Initial Costs

- Solar modules: (63 * 4,000 ZAR) + 11,100 ZAR + 3,000 ZAR = 266,100 ZAR
- Wind turbines: 4 * 360,000 ZAR = 1,440,000 ZAR
- Batteries: 2 * 15,000 ZAR = 30,000 ZAR

Total Initial Costs: 1,736,100 ZAR

Operational Costs (Annual)

- Solar modules: 63 * 50 ZAR = 3,150 ZAR
- Wind turbines: 4 * 9,000 ZAR = 36,000 ZAR
- Batteries: 2 * 2,690 ZAR = 5,920 ZAR

Total Annual Operational Costs: 47,030 ZAR

Potential Savings

- Annual Electricity Savings: 254,046.13 ZAR

Key Metrics

- Depreciation Costs (20 years): $\frac{1{,}736{,}100\ ZAR}{25\ years}$ = 69,444 ZAR/year
- Annual Cashflow: 254,046.13 ZAR - (47,030 ZAR + 69,444 ZAR) = 137,572.13 ZAR
- ROI: $\frac{137{,}572.13\ ZAR}{1{,}736{,}100\ ZAR}$ * 100 = 7.87 %
- Break-even Point: $\frac{1{,}736{,}100\ ZAR}{137{,}572.13\ ZAR}$ = 12.71 years

The 50/50 solar and wind hybrid system requires an initial investment of 1,736,100 ZAR making it cheaper than a wind-only system but more expensive than a solar-only system. However, it offers greater energy stability as it utilises both sources. With a return on investment of 7.87 % and a payback period of 12.71 years, it is more cost-effective than a wind-only system and ensures greater long-term reliability than a solar-only system.
Scenario 2 - Solar
In this scenario, the restaurant's total daily energy demand of 336.24 kWh is covered by solar energy alone, with no additional input from wind or gas. The purpose of this scenario is to analyse whether solar energy alone can cover the energy demand and to see the feasibility under real conditions. By isolating the solar component, the reliability and economic viability of the system can be analysed in locations where wind and gas may not be an option.

<u>Calculation of the number required per source</u>

- Solar

Solar energy covers the daily energy demand. The average solar radiation is 8 hours/day. An efficiency of 85% is assumed for the 400 W output of the solar modules. Based on the method, 126 Solar modules are required.

- Battery

Since the lithium-ion battery has a lifespan of only 10–15 years and the system runs for 25 years, two batteries are required over the project lifetime. Therefore, the total battery cost includes two units.

<u>Simulation Findings</u>
Sufficient solar energy: The PV array generates 60.06 kWh per day with 63 modules. For a configuration with 126 modules, the expected daily output would be approximately 120.12 kWh per day, doubling the current solar contribution. To meet the full 336.24 kWh per day, the number of modules would need to be scaled up by a factor of approximately 5.6, resulting in around 353 modules. Although this is theoretically possible, the land consumption and installation costs must be taken into account.
System Limitations: The absence of a backup energy source means power cannot be guaranteed during nighttime hours or cloudy days.

<u>Economic analysis</u>
Initial Costs

- Solar modules: (126 * 4,000 ZAR) + 11,100 ZAR + 3,000 ZAR = 518,100 ZAR
- Batteries: 2 * 15,000 ZAR = 30,000 ZAR

Total Initial Costs: 548,100 ZAR

Operational Costs (Annual)

- Solar modules: 126 * 50 ZAR = 6,300 ZAR
- Batteries: 2 * 2,960 ZAR = 5,920 ZAR

Total Annual Operational Costs: 12,220 ZAR

Potential Savings

- Annual Electricity Savings: 254,046.13 ZAR

Key Metrics

- Depreciation Costs (25 years): $\frac{548{,}100\ ZAR}{25\ years}$ = 21,924 ZAR/year
- Annual Cashflow: 254,046.13 ZAR - (12,220 ZAR + 21,924 ZAR) = 231,102.13 ZAR

- ROI: $\frac{231{,}102.13\ ZAR}{548{,}100\ ZAR}$ * 100 = 42.16 %
- Break-even Point: $\frac{548{,}100\ ZAR}{231{,}102.13\ ZAR}$ = 2.37 years

The analysis shows that a solar-only system requires a large initial investment 548,100 ZAR but has a high return on investment (42.16 %) and a short payback period of 2.37 years. A lifespan of 25 years was chosen as an estimate for the financial analysis. Even though solar modules can last up to 40 years, factors such as maintenance and environmental conditions can reduce their efficiency over time. The use of a worst-case scenario ensures a realistic valuation of investment payback and profitability.

Scenario 3 - Wind
In this scenario, the restaurant's total daily energy requirement of 336.24 kWh is covered by wind energy only. The goal of this scenario is to determine whether a wind-only system can reliably supply the required energy and to evaluate its financial feasibility. By isolating the wind energy, the performance of the system can be evaluated in locations where solar, or gas energy are not viable options.
<u>Calculation of the number required per source</u>

- Wind

Since wind is the only energy source in this scenario, the full 336.24 kWh/day must be generated by wind turbines. A VAWT B wind turbine has a rated output of 7.5 kW. With a capacity factor of 30% and an operating time of 24 hours/day, one turbine produces 54 kWh per day. Based on the method, 7 wind turbines are required.

- Battery

Since the lithium-ion battery has a lifespan of only 10–15 years and the system runs for 25 years, two batteries are required over the project lifetime. Therefore, the total battery cost includes two units.
<u>Simulation Findings</u>
Variability of wind energy: The total energy generated in the current configuration is 57.53 kWh per day and turbine. Scaling to 7 turbines results in 402.71 kWh per day, which exceeds the required demand. However, due to the considerable fluctuations in wind power output, these values should not be regarded as entirely realistic.
<u>Economic analysis</u>
Initial Costs

- Wind turbines: 7 * 360,000 ZAR = 2,520,000 ZAR
- Batteries: 2 * 15,000 ZAR = 30,000 ZAR

Total Initial Costs: 2,550,000 ZAR

Operational Costs (Annual)

- Wind turbines: 7 * 9,000 ZAR = 63,000 ZAR
- Batteries: 2 * 2,960 ZAR = 5,920 ZAR

Total Annual Operational Costs: 68,920 ZAR

Potential Savings

- Annual Electricity Savings: 254,046.13 ZAR

Key Metrics

- Depreciation Costs (25 years): $\frac{2{,}550{,}000\ ZAR}{25\ years}$ = 102,000 ZAR/year
- Annual Cashflow: 254,046.13 ZAR - (68,920 ZAR + 102,000 ZAR) = 83,126.13 ZAR
- ROI: $\frac{83{,}126.13\ ZAR}{2{,}550{,}000\ ZAR}$ * 100 = 4.75 %
- Break-even Point: $\frac{2{,}550{,}000\ ZAR}{83{,}126.13ZAR}$ = 21.06 years

The wind-only system requires a very high initial investment of ZAR 2,550,000, making it the most expensive scenario to date. The ROI is quite low at 4.75 % and the break-even period of 21.06 years shows that it takes a long time for the investment to amortise.

Scenario 4 – Solar, Wind & Biogas
In this scenario, the restaurant's daily energy requirement of 336.24 kWh is split evenly between all three energy sources. This means that solar, wind and gas each cover a third of the daily requirement, which is approximately

112.08 kWh. This distribution ensures that the system remains stable regardless of fluctuations in the sun or wind and utilises the benefits of each energy source.

<u>Calculation of the number required per source</u>

- Solar energy

Solar energy covers 112.08 kWh. The average solar radiation is 8 hours/day. An efficiency of 85% is assumed for the 400 W output of the solar modules. Based on the method, 42 Solar modules are required.

- Wind energy

Wind energy also covers 112.08 kWh of the total requirement. A VAWT B wind turbine has a rated output of 7.5 W. With a capacity factor of 30% and an operating time of 24 hours/day, one turbine produces 54 kWh per day. Based on the method, 3 wind turbines are required.

- Biogas

The restaurant's daily food waste is calculated on the basis of 0.15 kg of waste per meal and 2000 meals per day, resulting in 300 kg/day.

The energy content of the biogas is 6.4 kWh per m3 and the biogas plant has a capacity of 75 m3. One plant can produce 480 kWh/day, which is sufficient to cover the daily energy demand of 112.08 kWh.

Based on the given parameters (container weight of 55 kg and energy content of 13 kWh per kg), the result shows that 1 container is enough for the daily energy demand.

- Battery

Since the lithium-ion battery has a lifespan of only 10–15 years and the system runs for 20 years, two batteries are required over the project lifetime. Therefore, the total battery cost includes two units.

<u>Description and limitations</u>

In this scenario, it is assumed that the restaurant's energy needs are met equally by biogas, wind and solar energy. While the MATLAB-Simulink model successfully simulates the solar and wind energy components, a detailed model for the biogas generation is missing due to time constraints and the complexity of modelling gas-based energy systems. The lack of a biogas model is a limitation of this study, as a complete analysis of the hybrid system requires an integrated biogas simulation. The development of such a model requires specific expertise in gas energy modelling, which is beyond the scope of this project. Future work should involve a specialist to develop and validate a biogas energy model to ensure a comprehensive assessment of this hybrid approach.

<u>Expected results</u>

Contribution of wind and solar: The simulation provides information on the ability of the solar and wind components to generate electricity under different conditions. However, the lack of biogas contribution means that the system cannot be fully assessed. As a stable and weather-independent energy source, biogas could be an important backup for times when solar and wind generation fluctuate. Given its continuous availability, integrating biogas into the system would increase reliability and energy security. The time constraints of this project prevented the development of a comprehensive biogas model, but future research should prioritise this aspect to achieve a more robust and reliable hybrid energy solution.

Future development needs: To validate this scenario, an advanced energy model needs to be developed that takes into account the dynamics of biogas production, storage and gas consumption patterns.

For this scenario, the energy production from wind and solar was analyzed separately. Using the previous configuration, a PV array of 42 modules generated an average power of 1.652 kW and a total output of 39.65 kWh per day. Additionally, the simulation for three wind turbines produced a combined total output of 172.59 kWh per day (assuming each turbine provides 57.53 kWh per day). Together, wind and solar contribute 212.24 kWh per day, which falls short of the required 336.24 kWh per day. The missing 33% from biogas would need to account for approximately 124 kWh per day to balance the system.

However, since the biogas model is absent, this assumption remains purely theoretical. The final feasibility of this scenario can only be determined once a proper biogas simulation is implemented.

<u>Economic analysis</u>

Initial Costs

- Solar modules: (42 * 4,000 ZAR) + 11,100 ZAR + 3,000 ZAR = 182,100 ZAR
- Wind turbines: 3 * 360,000 ZAR = 1,080,000 ZAR

- Biogas plant: 43,000 ZAR + 53,000 ZAR + 26,943 ZAR + 141,600 ZAR = 264,543 ZAR
- Batteries: 2 * 15,000 ZAR = 30,000 ZAR

Total Initial Costs: 1,556,643 ZAR

Operational Costs (Annual)

- Solar modules: 42 * 50 ZAR = 2,100 ZAR
- Wind turbines: 3 * 9000 ZAR = 27,000 ZAR
- Biogas plant: 1 * 11,000 ZAR = 11,000 ZAR
- Batteries: 2 * 2,960 ZAR = 5,920 ZAR

Total Annual Operational Costs: 46,020 ZAR

Potential Savings

- Annual Electricity Savings: 254,046.13 ZAR

Key Metrics

- Depreciation Costs (20 years): $\frac{1{,}556{,}643\ ZAR}{20\ years}$ = 77,832.15 ZAR/year
- Annual Cashflow: 254,046.13 ZAR - (77,832.15 ZAR + 46,020 ZAR) = 130,193.98 ZAR
- ROI: $\frac{130{,}193.98\ ZAR}{1{,}556{,}643\ ZAR}$ * 100 = 8.36 %
- Break-even Point: $\frac{1{,}556{,}643\ ZAR}{130{,}193.98\ ZAR}$ = 11.96 years

The analysis shows that although the system requires a significant initial investment of 1,556,643 ZAR, it proves to be economically viable with a break-even point of 11.96 years and an ROI of 8.36 %, primarily due to the significant annual savings of ZAR 254,046.1

6. Conclusion

This study evaluated the feasibility of a hybrid renewable energy system for an off-grid commercial restaurant in Cape Town, using MATLAB Simulink for dynamic modelling and RETScreen for techno-economic analysis. The results point to something more complicated than a straightforward endorsement or rejection of hybrid renewable energy at this scale. Viability is not purely a generation capacity problem — it is equally a question of system design, economic context, and what is actually practical for a specific site.

No single scenario tested in this study was able to fully and reliably meet the restaurant's daily energy demand of 336.24 kWh. The 100% solar configuration was financially the strongest, returning an ROI of 42.16% with a payback period of 2.37 years, but it cannot stand alone as a dependable supply solution. Wind-only performed poorly on both fronts — the power output was highly erratic, and with an initial cost of ZAR 2,550,000, a 4.75% ROI, and a payback period exceeding 21 years, it is difficult to justify from a commercial standpoint. The 50/50 solar-wind hybrid sat between these extremes. At 290.18 kWh per day it still fell short of full demand, but the combination improved supply consistency and produced a more defensible long-term financial case, with a 7.87% ROI and break-even at 12.71 years. The pattern across all three scenarios is telling: hybridisation does improve reliability, but it does not on its own solve the energy sufficiency problem.

The biogas exclusion deserves more than a footnote. The decision to remove it from the practical simulation was not arbitrary — insufficient organic waste at the scale of a single restaurant, combined with the infrastructure requirements of biogas-to-electricity conversion, made it genuinely impractical for this context. This matters because it challenges a common assumption in the hybrid energy literature, that a multi-source configuration is always extensible to real-world settings. Here it was not, and that finding is arguably as informative as any of the modelled scenarios.
The choice to combine MATLAB Simulink with RETScreen held up well under the demands of this study. Simulink gave a level of component-level and temporal detail that a techno-economic tool alone would not have captured, while RETScreen grounded the technical outputs in financial reality. The limitations that emerged — no battery storage model, a simplified wind turbine representation — do narrow the scope of what can be conclusively stated, but they also sharpen the focus for what needs to be done next.

Three areas stand out as priorities for future work. Battery storage modelling is the most pressing. The study consistently flagged a supply deficit during low-generation periods, and without storage, any off-grid system at this scale will struggle to achieve genuine energy independence. Wind modelling also needs refinement — the current approach introduced enough deviation from realistic behaviour to limit confidence in the wind-heavy scenarios. Beyond those two, hydrogen fuel cells are worth serious investigation as a long-term storage and stability solution, particularly given that biogas has been ruled out for this setting.

What this study ultimately offers is not a finished solution, but a grounded starting point. The dual-method framework applied here is transferable, the financial and technical data are specific enough to be actionable, and the gaps identified are well-defined enough to guide the next phase of research. Off-grid energy independence for commercial facilities in contexts like Cape Town is not a distant prospect — the resources and the technology exist. Closing the remaining gaps in system design and modelling is what will make it a realistic one.

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